UNIVERSITÉ DU QUÉBEC EN OUTAOUAIS

DOCTORAL THESIS

PRESENTED TO

DÉPARTEMENT D'INFORMATIQUE ET D'INGÉNIERIE

IN PARTIAL FULFILLEMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

FARHAD KHOSROJERDI

AN ONTOLOGY-BASED DECISION-MAKING FRAMEWORK MODELING POWER EFFICIENCY FOR PHOTOVOLTAIC SYSTEMS

GATINEAU, 2020

BOARD OF EXAMINERS

THIS THESIS HAS BEEN EVALUATED

BY THE FOLLOWING BOARD OF EXAMINERS

Mr. Stéphane Gagnon, Thesis Director
Département des sciences administratives, Université du Québec en Outaouais

Mr. Raul Valverde, Thesis Co-Director
John Molson School of Business, Concordia University

Mr. Hamid Mcheick, Member of the jury
Département d'informatique et de mathématique, Université du Québec à Chicoutimi

Mr. Wahab Hamou-Lhadj, External Evaluator
Department of Electrical and Computer Engineering, Concordia University

Mr. Péricles Sobreira, Internal Evaluator
Département des sciences administratives, Université du Québec en Outaouais

2020

AT UNIVERSITÉ DU QUÉBEC EN OUTAOUAIS

ACKNOWLEDGEMENT

I would like to:

- Express my deepest gratitude to my supervisor Dr. Stephane Gagnon and my co-supervisor Dr. Raul Valverde for their support, continuous motivation, and encouragement. Their valuable advice and deep knowledge about educational system assisted me to overcome obstacles throughout my research.
- Thanks to my family, especially my wife, for supporting me for no matter what decision I had to make during the years of my research.

UN CADRE DE PRISE DE DÉCISION BASÉ SUR L'ONTOLOGIE PERMETTANT DE MODÉLISER L'EFFICACITÉ ÉNERGÉTIQUE DES SYSTÈMES PHOTOVOLTAÏQUES

FARHAD KHOSROJERDI

SOMMAIRE

Les applications des systèmes photovoltaïques (PV) ont été considérablement augmentées en raison de l'installation pratique d'un tel système. Les consommateurs non techniques utilisent des outils logiciels pour planifier les systèmes PV. Ils s'appuient sur les rapports d'estimation de puissance fournis par ces outils de planification. Cependant, même le logiciel le plus fiable, le modèle de conseiller système (SAM), néglige le déclin des générations d'énergie causé par les chutes de neige. Les méthodes de suivi du point de puissance maximale (MPPT) sont utilisées pour surmonter cet obstacle, permettant aux modules PV de fonctionner efficacement dans différentes conditions ambiantes. Pourtant, il n'existe aucun outil de planification PV qui offre des informations ou toute sorte de données sur les méthodes MPPT. De plus, traiter les caractéristiques d'un système de contrôle basé sur MPPT nécessite des connaissances techniques sur le sujet. Dans ce travail, nous proposons un modèle d'ontologie de base de connaissances représentant des concepts clés sur les conditions d'ombrage et les facteurs environnementaux affectant l'estimation de puissance rapportés par les outils de planification. Le modèle proposé, nommé MPPT-On, fournit des recommandations de conception de système, des suggestions et des corrections de puissance de sortie que la plupart des outils de planification PV ne parviennent pas à rapporter. MPPT-On est développé en utilisant les règles et requêtes SWRL faisant face aux conditions d'ombrage causées par plusieurs particules en suspension dans l'air ainsi que des chutes de neige. L'évaluation de l'ontologie proposée est réalisée à l'aide d'une étude de cas. Nous considérons deux scénarios pour les conditions d'ombrage PV prévoyant des durées de plus en plus courtes pour les couvertures de neige. L'analyse de trois types d'ensembles de données : I) les puissances de sortie rapportées par le modèle SAM, II) les puissances de sortie corrigées par MPPT-On, et III) les puissances de sortie mesurées sur site démontre des améliorations significatives en utilisant l'ontologie proposée. De plus, nous proposons une base de données MPPT comportant des règles et des requêtes pour présenter les informations techniques nécessaires au système de contrôle d'un projet PV. Nous affirmons qu'une telle base de données MPPT doit être ajoutée aux outils de planification PV. Le modèle basé sur l'ontologie fournit un système d'aide à la décision aidant les planificateurs et les praticiens de systèmes PV à installer des systèmes efficaces et à améliorer les estimations de puissance rapportées par les outils de planification.

AN ONTOLOGY-BASED DECISION-MAKING FRAMEWORK MODELING POWER EFFICIENCY FOR PHOTOVOLTAIC SYSTEMS

FARHAD KHOSROJERDI

ABSTRACT

Applications of photovoltaic (PV) systems have been increased significantly due to the convenience installation of such a system. Non-technical consumers employ software tools for planning PV systems. They rely on power estimation reports provided by these planning tools. However, even the most reliable software, system advisor model (SAM), overlooks the decline of power generations caused by snowfalls. Maximum power point tracking (MPPT) methods are used to overcome this obstacle, enabling PV modules to operate efficiently in different ambient conditions. Yet, there is no PV planning tool that offers information or any sort of data about MPPT methods. Moreover, dealing with characteristics of an MPPT-based control system requires technical knowledge about the subject. In this work, we propose a knowledge base ontology model representing key concepts about shading conditions and environmental factors affecting power estimation reported by planning tools. The proposed model, named MPPT-On, provides system design recommendations, suggestions, and power output corrections that most PV planning tools fail to report. MPPT-On is developed using SWRL rules and queries coping with shading conditions caused by snowfalls. Evaluation of the proposed ontology is performed using a case study. We consider two scenarios for PV shading conditions expecting longer and shorter durations for snow coverings. The analysis of three types of datasets: I) output powers reported by SAM model, II) output powers corrected by MPPT-On, and III) onsite measured output powers demonstrates significant improvements by employing the proposed ontology. Furthermore, we propose an MPPT database featured with rules and queries to present technical information required for the control system of a PV project. We claim that such an MPPT database needs to be added to PV planning tools. The ontology-based model provides a decision support system assisting PV system planners and practitioners to install efficient systems and improve power estimations reported by planning tools.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ABC	Artificial Bee Colony
AC	Alternating Current
ANFIS	Adaptive Neuro-Fuzzy Inference System
ANN	Artificial Neural Network
BA	Bat-inspired Algorithm
CS	Cuckoo Search
DC	Direct Current
DE	Differential Evolution
D	Diode
DPO	Dolphin Partner Optimization
DS	Design Science
EA	Evolutionary Algorithm
FL	Fuzzy Logic
FOA	Fruit fly Optimization Algorithm
GWO	Grey Wolf Optimizer
HC	Hill Climbing
IS	Information Systems
IT	Information Technology
MCU	Microcontroller
MBO	Marriage in Honeybees Algorithm
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
MW	Mega Watts
NRC	Natural Resources Canada
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database
OC	Open Circuit

OWL .... Web Ontology Language
PE .... Power Electronics
PSC .... Partial Shading Condition
PSO .... Particle Swarm Optimization
PV .... Photovoltaic
P&O .... Perturbation and Observation
PWM .... Pulse Width Modulation
R .... Resistance
RDF .... Resource Description Framework
RDFS .... Resource Description Framework Schema
RSF 1 .... Research Support Facility 1
RSF 2 .... Research Support Facility 2
S&FT .... Science & Technology Facility
SAM .... System Advisor Model
SC .... Short Circuit
SI .... Swarm Intelligence
SQWRL .... Semantic Query Enhanced Web Rule Language
SRRL .... Solar Radiation Research Laboratory (at NREL)
STC .... Standard Test Conditions
SWRL .... Semantic Web Rule Language
UML .... Unified Modeling Language
USC .... Uniform Shading Condition

INTRODUCTION

A photovoltaic (PV) system as an environmental-friendly and sustainable source of energy requires little maintenance [1, 2]. Since 25 years ago, solar energy has become one of the main contributors among other forms of renewable energy resources [3]. Its productions are expected to grow (70,000 MW) by 2020 [4]. The convenience of PV system installations has motivated residential and commercial consumers to consider it as an important source of energy. Consumers with minimum or basic knowledge about the system components attempt to install PV systems. Thus, non-technical users are involved in the system planning. However, the planning engages consumers with the process of making decision about different characteristics of the system design. non-technical practitioners use planning software to plan the system that fulfil their needs of energy. These planning tools provide performance predictions and cost of energy for PV projects based on the installation and operating costs and system design parameters. As a result, software users rely on power estimations reported by such products. Yet, the accuracy of such reports is extremely dependent on different environmental elements. Solar panels perform poorly under shading conditions. Determining technical characteristics of a PV system and its components demand experts' knowledge [5]. Solar panel performances are drastically degraded in shaded environments or varying ambient conditions [6]. PV shadings are caused due to various ambient terms. Adjacent buildings, trees, clouds, pollution, dust, and snow considerably reduce energy generations of a solar panel. Being partially or uniformly shaded, PV systems require distinctive power management approaches to improve incorporated power reductions. While maximum power point tracking (MPPT) methods are used to cope with varying partial shading conditions (PSCs), there is no practical solution for constant and long-lasting uniform shading conditions (USCs). Therefore, a PV planning software must be capable of simulating power degradations caused by shading conditions.

In the case of designing MPPT-based control system, non-technical installers confront with a complex situation. The complexity includes choosing an appropriate algorithm, determining its parameters, initial values, and the control system's components. The system needs to be modeled and simulated prior to the planning and installation. In a previous work, we have shown that applying different irradiance patterns will result in unlike efficiencies, even with the application of alike MPPT method. It means the efficiency of a PV system can be assessed greater if the input patterns modelled with less alterations [6]. It has been depicted in a PV system experiencing three different input patterns, in shapes and alterations (11366, 11372, 11702), resulted in three various efficiencies, 97.4%, 95.331%, and 95.536%, respectively.

The above-mentioned problems demonstrate how unpredictable and unproductive is to use a planning software without a decision support system. The impacts of numerous ambient conditions and climate factors on PV performances make it difficult for consumers. Furthermore, establishing a decision-making framework that represents the power efficiency can assist non-technical users toforecast energy reductions for PV modules operating under USCs, especially in snowy conditions. While environmental factors are overlooked in the power estimation reports, there is a need for a framework that offers recommendations and suggestions in order to improve the reports.

In this work, we propose an ontology model representing semantics and information required for planning PV systems operating efficiently in different ambient conditions. The proposed ontology aids to define required parameters for an MPPT-based controller. Moreover, it provides SWRL rules for extracting information about power degradations due to snow-covered modules and airborne particles. The designed ontology, named MPPT-On, is developed using Semantic Web Rule Language (SWRL) and queries. Evaluation of the proposed ontology is performed using a case study. System Advisor Model (SAM) is employed for planning the PV project. Then, we compare power estimations reported by SAM with the actual power productions collected onsite for the case study. In addition to offering MPPT design information, we show that the application of the proposed model helps to estimate more accurate output results for months expecting snowfalls.

CHAPTER 1 PRESENTATION OF THE RESEARCH PROJECT

In this chapter, the structure of the research including its objectives, problem solving approaches, and methodology are explained. Undertaken several phases described in the research methodology, the objectives are accomplished. Then, we portray the research project phases, technologies deployed, development of the proposed model, the analysis and evaluation of the ontology. This chapter is structured as follows: Section 1 describes the basic elements of the research such as the main context, goals, motivations, and beneficiaries. In addition, the role of a knowledge base model in this research is described in the subsection. Research objectives are stated in section 2. It explains why contributions of this study can benefit renewable energy sector especially practitioners in solar industry. In section 3, research methodology is presented in detail. The steps taken to implement the research methodology are defined as well as planning phase, data gathering, analyzing the results, and contributions. This framework of the research project demonstrates inputs, processes taken, and research outcomes. Finally, the structure of this dissertation is provided in the last section of this chapter.

1.1 Background of the Thesis

Nowadays, photovoltaic systems are broadly used to supply electricity to the power grid as substitutes of fossil-based energy since they are environmental-friendly and sustainable, requiring little maintenance [7]. They are environmental-friendly and sustainable renewable energy resources, requiring little maintenance. However, the low energy conversion efficiency (about 9-17%) [5], particularly under variable climate conditions, impede extensive applications of PV systems in power networks. A control system allows a solar panel installation to overcome the low efficiency linked to environmental conditions. It helps the performing system to operate in its maximum power point. This aim can be accomplished by applying an MPPT method that makes a PV system to operate in its optimal operation.

In Canada, the domestic market has been growing on average at about 26% per year since 1993 and about 48% since 2000 [8]. To fulfill customers' needs, several online software tools have been developed. They provide PV planning, the system design, simulation, analysis, and power output estimations. Software users rely on output reports of these applications. However, it is difficult for non-technical installers or system planners to define many variables during planning. Theses factors are associated with PV module technology and type, weather databases, MPPT systems, and PV performance models. Consequently, power estimations and system designed in this manner will be insufficient and unreliable.

Power productions of a PV system depend on ambient conditions when the system operates under various irradiances and temperatures. Shading conditions and extreme temperatures decrease power outputs. Although we cannot change the climate or some of the sources originating shadings, there exist power management approaches to eliminate consequences of these environmental impacts. Most PV planning software tools cannot include the effect of panel shadings especially in snowy days. In addition, there are several other environmental factors that can affect PV performances. The role of the airborne particles, for example, is overlooked in PV planning applications. Hence, power productions are overestimated for cold months particularly for PV plants located in cold climates such as Canada. Although there is a technical solution for controlling the PV system operating in a harsh climate, the problem of neglecting snow coverings remains.

In the domain of power management and power electronics, an MPPT-based control system implements a solution. It assists a PV system to operate in the maximum point of its *P-V* curve. PV arrays without MPPT hardware lose lots of power productions because of operating under shading conditions. The main idea behind MPPT systems is the application of an MPPT algorithm that allows the system to track the maximum power point (MPP). Then, control signals are provided to the converter to operate around the MPP. In addition to dealing with MPPT characteristics, PV system modeling and the simulation of the control system is the bottleneck of the design. There is enormous technical information associated with modeling PV systems and energy efficiency that makes PV system modeling a complex task. Interdependence relationships of those variables create even more compound situations. This will result in designing incorrect system modeling that cannot perform efficiently under shading conditions.

The following (Table 1-1) outlines the major elements of the research including the context, goal, motivation, beneficiaries, and the deliverable. The research outcome is the proposed ontology including its reasoning and queries that can be used alone or alongside with any PV planning tools. In the first case, on the designed ontology can be run in Protégé.

Table 1-1 The basic elements of the research

Research Element	**Highlights**
Context	- PV system modeling and simulation - PV shading and MPPT methods - PV planning, ontology design methodology and ontology technologies
Goal	- Designing a decision-making support framework for planning PV projects
Motivation	- Reliable power forecasting and correct estimation of power production for a designed PV system - Improving the quality of PV planning and designing tools - Increasing use of non-technical PV installers
Beneficiaries	- PV planners - PV design software developers and software quality engineers - PV plant Project managers
Deliverable	- An ontology model representing knowledge base of MPPT and PV planning

It represents important concepts and factors affecting power outputs of a PV system in various ambient conditions. It further demonstrates interrelationships of elements involved in shading conditions. MPPT methods and their characteristics are presented in the ontology as instances. They are collected in an Excel file and considered as a database that can be added to data library of any PV planning software. This trend aids PV practitioners to rely on the power estimations generated by the planning tool. In the other hand, when the model is being used alongside a planning tool, it provides design recommendations and planning considerations. Additionally, the ontology model can correct miscalculations due to snowfalls. Considering the two functions of the proposed ontology, MPPT-On, the user needs some knowledge about using Protégé.

1.1.1 A Knowledge-based Model

A knowledge base model can cope with many types of data including contextual language data, weather databases, datasheets, and online data gathered from detectors or sensors. During recent years, developing conceptual frameworks has been grown significantly, allowing knowledge reuse and sharing [9]. In this work, the proposed model acts as a reference model for the decision-making process representing semantics and information required to achieve maximum possible power in various ambient conditions. Figure 1.1 depicts the processes of the semantic web architecture of the model (adapted from [10]).

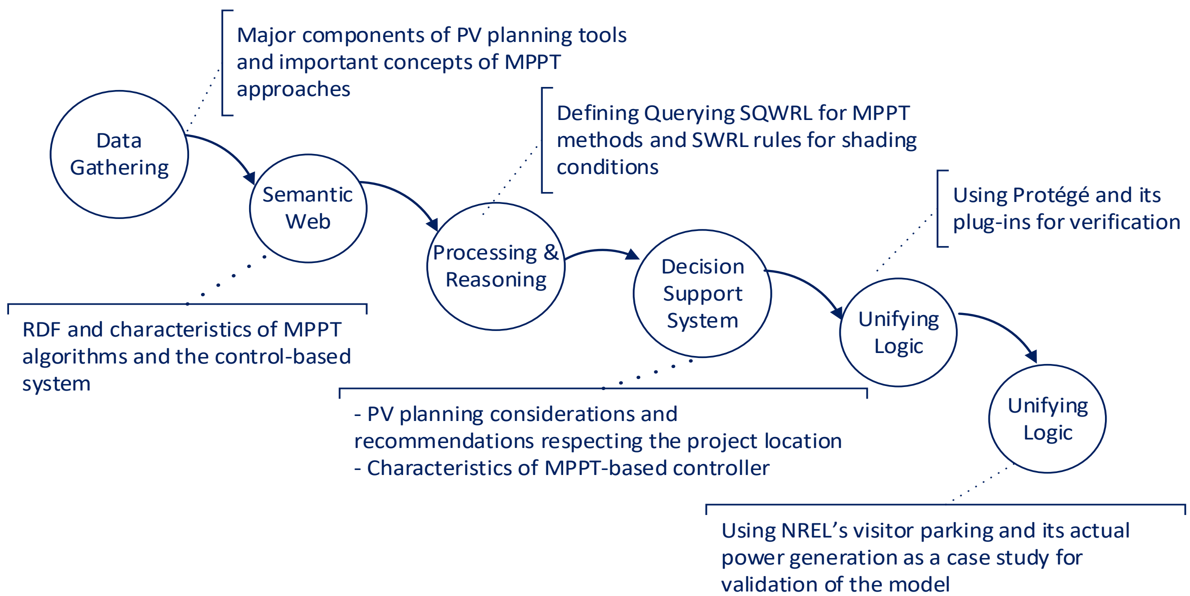


Figure 1-1 The semantics web architecture of the proposed model

As observed in the figure, adapting from the architecture, we apply the process of PV system designing for the proposed ontology model. The architecture of the proposed model will be described in several sections in the upcoming chapters. The proposed ontology offers a smart framework that connects two interrelated sets of semantics with a logical base of SWRL rules. The ontology reasoning assists end-users to deal with non-trivial processes involved in planning efficient PV systems.

1.2 Objectives

The aim of this research is to propose an ontology model offering data and information required for planning a PV system. In this manner, we consider two main knowledge base areas: I) PV planning tools and II) MPPT methods. The proposed model is supposed to provide a decision support framework to deal with shading conditions and improve power estimation reports of the PV planning software. The framework, through which the relevant information about MPPT methods and PVs performances, can be shared and reused.

During recent years, developing conceptual frameworks has grown significantly, allowing researchers to reuse and share information within interested communities [9]. Modelling disparate conceptual data from different domains implies using artificial intelligence, that involves semantics and computer processable languages [11, 12]. Semantic Web technologies offer software languages for representing knowledge-based models. One of the main reasons for using ontology is the capability of the model made. It can deal with complex data forms regardless of the sources used. In addition, we need a model that understand logic of the context and can extract various information from distinctive resources. Ontology allows a model to represent data and information with various repository and perform rules to support context-aware systems [13]. In our research context, it can provide potential alternatives and solutions to design a PV system efficiently and plan the project effectively.

As described in the previous sections, the goal of the research is to deliver a model that its application is to support decision-making process in PV planning. The proposed framework contains the state of the art PV domain-related context and information needed for the planning. The model aims to include all essential parameters and factors influencing the system design, and consequently the planning. The rule-based ontology model offers potential solutions to multi-domain nature of planning PV projects.

1.2.1 Scope of the Research

Shading, soiling, reflection, bifacial, DC wiring, module mismatch, DC power optimizer loss, diodes and connections are the major reasons initiating DC losses. Shading conditions produced by snow coverings and soiling are the key factor for false power estimations since precipitations are not included in many weather databases. Furthermore, other losses are not affected by other factors linked to ambient conditions. This work focuses on DC productions due to shading conditions and environmental factors created them. In addition, MPPT methods as the main concept of power efficiency approaches are investigated as well.

1.3 Research Methodology

Figure 1-2 depicts the research methodology and steps taken to accomplish the research objectives. The four stages of the research methodology represent the processes implemented from the beginning of the research project to the evaluating phase.

- Stage 1) as depicted in the figure, the context of power productions and performances are studied in the first stage. In this early phase, we review possible research methodologies and scientific approaches. In addition, MPPT methods, optimization techniques, metaheuristic algorithm, PV system modeling, and simulation are investigated.
- Stage 2) in this stage, class axioms and their relationships are defined. Searching for various concepts representing PV planning and MPPTs is the key aim in this step.
- Stage 3) the third stage, the proposed ontology model is designed and developed containing classes, data, and objective properties, as well as SWRL rules and queries.
- Stage 4) in the last step, evaluation of the proposed ontology is performed using a case study, NREL visitor parking. Available datasets help us to validate the ontology while semantically verifications of the ontology are undertaken using Protégé reasoning plug-ins.

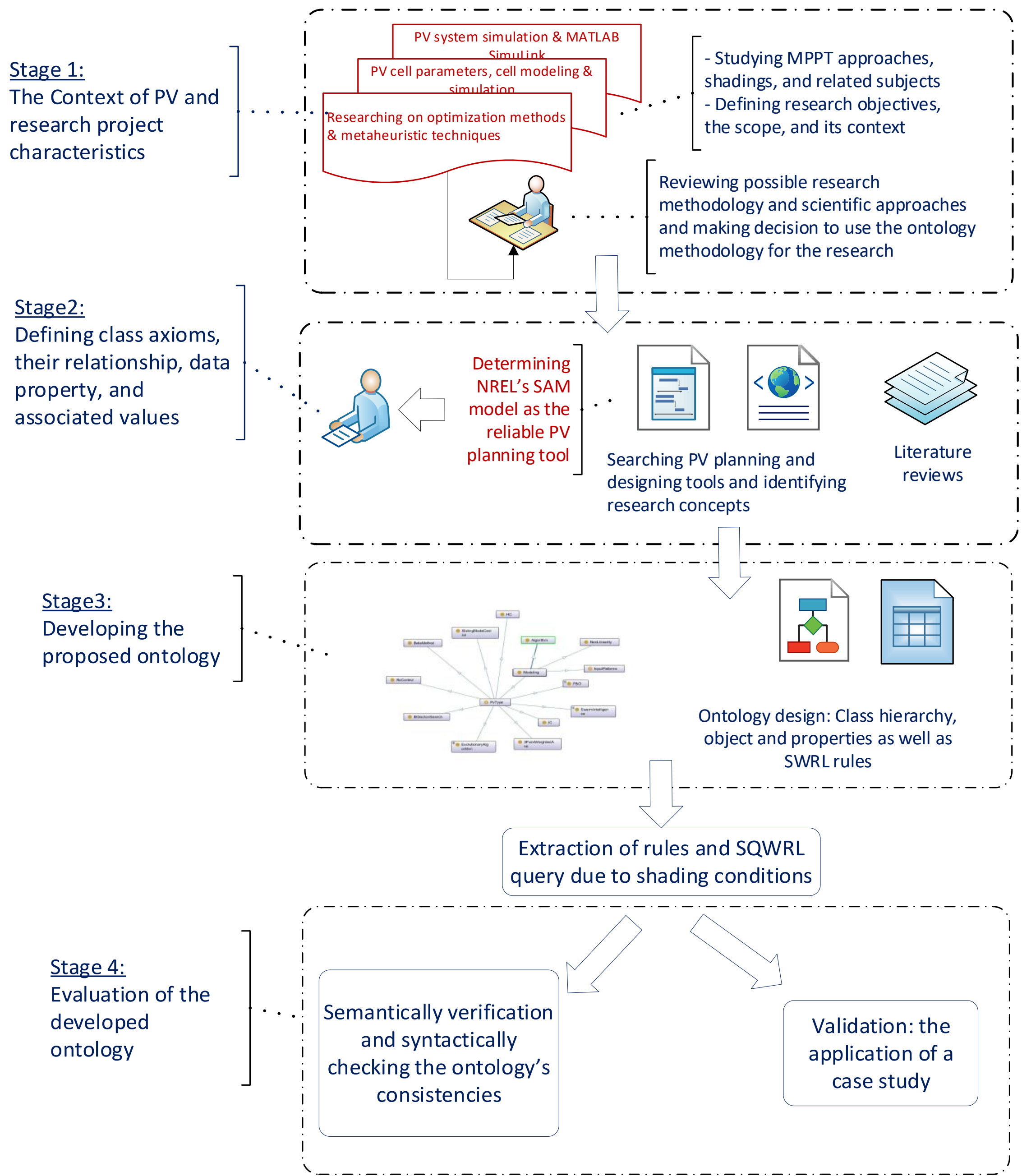


Figure 1-2 The research methodology

1.3.1 Implementing the Research Project

The research project is managed considering different processes defined for each phase. The detailed flowchart of the research project phases is shown in figure 1-3 (see the next page). As illustrates, activities start with identifying needs and problems in PV system design and finish with validation and verification of the proposed ontology. The processes demonstrate the key elements in each phase. To simplify the flowchart, many efforts are not presented in the figure.

- In the initial phase, the attempt is to figure out the research initiatives including:

I. Identifying problems in PV system design and power conversion as well as focusing on MPPT methods

II. Defining research objectives, scope, and the methodology for research implementation

III. Defining tools and technologies needed to perform throughout the research project

IV. Preparing the initials, regarding the previous step, and installing the essential software programs (for instance Endnote, MATLAB Simulink, etc.)

- In the planning phase, we search for scientific approach(s) to fulfill research objectives. The processes are:

I. Creating Endnote libraries based on the subject matters that have been recognized initially: MPPTs, shading conditions, modeling, and ambient conditions in a PV system.

II. Studying papers and reviewing available research methodologies and scientific solutions to draw a framework for the research implementation.

III. Meanwhile if there is any new concept and/or subject that may affect the research study, it is evaluated and considered.

IV. Reviewing ontology design methods, reasoning methods, and evaluation techniques

V. At the end of this stage, the decision is made to apply ontology methodology for the research implementation.

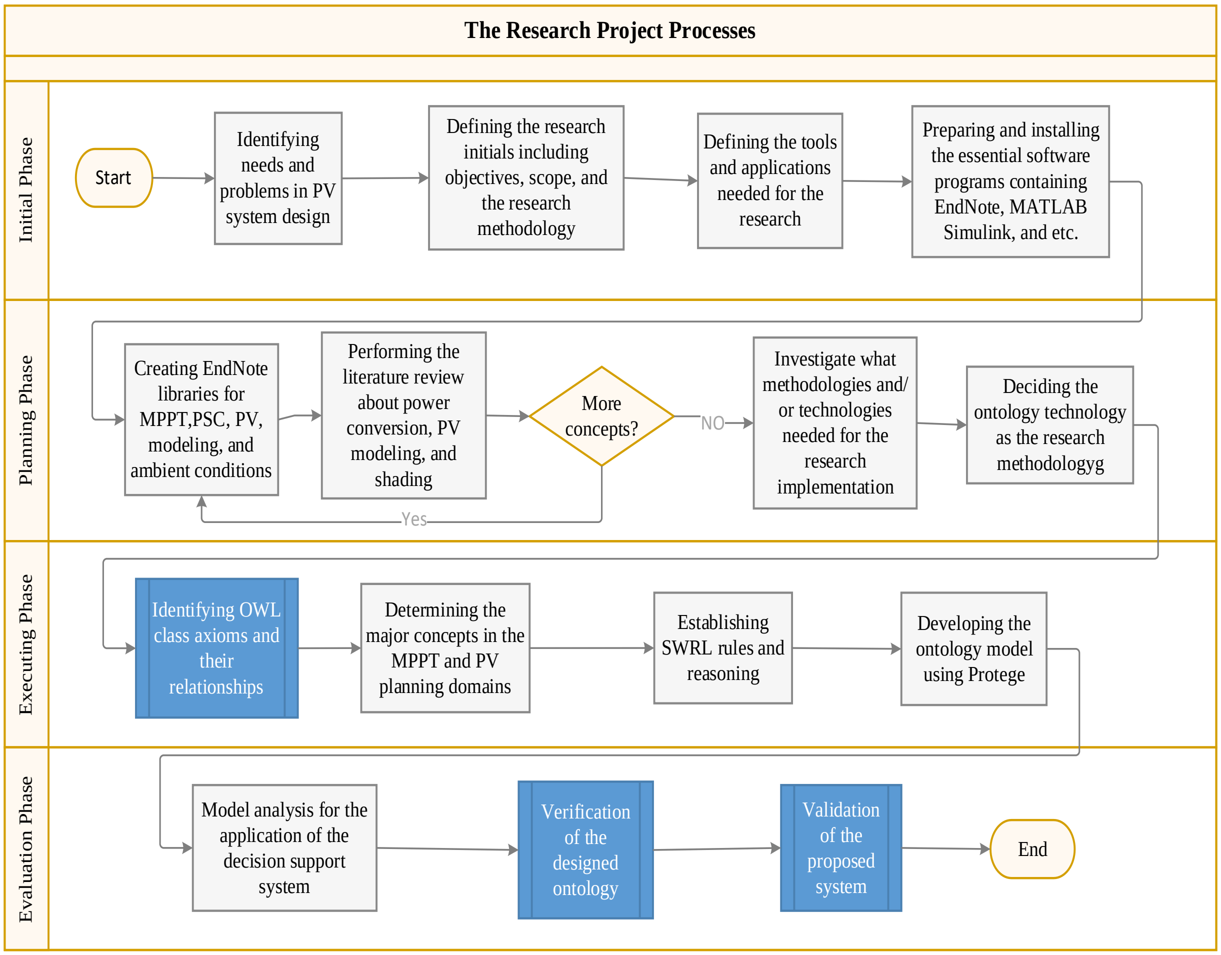


Figure 1-3 The detailed flow chart of the research project phases

- The proposed knowledge base model is developed in the executing phase of the research project. There are two key processes in the research methodology consisting of the literature review and involving the practitioners. The other three processes in this phase have internal interaction with them and among each other during the research study. Then:

I. The literature review and investigating PV planning software allow us to identify PV design and planning factors that play important roles in the subject.

II. As a result, class axioms and important parameters as well as their properties are known and defined in the ontology model.

III. SWRL rules are determined as well.

IV. MPPT-On is developed by using Protégé and associated plug-ins.

- The proposed ontology is evaluated, and results are analyzed in the evaluation phase. The main processes are:

I. Applications of the proposed model are shown. The decision support system offers suggestions, recommendations, and adjustments to improve the output reports of any PV planning tools.

II. The validation of the model is tested in a case study.

III. The semantic verification of the proposed ontology is performed using Protégé plug-in reasoners.

1.3.2 The Executing Phase: Development of the Proposed Model

The proposed knowledge base model is created and developed in the implementation phase of the research project. Figure 1-4 shows that the first process of the execution phase is a sub-process for identifying OWL class axioms and their relationship that includes processes for finding important concepts representing the context. The ontology-based model is developed complying with Ontology Development 101 guidelines (Noy and McGuinness) [14]. This technology can help to deliver a PV knowledge-based model representing various concepts in the domain.

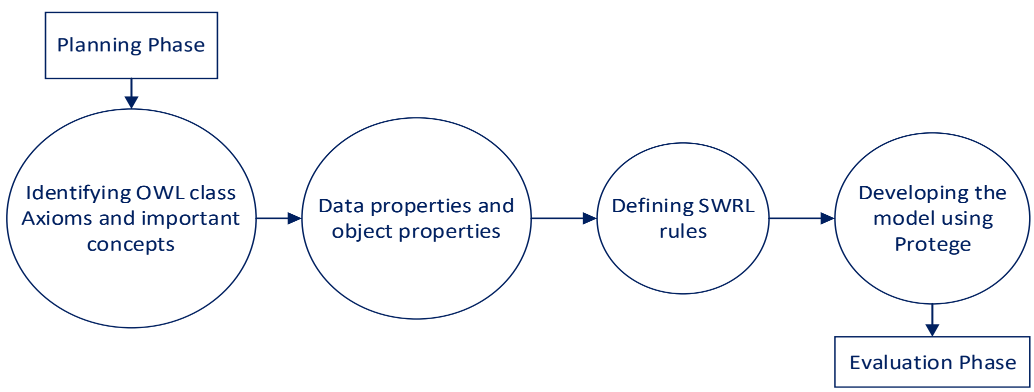


Figure 1-4 Implementation of the ontology model (Executing Phase of Figure 1-3)

These processes are introduced and explained in detail in chapter 5, section 2. The processes draw a framework for gathering information and identifying concepts needed for building a knowledge-based model in a domain-specific application. This approach can be used in an area of study that the goal is to deliver an ontology model which is perceived as an artifact and a reference model. The technique has been presented to gather and reuse knowledge using ontology engineering for business solution artifacts [15].

1.3.3 Analysis and Evaluation

Ontology evaluation of an ontology model is one of main step of the ontology development. The ontology evaluation is performed by confirming the ontology verification and the ontology validation [16]. On one hand, ontology verification reflects technical characteristics for syntactic correctness assurance [16] of the knowledge base model. On the other hand, ontology validation identifies that whether the ontology agrees with the phenomenon it represents [17]. The MPPT-On is semantically verified by a case study. PV arrays installed on the rooftop of NREL visitor parking (Golden, CO) are used as the case study. Its datasets are available online [18]. The datasets include power outputs (measured powers at the site), snowfalls data, and installation layout and technical information for 2012. To validate the proposed ontology, a plug-in reasoner incorporated in Protégé 5.5 (Pellet) is implemented to eliminate anomalies in the ontology. As depicted in Figure 1-5, the last phase of the research project illustrates three key sub-processes of the model analysis, the validation, and the verification of the proposed ontology. After developing the ontology model, it is analyzed from technical perspectives to define if it can perform what it has been built for. In addition, the model is reviewed and assessed to identify its capabilities. The other two key sub-systems in this phase represent the ontology evaluation processes.

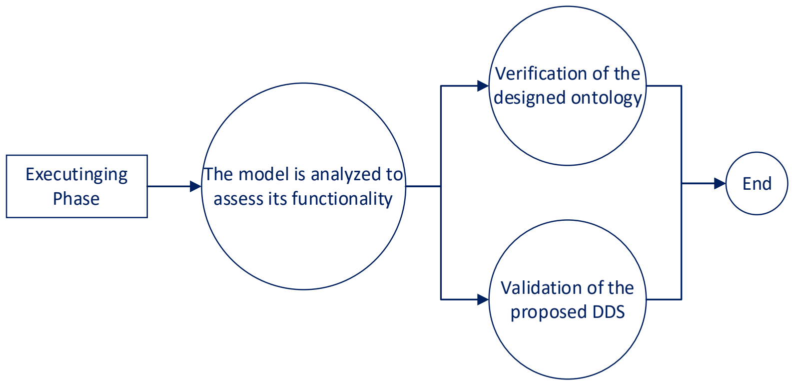


Figure 1-5 The evaluation phase of the research project

1.4 Structure of the Dissertation

Figure 1-6 depicts the structured of this work. Chapter 2 presents backgrounds of PV performances, modeling, and provide a literature review about MPPT techniques. In chapter 3, basic notions of the ontology technology including the semantic web architecture, definitions of ontology engineering, and ontology languages are explained. Applications of ontologies in different domain especially in the energy sector and PV domain are described as well. The proposed model and its implementation are presented at the end of this chapter. Chapter 4 concentrates on designing MPPT-On and the applied methodology. The most important parts of the ontology design, defining the OWL model assertion axioms and their relationships, are stated in this chapter. The activities allow us to develop the proposed ontology and create the model that can be used as a planning support system. Extraction of rules, SWRL rules, and queries are developed in Chapter 5.

Evaluation of the proposed model is performed in chapter 6. We use a case study to practice the impact of the ontology on planning the PV project expecting two scenarios for snow covering predictions. The conclusion is made in Chapter 7, outlining the fulfilment of research objectives, research contributions, significance of the model, limitations of the study, the potential application, and future works.

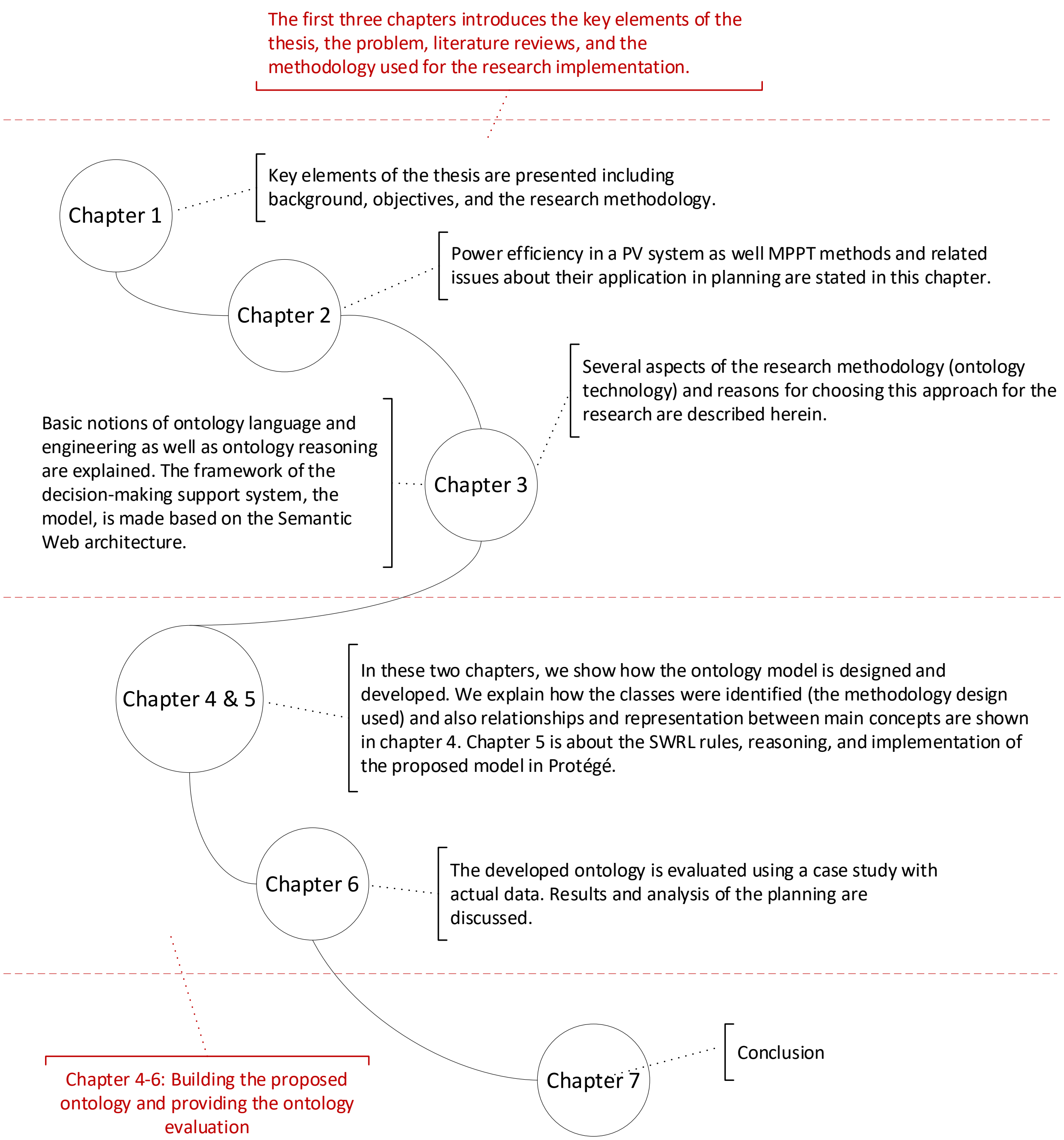


Figure 1-6 Structure of the thesis: links between the chapters

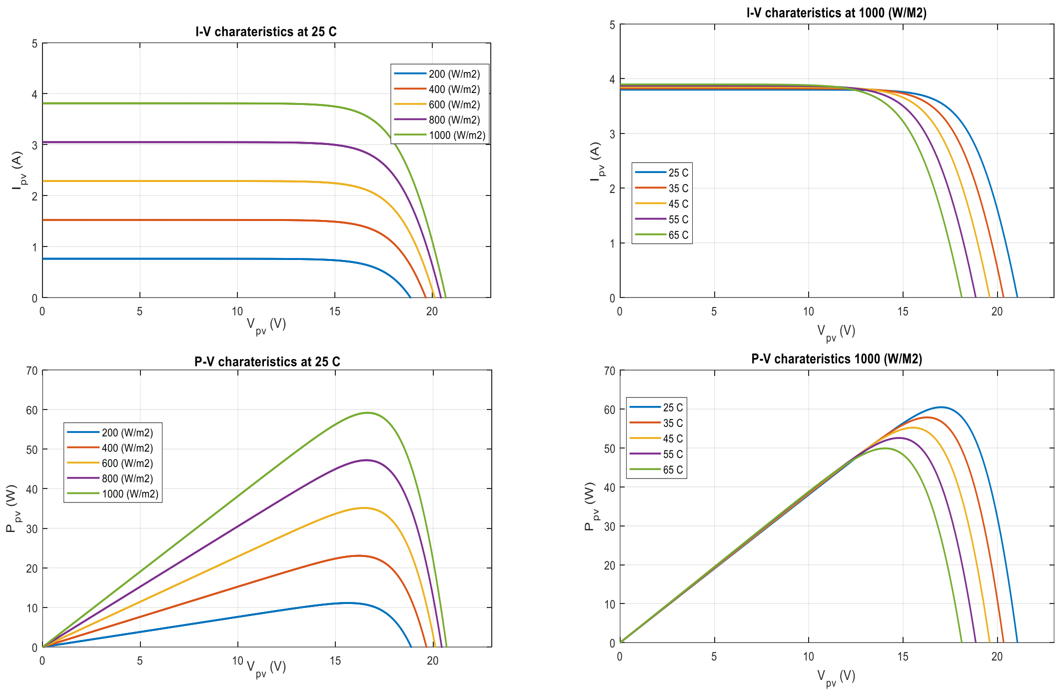
CHAPTER 2 LITERATURE REVIEW

PV systems can be designed stand-alone or grid-connected, depending on the application. Stand-alone PV systems normally deliver power to a single load or off-grid network of electric loads. Grid-connected PV systems deliver power to the grid and can interact with the power network [19]. In this chapter, the performance of a PV system and its energy productions under shading conditions are reviewed to describe the background of the research. Solar production installations are viewed from power conversion perspective. Thus, technical challenges of a grid-tied or stand-alone system regarding MPPT approaches are not the concern of the following sections.

2.1 Background of PV Systems

A PV array is built of strings of solar modules connected in parallel. Each string consists of modules connected in series. The Module data are provided by manufacturers in standard test conditions (STC) datasheets reflecting condition of 1000 (W/m^2) with 1.5 air mass spectral distribution at temperature 25 °C contributed by a solar simulator called Flash Tester [20]. STC datasheets provide values of PV modules operating under different USCs, usually sun insolation 1000 (W/m^2) and at temperature 25 °C. Some of them even provide the tabulated variables including open circuit voltage (V_{OC}) short circuit current (I_{SC}) maximum power point (MPP) current (I_{MPP}), MPP voltage (V_{MPP}), and MPP power (P_{MPP}) that are different from the circuit parameters in the model such as I_{PV}, I_0, a, R_S, and R_P. Characteristics of a PV module, *I-V* and *P-V* cures, are presented in the two normal conditions of 1000 (W/m^2) irradiance and at 25 °C.

Figure 2-1 (a) depicts *I-V* and *P-V* curves of a PV module at 25 °C under various irradiance. The degradation in irradiance means producing less energy so that the produced power and current drop accordingly. However, the generated voltage remains almost the same when a PV module receives less amount of energy from the sun. Figure 2-1 (b) illustrates the curves at different temperatures and the irradiance1000 (W/m^2). In this case, Likely, the PV current is affected slightly; so that changes in the I_{PV} are appeared around the MPP, which is about %80 of V_{oc}. In fact, change in temperature causes a fewer alteration in the produced power when a panel is under the same irradiance.



(a) (b)

Figure 2-1 *I-V* and *P-V* curves: (a) at 25 °C, (b) at 1000 (W/m^2)

To display *I-V* and *P-V* characteristics of an actual module, the SunPower SPR-X20-250-BLK module is chosen for the simulation (the module used in the case study demonstrates the similar performance as this brand). Table 2-1 presents the module data later used in the simulation for displaying PSCs and its *I-V* and *P-V* cures.

Table 2-1 The module data of the PV brand used

SunPower SPR-X20-250-BLK	
Maximum power	P_{MAX} = 213.15 (W)
Open circuit voltage	V_{OC} = 36.3 (V)
Voltage at MPP	V_{MPP} = 29 (V)
Cells per module	Number of Cell = 60
Short-circuit current	I_{SC} = 7.84 (A)
Current at MPP	I_{MPP} = 7.35 (A)

Figure 2-2 depicts *I-V* and *P-V* characteristics of the module (modified from the original cures presented in MATLAB/Simulink [21]) named SunPower SPR-X20-250-BLK.

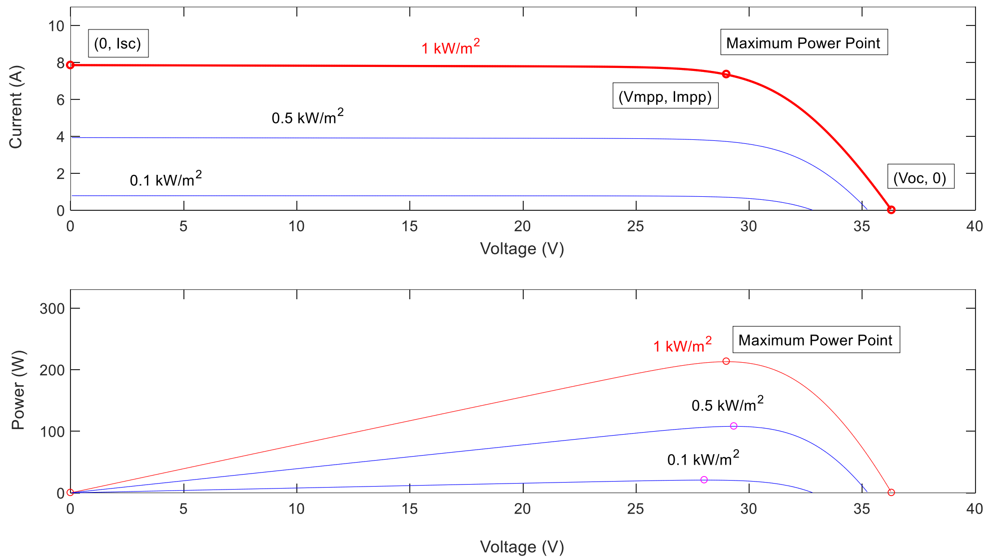
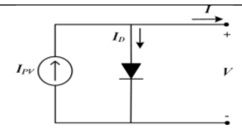
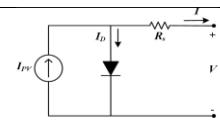
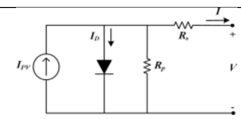
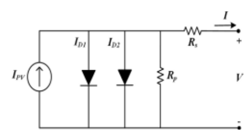


Figure 2-2 PV characteristics for SunPower SPR-X20-250-BLK module ([21] modified)

2.1.1 PV Cell Models

An electrical circuit model enables a PV system designer to predict variations of *I-V* and *P-V* curves to the ambient conditions and environmental factors. Using appropriate electrical circuit model and estimation of the parameters are crucial to envisage the system performances and its energy yield. Furthermore, an accurate cell model defines major attributes including efficiency of the system, the MPP, and the interaction between the power converter and the solar panel. Calculations of parameters in the model also describe performance of a PV system. System designers use the model to accurately simulate the entire system. The simulation represents technical characteristics of the system and its performance in various conditions. The most important element of a PV system is the cell [22]. The cell behaves as a simple diode, *p-n* junction representing two layers of semiconductor material. MATLAB/Simulink is widely used to simulate PV cells and determine electrical parameters. It enables the system designers to depict the *I-V* and the *P-V* curves in different environmental circumstances. Table 2-2 shows the four well-known equivalent electrical models [23] used for PV modeling.

Table 2-2 PV cell models

Model Name	**Equivalent Circuit**	**Equation and required Parameters**
The ideal model		$I = I_{PV} - I_0[\exp\left(\frac{qV}{akT}\right) - 1]$ *I_{PV}, I_0, a
The single diode R_S-model		$I = I_{PV} - I_0[\exp\left(\frac{q(V+IR_S)}{akT}\right) - 1]$ *I_{PV}, I_0, a, R_S
The single diode R_P-model		$I = I_{PV} - I_0\left[\exp\left(\frac{q(V+IR_S)}{akT}\right) - 1\right] - \frac{V+IR_S}{R_p}$ *I_{PV}, I_0, a, R_S, R_P
The two-diode		$I = I_{PV} - I_{01}\left[\exp\left(\frac{q(V+IR_S)}{a_1kT}\right) - 1\right] -$ $I_{02}\left[\exp\left(\frac{q(V+IR_S)}{a_2kT}\right) - 1\right] - \frac{V+IR_S}{R_p}$ *I_{PV}, I_1, I_2, a_1, a_2, R_S, R_P

Characteristics of the diode is explained by Shockley diode equation (1). This part of equation is modified as the model is improved by adding resistances R_S and R_P in single diode R_S-model and single diode R_P-model.

$$I_D = I_0[\exp(qV/akT) - 1] \quad (1)$$

In the MATLAB/Simulink, The single diode R_P-model is utilized in simulations implemented [21]. Other PV models either neglect important physical characteristics of a PV cell, such as ideal model and single diode R_S-model, or present more parameters with further simulation time [23]. Equation (2) describes the *I-V* relationship in a single diode R_P-model.

$$I = I_{PV} - I_0[exp(q(V+IR_S)/akT) - 1] - (V+IR_S)/R_p \quad (2)$$

where I_{PV} is the PV current and has a direct relationship with sun intensity and temperature changes. The saturation current (I_0)depends on temperature differences, a is the ideality (or quality) factor of the diode, q is a constant amount of -1.6021764x10^{-19} representing electron's charge, k is Boltzmann's constant (-1.380653x10^{-23} J/K), T (°K) is the absolute temperature of the p-n junction, R_S and R_P are the series and parallel equivalent resistances of the solar panel respectively [24].

Precise estimations of parameters of a PV model enables system designers to predict variations of I-V and P-V curves and efficiency in various ambient conditions. These values are not valid due to frequently transformed meteorological factors. To involve several environmental effects manipulating the estimation results, the values of the model parameters need to be estimated [23].

2.1.2 PV System Configuration and Device Components

PV systems can be designed stand-alone or grid-connected depending on the application. Stand-alone systems normally deliver power to a single load or off-grid network of electric loads. Grid-connected systems deliver power to the grid and can interact with the power network [19]. Defining PV model and equivalent electrical circuit are the most important elements of the system model as they describe the system performance under various ambient conditions. Accuracy in parameters and components of a PV system model helps to design it efficiently and forecast power outputs in various ambient conditions [25]. A proper PV model, reflecting characteristics of the system enable system designers to calculate the system performance correctly. Thus, PV planning tools that are produced applying that model can be trusted by practitioners.

A typical and simple PV system includes a PV array, a dc-dc converter controlled by a MPPT-based system and a load. Practically in a usual application, PV array is connected to a DC-DC buck converter controlled by MPPT and a DC-AC inverter. The controller provides appropriate duty cycles to the DC-DC buck converter. The MPPT algorithm modulates the duty cycle for the converter and enables PV system to perform in its maximum efficiency. Grid-connected PV systems deliver power to the grid and can interact with the power network [19]. The electrical circuit-based models are used to simulate a PV system and model it in integration with its power conversion system including MPPT controller, DC-DC converter, DC-AC inverter, and other components based on the application and the system design requirements. The overall topology of such a system is shown in figure 2-3.

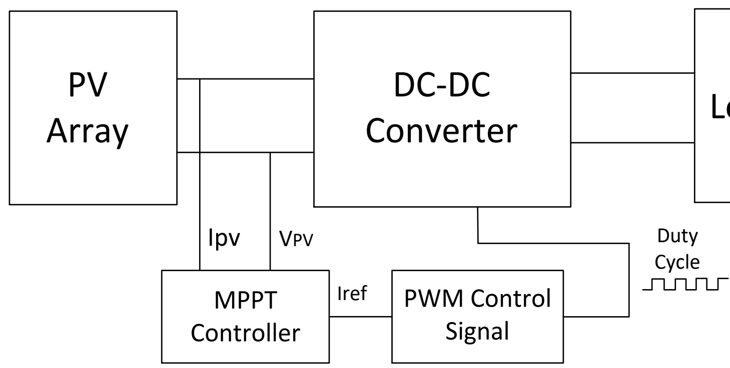


Figure 2-3 A typical and simple PV system

This setup demonstrates the overall topology of a stand-alone configuration of a system connected to a single load through a DC-DC converter. The system is equipped with a combination of the MPPT controller and Pulse Width Modulation (PWM) controlling current and voltage of the module output and provide duty cycle to the DC-DC, respectively.

2.2 Background of the Power Efficiency in a PV System

Planning for installation an efficient PV system require designing an MPPT control system in the planning phase of the project. Practically, even in solar power plants without any adjacent building, PSCs or USCs are inevitable due to clouds, dust, snow, or pollutions. Hence, project planners need to take into account MPPT applications that requires planning an MPPT-based control system. In the case of ignoring PSCs, MPPT techniques are not applicable; thus, predicted power outputs cannot be accomplished. In the other case, the hardware and interfaces are provided by the software, usually picked from a database including commercially available MPPT control systems or defined by the system designer/engineer.

In term of having the option of choosing an appropriate MPPT method, the system planner/designer should make the decision about collecting a method from soft computing or conventional approaches. The efficiency of each method can be compromised by complexity, convergence speed, and cost. Besides, even conventional methods can track the global point in most real-world conditions that cause more uncertainty in appointing exact MPPT method. The other factor is the redundancy and similarity in soft computing techniques that cause the making-decision process an arbitrary choice. The most important factor challenging MPPT classifications and efficiencies entitled to each technique is dependency of the method to various internal and external factors affecting the assessment. The following section and subsections identify one of those and show its impact on altering the efficiency.

2.2.1 Impacts of Shading Conditions on PV Curves: The Simulation

PSC is the outcome of shaded panel(s) which is caused by buildings or trees, existence of clouds, pollution, dust, and snow. Impacts of the PSC depend on the module type, fill factor, bypass diode placement, severity of shade and string configuration [26]. In result, multiple local points and one global maximum are depicted in the *P-V* and *I-V* curves. A PV system is built in a series-parallel configuration to produce desire output power and voltage. In practical, they are connected in series to form a module of 36, 60, or 70 cells. Then the modules are assembled in different series and parallel configurations to form an array at the desired output voltage and current [26-29]. For example, solar arrays are built today in a fixed series-parallel configuration and the single module is equipped with bypass diodes included in different configurations. A bypass diode allows current from non-shaded parts of the module to pass by the shaded part and limits the effect of shading to the only neighboring group of cells protected by the same bypass diode [26, 30]. When the bypass diode begins conducting, the module voltage will drop by an amount corresponding to the sum of cell voltages protected by the same bypass diode plus the diode forward voltage. However, the current from surrounding unshaded groups of cells continues around the group of shaded cells [26]. MATLAB Simulation Toolbox is chosen to demonstrate effects of PSCs on characteristics of a PV array. To demonstrate effects of PSCs on module characteristics, a PV configuration is simulated in MATLAB (figure 2.4). The figure demonstrates a parallel connection of two modules connected in series. Each array is built of strings of modules connected in parallel, while each string includes modules connected in series. SunPower SPR-X20-250-BLK PV module is chosen in the simulation (for the module data see table 2-1).

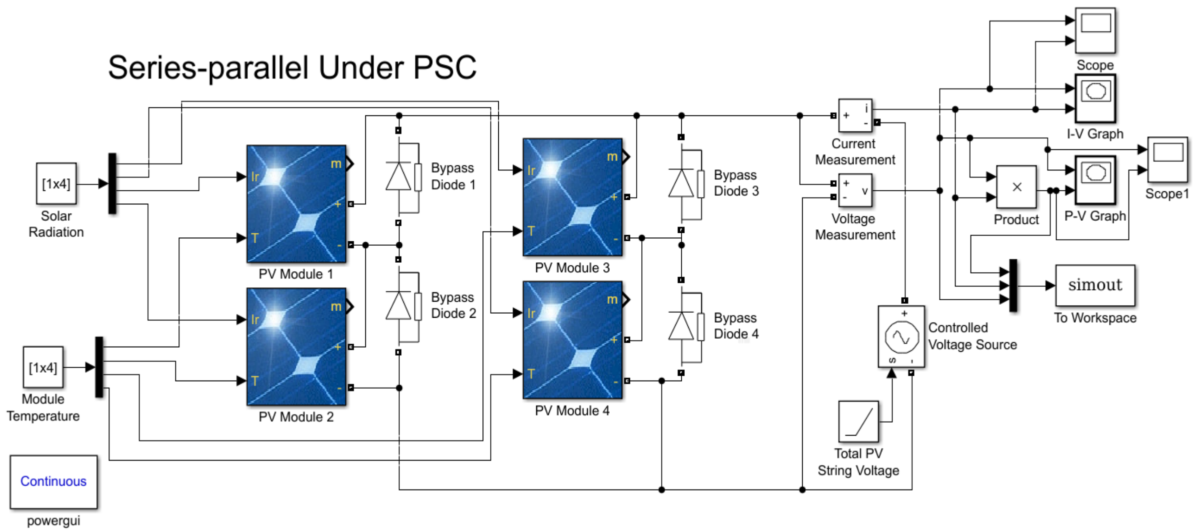


Figure 2-4 The simulated model for the PV arrays under PSC

Figure 2-5 shows the *P-V* and *I-V* characteristics of the arrays uniformly shaded of 1000 (W/m^2) irradiance at 25 °C. The maximum power of about 1000 (W) demonstrates more than 12 (A) output current. Figure 2-6 shows the *P-V* and the *I-V* curves of the partially shaded modules affected by distinctive solar radiations 500 (W/m^2), 100 (W/m^2), 1000 (W/m^2), and 300 (W/m^2). Two local points and one global maximum with the output power of 316 (W) demonstrate the *P-V* characteristic of the model. The *I-V* curve similarly experiences three points of slopes where the points of *P-V* changes occurred. As expected in the case of PSC, the generated output power of the configuration presents greater power than when the arrays experiencing different shading conditions. MPPT methods are employed to solve this obstacle and ensuring that the module operates efficiently at its MPP. An MPPT algorithm allows a PV system to perform in its optimal operation. This objective can be accomplished by a MPPT controller.

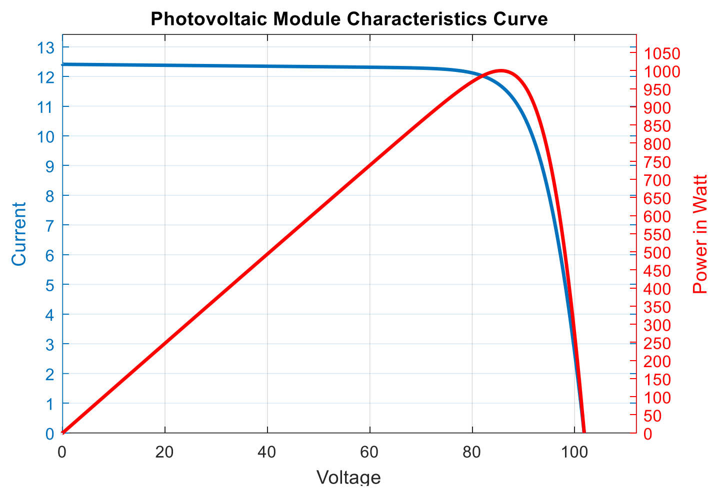


Figure 2-5 The P-V and the I-V characteristics of the uniform shaded PV arrays

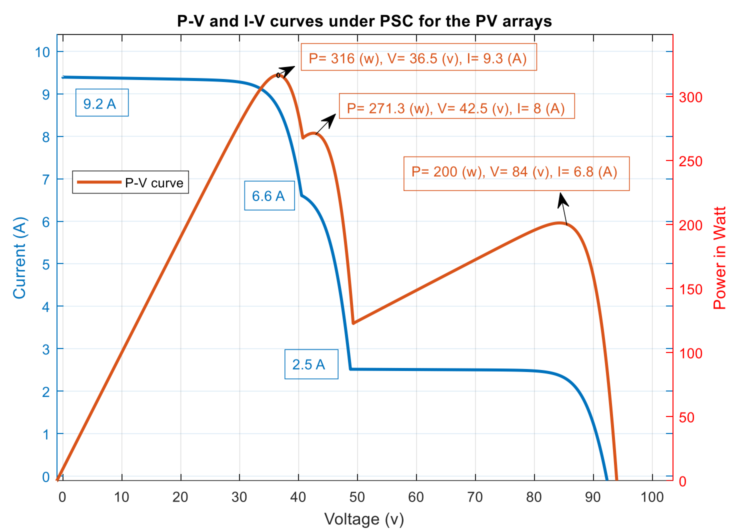


Figure 2-6 The P-V and the I-V characteristics of the partially shaded PV arrays

2.2.2 Efficiency Reductions due to Ambient Conditions

Ambient conditions and environmental factors play a substantial part in the planning of a solar power generation due to the power efficiency reductions. Snowfalls and particle aggregations associated with cold climates origin depletion in PVs performances. As demonstrated previously, these are considered as PSCs and/or USCs. PSCs are accrued because of aggregation of different particle originated mostly from pollution, dust, snow, and ice. In a research [31], five typical elements of air pollution consisting of red soil, carbonaceous fly ash, sand calcium carbonate, and silica are investigated to assess their effects on power efficiency. Definition of dust and related sources generating them are addressed as well. It is argued that properties of different dusts and local environmental parameters interacting with each other. They can exceed the negative effect comparing to applying each factor individually. Snow build-up can reduce the output power of an array and result in performance degradation [32]. However, the criteria for accretion of snow and ice on a panel depends on type of the snow and tilt angle of the panel and cannot be mathematically modelled due to material complexity and ambient parameters [32, 33]. Further, it is argued that distinctive types of snow and ice have different conductivity and thermal insulation [32]. Although the severity of shading depends on different parameters, it is argued that temperature, humidity, and tilt angle of modules are the key elements. The influential factors that can affect the severity of shading conditions are outlines in table 2-3.

Table 2-3 Factors influencing the severity of shading conditions

Factors	**Description**
Type of particle	red Soil, carbonaceous fly-ash, sand, calcium carbonate, silica [31], snow and ice [32, 33]
Effects	chemical, biological, electrostatic [31]
Property	size, shape, and weight
Site location	rural or urban environment, longitude & altitude, adjacent buildings, and structures
PV type	monocrystalline, poly-crystalline, amorphous, thermal
Glazing	I) sticky surface including furry, rough, adhesive residues, electrostatic build-up, initial onset of dust, II) smooth surface
Tilt angle	flat or inclined surfaces
Ambient condition	Irradiance, wind direction and speed, temperature, humidity

2.2.3 The Application of an MPPT-Based Control System

MPPT methods are developed to overcome the impacts of PSCs on PV system performances. An MPPT controller performs based on the data received from voltage and current sensors. In a MPPT-based control system, the control parameters can influence the functionality of each algorithm so that the comparison result may be altered slightly [34]. It provides reference voltages or reference currents needed for the PV module. Then according to these references, the pulse width modulation (PWM) generator provides appropriate duty cycle to the converter. One essential part of any MPPT controller system is voltage regulator. Voltage regulator tracks the reference value provided by the running algorithm [19]. The reference value is sensed by a microcontroller (MCU) equipped with current and voltage sensing. The overall topology of a PV system is shown in Figure 2-7.

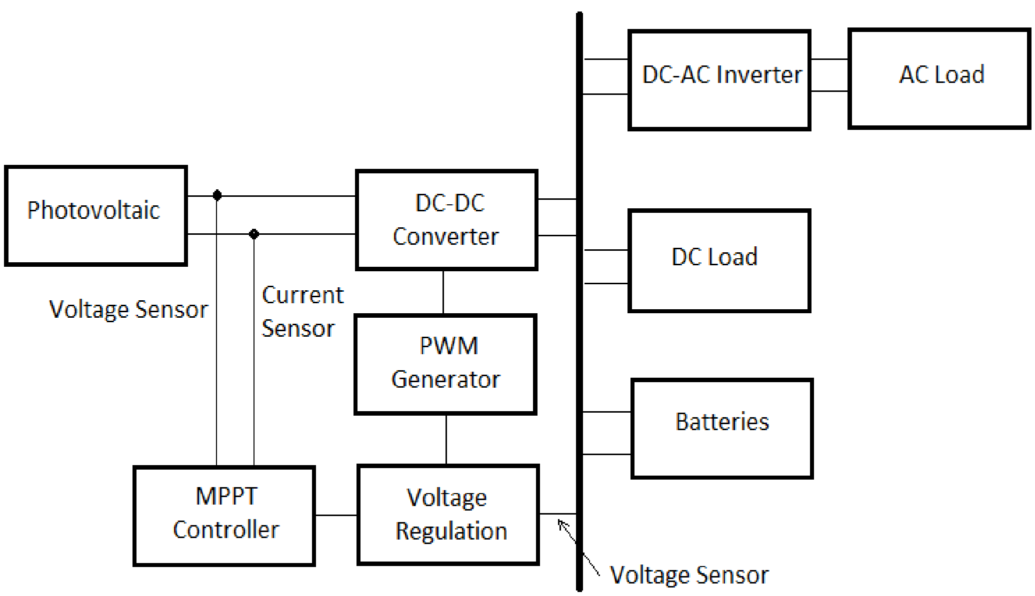


Figure 2-7 The overall topology of a PV system (source [19])

MCUs offer a variety of solutions for solar energy harvesting [35]. They provide system control and support communication technologies allowing system designers to control the output power of the PV arrays. Moreover, their flexibility in applying sophisticated algorithms fulfill specific technical requirements [36]. MCUs can detect PSCs and replied accordingly due to their capability of dynamic responses. Besides, MCU-based PV systems use fewer components while increasing reliability with minimum cost than conventional or analog technologies [36]. Todays' advanced MCUs offer various technical features, capable of producing multiple PWM, simultaneously. As a result, the MPPT identifies the optimal operation for the PV system [37].

2.2.4 The Architecture of a PV System

PV system components including the DC-DC converter and the MPPT control unit can constructed in three different configurations: I) centralized or field MPPT (FMPPT), II) distributed MPPT (DMPPT), and III) differential MPPT. Regardless of employing the methods capable of tracking global maxima under PSCs and/or in harsh environmental conditions, such power is less than the addition of the maximum powers that the mismatched panels can produce [38]. In centralized approach (figure 2-8), a single MPPT method can be tracked [39]. In this approach, each module consists of one DC-DC converter and the controller; so that each module performs at its own MPP. A convenience conventional method, such as P&O, can be applied at the module level. An obvious benefit of this method is that malfunction of each PV unit affects only that unit instead of the entire solar units.

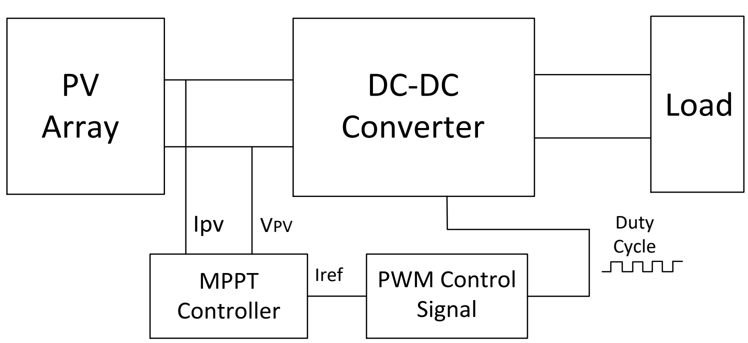


Figure 2-8 Centralized or field MPPT (FMPPT) architecture (source [39])

In DMPPT architecture (figure 2-9), each cell, string, or module has its own MPPT controller. There is an analog technique which is suitable for DMPPT applications called TEODI [40], explained in the next section. Operating points of two identical PVs are evenly matched in this technique.

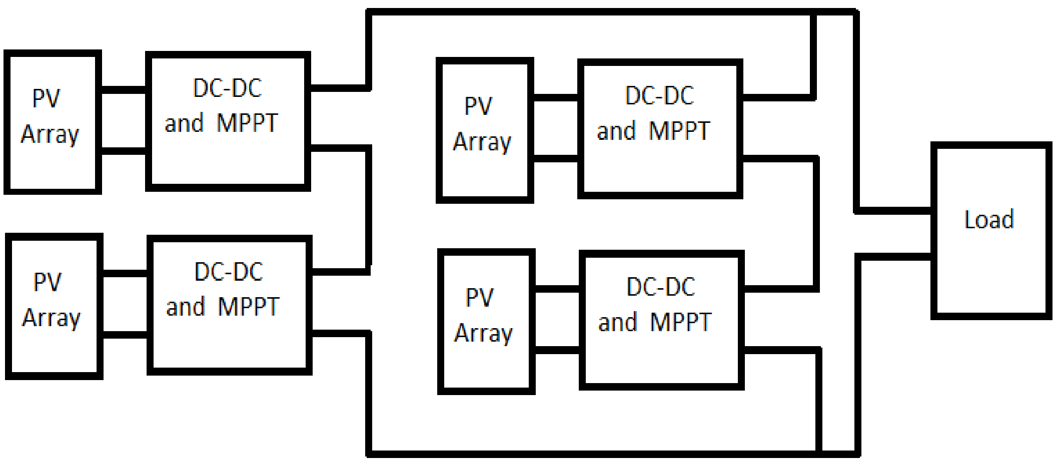


Figure 2-9 Distributed MPPT (DMPPT) architecture (source [39])

In differential power processing (DPP) approach, converters located between adjacent PV modules provide the current differences at the MPP of the two PVs (figure 2-10). The MPPs are local maxima in neighboring panels and can be tracked applying any simple conventional method. Depending on PV system applications, a MPPT architecture is selected.

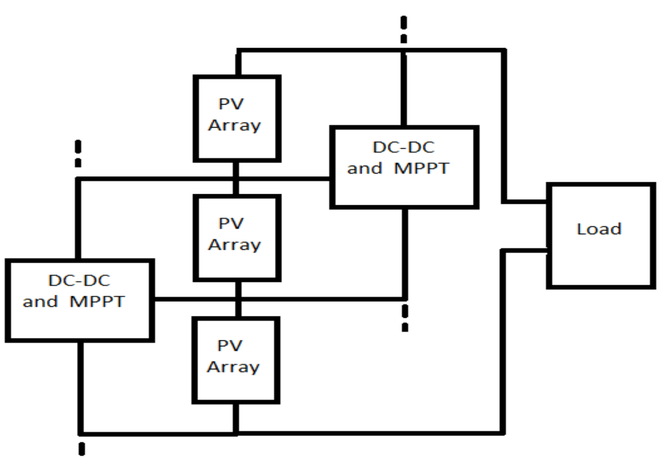


Figure 2-10 Differential MPPT architecture (source [39])

Energy yield in the DMPPT approach will result in cost increase comparing to the FMPPT, although it offers greater efficiency. Simple conventional techniques are utilized for DMPPT as a single unit can trace a single maximum point. Reliability of the PV system using DMPPT architecture is higher than a centralized approach. Each sub-unit operates individually, and the entire PV system is not affected if a single unit fail to perform. In the DPP approach, power losses are minimum due to detecting the power differences of two PVs.

2.3 Survey of MPPT Algorithms

Over the past decades, numerous algorithms have been provided by researchers to find MPP under different ambient conditions. Classifications of existing methods representing functionality of the algorithms are widely distinctive. These perceptions mainly focuses on MPPT applications, optimization methods, costs, parameters used, efficiencies, tuning parameters, the system complexity, and the rapid convergence [11, 34, 39, 41, 42]. Ultimately, the most common clustering can be defined as: I) conventional or classical methods, II) modern or soft computing methods, and III) hybrid methods, and IV) power electronics (PE) based methods.

Conventional methods offer convenience and simplicity [43]. However, they may be trapped in local points and detect one of the local points as the MPP for the system consisting of several PVs performing under PSCs. Furthermore, they provide lesser efficiency and convergence speed comparing to soft computing methods [39, 42]. They have played important roles in engineering applications based on their simplicity, flexibility, gradient-free mechanism, and capability of searching global optima [44, 45]. Soft computing methods can be categorized into the artificial intelligence (AI) and meta-heuristic optimization techniques [24, 44, 46]. Meta-heuristic methods can be categorized into two subdivisions, the evolutionary algorithm (EA) and population-based or swarm intelligence (SI) methods. SI techniques mimicking evolution and social behavior of creatures in nature [45]. Some researchers have been improved conventional and soft-computing approaches by hybridizing these techniques. It means that some studies have modified one method or combine two methods from different MPPT classifications and improve the functionality of the origin algorithm [47]. Therefore, combination of any method in each category with another approach can result in developing a hybrid method. Obviously, due to the complexity of their algorithms, applications of these methods in real-world are questionable. In fact, implementation of an MPPT algorithm is an important technical concern leading us to add a new branch to the MPPT classification. Employing hardware and technical features of the power electronics components are the reason they are called PE-based methods. In a previous work [48], we studied these methods and highlighted the importance role of microcontroller-based (MCU-based) MPPT techniques. Unlike numerous studies concentrating on developing redundant soft computing MPPT algorithms, major elements of a PV system and its architecture are briefly described as important factors to improve performance of PV systems under PSCs. It is notified that advanced features of nowadays' MCUs such as temperature and irradiance sensors as well as Wi-Fi connectivity can be developed in the context of power conversion. As a result, we add PE-based methods to the usual MPPT methods classification. Figure 2-11 demonstrates the described clustering.

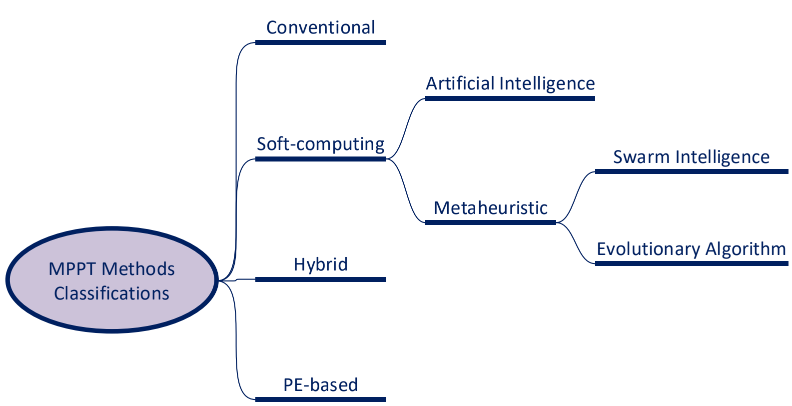


Figure 2-11 MPPT method classifications and the main subclasses

2.3.1 Classical/Conventional MPPTs

Major conventional methods are known as: Perturbation and Observation (P&O), Incremental Conductance (IC), hill climbing (HC), fractional short-circuit current, fractional open-circuit voltage, ripple correlation control, three-point weighted average, extremum seeking (ES) control, sliding mode control, load current/voltage maximization, bisection search and β-method. In most cases when a PV module involved in the system, these methods capable of tracking MPP even in varying ambient conditions. However, they may be trapped in local points and detect one of local points as the MPP for the PV system consisting of several PVs performing under PSCs. Describing the P&O algorithm can identify the logic behind classical techniques, attempting to add a small portion to the voltage or the current of a PV system to the previous ones.

2.3.1.1 Perturbation and Observation (P&O) Technique

The P&O is the well-known conventional MPPT technique broadly used commercially for many years [11, 47]. This method provides a convenience control system with minimum complexity and acceptable efficiency that can rapidly trace the MPP under USCs. To be able to improve the efficiency of an overall PV system, the P&O MPPT controller provide appropriate duty cycles to the DC-DC Buck converter. The P&O algorithm modulates the required duty cycle for the DC-DC power converter to trace the MPP of the module.

2.3.2 Soft-Computing Methods

Soft computing methods can detect global maxima in PV arrays where several local maximum points and one global maximum exist due to partial shading conditions. Dealing with nonlinearity and PSCs are the advantages of these intelligent techniques [49]. Complexity of algorithms and cost associated with controlling systems are their major obstacles. These methods can be categorized into the artificial intelligence (AI) and meta-heuristic optimization techniques. AI-based algorithms can track even under rapidly changing environment dealing with nonlinear characteristics of PV system.

2.3.2.1 AI-Based Methods

AI-based methods comprise the Artificial Neural Network (ANN), the Fuzzy Logic (FL), and a hybrid method, the adaptive neuro-fuzzy inference system (ANFIS). AI-based algorithms can track even under rapidly changing environment dealing with nonlinear characteristic of PV systems [11]. These techniques offer more efficient, faster convergence and no oscillations at MPP than conventional methods. AI is broadly used for MPPT applications; however, the mainstream of soft-computing MPPT approaches is originated by meta-heuristic optimization techniques. They have played important roles in engineering applications based on their gradient-free mechanism and capability of searching global optima [44, 45]. They can deal with multi-objective, nonlinear, multi-dimensional, and noisy functions [45, 50].

- **Fuzzy Logic Controller (FLC)**

The concept of fuzzy logic (FL) is based on applying expert knowledge in designing a fuzzy logic controller. FLCs are capable of performing uncertainties associated with the inputs, without the need for an accurate mathematical model [51]. In addition, dealing with nonlinear data and their fast convergence are the advantages of these intelligent techniques [49]. The FL-based MPPT controller is extremely dependent on the designer knowledge and experience about the PV system [4, 51].

- **Artificial |Neural Network (ANN)**

The ANN learning algorithms can perform in a time-varying conditions with a minimum amount of human intervention. An ANN-based controller relies on the trained data instead of requiring prior knowledge about the PV parameters [49, 52]. Under PSCs, the ANN is trained to predict the global MPP voltage and power by observing the P-V curve under several shading conditions on the PV array. Then, the difference between the prediction voltage and the actual voltage from the PV array gives an error input for the MPPT controller to track the maximum power. Yet, the ANN requires a comprehensive training process demanding more advanced microcontroller with higher cost [51].

- **Adaptive Neuro-Fuzzy Inference Systems (ANFIS)**

The ANFIS is a hybrid method incorporating the benefits of the FLC and the ANN. This technique constitutes a fast and appropriate systematic solution to the PV system even with inaccurate meteorological data [53]. Similar to ANN, the ANFIS can benefit from being trained from previous operational data [54]. However, the complexity of application of ANFIS-base controllers remains as a drawback for this method. The ANFIS-base controller similar to the ANN and the FL provides poor performances dealing with PSCs; additionally, the complexity of the application is a problem for this method.

2.3.3 Meta-heuristic and Population-based Techniques

Meta-heuristic performs the optimization using a set of solutions (population). In this case, the search process starts with a random initial population (multiple solutions), and this population is enhanced over the course of iterations [44]. Meta-heuristic methods can be categorized as: I) the Evolutionary Algorithm (EA), and II) Swarm Intelligence (SI) techniques mimicking evolution and social behavior of creatures in nature [45]. Because EA techniques are developed based on their evolutionary concept and SI-based approaches identified according to the swarm notions in nature, it is possible that SI methods is defined as population-based optimization [44]. However, both EA and SI based approaches have been developed using a set of solutions or population. In the followings, these two categories are not separated, preventing new branches or confusion in the classification.

2.3.3.1 EA-Based Algorithms

EA-based algorithms are inspired by the evolutionary concepts of the nature. Evolving an initial random solution perform optimization by creating a new population by the combination and mutation of the previous generation. One of the most practiced EAs employed in PV systems is Differential Evolution (DE). In addition, several hybridized methods have been developed by improving DE or combining it with different techniques.

- **The DE Technique**

As a stochastic population-based search technique, the DE has been employed for various applications since it was introduced by Storn and Price in 1997 [50]. The DE is one of the most eminent and broadly used EA-based MPPT approaches that delivers simplicity, flexibility, derivation-free mechanism, and local optima avoidance [44]. The simplicity of the algorithm using a few parameters to handle nonlinear, multidimensional, and non-differentiable functions is the main reason to employ the DE method for practical problems [55]. Several adapted DE algorithms as well as hybrid methods are applied for MPPT purposes [56, 57]. Modifying parameters in mutation or crossover and altering the DE's operators are presented in the literatures as well [58-61]. Herein, DE optimization methods and its three operation processes are described, as the operation of algorithms for many evolutionary optimization methods follow the same concept in MPPT application.

A major drawback of of the DE method is to define its random parameters (F, CR) by which reliability of the GP tracing is uncertain [25, 61]. Thus, many hybrid DE methods are developed to modify the standard DE algorithm to ensure its effectiveness in dealing with nonlinear characteristics of the MPP. In a hybrid DE method, two additional operations, accelerated phase and migrating phase are embedded into the conventional DE. An adaptive form of DE, Fuzzy Adaptive Differential Evolution Algorithm [62], experiencing lower number of search parameters required to be set by the user.

2.3.3.2 SI-based Algorithms

SI-based algorithms have been one of the favorable branches of population-based meta-heuristics optimization methods in PV domain. Numerous SI-based have been developed for the MPPT application. These techniques are mostly inspired from natural colonies, flock, herds, and schools. Mirjalili et al., Gray Wolf Optimizer (GWO) developer, introduces several swarm-based algorithms in the paper: Bat-inspired Algorithm (BA), Marriage in Honey Bees Algorithm (MBO), Wasp Swarm Algorithm, Artificial Fish-Swarm Algorithm, Monkey Search, Cuckoo Search (CS), Fruit fly Optimization Algorithm (FOA), Krill Herd (KH), Dolphin Partner Optimization (DPO), Bee Collecting Pollen Algorithm, and Firefly Algorithm [44]. There are many stochastic optimization methods have been already applied in PV systems for searching MPP. The best-known approaches are briefly described in the following sections.

- **Particle Swarm Optimization (PSO)**

The most notified swarm optimization algorithm that has been utilized in the PV application is PSO [44, 46, 63]. In this technique, several particles move in a search space to find the best solution. The movement is adjusted by following the best found solution while trying out new solutions [64]. To meet the optimal solution, the position of the particle must follow the best position of the particle or the neighbour best position. Assume that a PV array has an *N* number of modules and is connected in series. Partial shading occurs on one of the modules will be different from an unshaded module. Under this condition, multiple local maxima will occur on PV characteristic. The PSO reaches the optimal output when the global voltage is achieved.

- **Artificial Bee Colony (ABC)**

Artificial bee colony (ABC) algorithm has several characteristics that make it more attractive than other bio-inspired methods. Particularly, it is simple, it uses fewer control parameters and its convergence is independent of the initial conditions [65]. It is a swarm based meta-heuristic algorithm that was introduced for solving multi-dimensional and multimodal optimization problems. In case of PV application, the duty cycle is adjusted directly by the algorithm without the need of using linear controller [65]. The advantages of using this method are: excellent tracking capability with a good accuracy, no requirement of knowledge about the characteristics of the PV array, and the use of just two control parameters, allowing great flexibility and simplicity [65].

- **Gray Wolf Optimizer (GWO)**

The GWO method is a recently developed meta-heuristic algorithm inspired by gray wolves attacking a prey for hunting purpose. The adaptive values of the GWO parameters allow a smooth transition between exploration and exploitation. It is more robust and has low-medium implementation cost than many MPPT approaches in this category [4, 66]. Moreover, it requires fewer parameters for adjustment and less operators compared to other evolutionary approaches [66].

2.3.4 Hybrid Methods

Hybrid methods are developed to enhance, improve, or modify different aspects of one or two MPPT methods by combining them. This may be achieved by alterations in parameters, processes, or equations in algorithm of a method [59], or by employing a few characteristics of an algorithm inside another one [57]. There exist more methods in this cluster than any other MPPT approaches, and the reason is that the modifying one method or hybridizing two established algorithms will lead to create an effective method with minimum risk of wasting time and effort on working on totally a new approach. In this regard, we can name numerous hybrid methods utilizing different approaches from the classification and establish a new hybrid method. One of the setbacks of any hybrid method is the complexity of algorithm and consequently its implementation so that the application of it would be difficult. Therefore, the associated cost is high.

2.3.5 PE-based Approaches

A few literature reviews mention MPPT methods, which are based on PE devices, or highlight microcontroller devices [39, 67]. PE-based MPPT methods use characteristics and technical features of MCUs and PE circuits to track MPPs. Prior to introducing PE-based techniques, it is essential to mention a few facts using them. MCUs operate at very high frequencies, usually in the 20-80 kHz range [68]. Although the benefit of high frequency circuits means low power consumption with minimum power loss using small components, a few drawbacks associated with these methods. The excessive usage of PE equipment and devices jeopardizes the overall system performance in grid-connected applications, due to non-linear nature of PE devices. It increases harmonic emissions and electromagnetic interference [69].

In this case, the role of the MCU and its features constructing the control system are significant. In fact, functionality of MCUs, their technical features, and performances of PV subsystems are defined as solutions. MCU-based MPPT approaches are implemented in two ways: I) using characteristics of PE circuits, and II) changing the PV system architecture [39]. In some cases, the PV system architecture can be recognized as PE-based MPPT approaches as well. For instance, differential power processing (DPP) which is identified as PE-based MPPT approach [39, 70] can be defined as a PV system configuration. The next two sections describe these two approaches in which MCUs play a significant role.

Since the PV cell is observed as a black box, PE-based techniques are not affected by PV types or electrical equivalent model used. The three major PE-based MPPT methods are named as: the bypass diode method, the PE equaliser, and TEODI [38, 71].

2.3.5.1 Bypass Diode Method

In a PV system using Module Integrated Converters (MIC), a voltage shortage is detected whenever the bypass diode is active showing shading conditions. Therefore, the voltage of the bypass diode indicates the PSC, and the technique initializes a global search on *P-V* curve to locate the global maximum. The drawback of this method is that sometimes without any change in bypass diode voltage a local maximum may occur.

2.3.5.1 PE Equalizer

Power Independence Principle (PIP) defines a topology in which series connected cells can be operated with different voltages and currents. PE equalizer establishes an equivalent power throughout the PV modules either shaded or non-shaded by sharing the power between these PVs. Capacitors are used to store the energy from the non-shaded modules [71].

2.3.5.1 TEODI

"*This techniques is based on the equalization of the output operating points in correspondence of the forced Displacement of the Input operating points of two identical PV systems and will be indicated with the acronym TEODI*" [38]. In basic TEODI, the PV system has two PV modules connected in parallel to its own DC-DC boost converter. This technique is based on the equivalence output power of the two boost converters in correlation to their input voltages [71].

2.4 Merits and Demerits of MPPT Methods

Conventional and soft-computing methods have been drawn more attention than PE-based methods among researchers due to their dependencies to PV system architecture and hardware components of the system. Therefore, advantages and disadvantages of the two main categories of MPPT methods, soft computing and conventional, are considered here.

Dealing with nonlinearity and PSCs are the advantages of these intelligent techniques [49], although a few drawbacks affect utilizing them. The ANN requires a comprehensive training process demanding more advanced microcontroller with higher cost [51], and the FL-based MPPT controller is extremely dependent on the designer knowledge and experience about the PV system [4, 51]. In addition, complexity of algorithms and cost associated with controlling systems are their major obstacles. On the other hand, there are meta-heuristic MPPT algorithms dealing with nonlinearity and PSCs. The dominant methods and most practiced ones can be named as genetic algorithm such as cuckoo search (CS), particle swarm optimization (PSO), and ant colony optimization (ACO). Regardless of undeniable merits provided by these techniques, their algorithms require sophisticated and costly control systems. Besides, the dependency to PV type in FL techniques prevent the system designers to rely on these methods. Therefore, mobile applications and PV systems operating in remote areas will be affected by the extra cost and equipment needed for the control systems. Table 2-4 presents advantages and disadvantages of well-known soft-computing MPPT methods.

Table 2-4 Merits and demerits of dominant soft computing MPPT methods

MPPT Method	Reference	PV dependent	Complexity	Speed	Cost	Efficiency
FLC	[24, 42, 46]	Yes	Medium	Fast	High	≥ 98%
ANN	[42, 46]	Yes	Medium	Fast	High	High
ANFIS	[42, 46]	Yes	High	Fast	High	High
DE	[4, 46]	No	Medium	Fast	N/A	High
GA	[4, 46]	No	High	Fast	N/A	High
PSO	[4, 46, 72]	No	Medium	Fast	N/A	≥ 99.8 %
ACO	[4, 46]	No	Medium	Fast	N/A	High

Most practical conventional methods are summarized in table 2-5, with regards to the main criteria that affect their implications. It demonstrates the overall benefits of the P&O compare to the other methods. The P&O is the well-known conventional MPPT technique broadly used commercially for many years [11, 47]. Although there exist other approaches representing slightly better performance, the popularity of the P&O method among PV system designers is undeniable. It is widely used for stand-alone and grid-connected applications and can be implemented in analog circuits or cheaper digital elements [11]. Its acceptable high efficiency, more than 93% in most cases [11, 42], and simple implementation of the algorithm have been convinced PV system designers to employ this MPPT method more than any other approaches. This advantage is a great favor of using PVs in mobile applications and/or remote locations. conventional methods offer convenience and simplicity. However, they may be trapped in local points and detect one of the local points as the MPP for the system consisting of several PVs performing under PSCs.

Table 2-5 Merits and demerits of well-known conventional MPPT methods

MPPT Method	Reference	PV dependent	Complexity	Speed	Cost	Efficiency
P&O	[6, 39, 42, 52]	No	Low	Fast	Low	≥ 94%
IC	[11, 24, 39, 42]	No	Medium	Varies	Varies	≥ 97%
HC	[11, 52]	No	Low	Varies	Low	≥ 95%
Fractional-SCC	[11, 24]	Yes	Medium	Medium	Low	≥ 89%
Fractional-OCV	[11, 24]	Yes	Low	Medium	Low	≥ 86%
RC Control	[11, 52]	No	High	Fast	High	High

3-point weighted avg.	[11, 52]	No	Medium	Varies	Low	High
ES Control	[11, 24]	No	Medium	Fast	Low	≥ 98%
Sliding mode control	[39, 52]	No	Medium	Fast	Medium	≥ 98%
Load C/V max.	[11, 39]	Yes	High	Fast	High	≥ 98%
Bisection search	[11, 39]	No	Low	Varies	Low	Low
β-method	[11, 39, 52]	No	Medium	Fast	Medium	High

2.4.1 Characteristics of an Effective MPPT Method

Based on the previous sub-sections, there are several characteristics required for an effective method. However, there are no ultimate rules for choosing an appropriate method for a PV system. In fact, it depends on the PV application and planning requirements. Table 2-6 outlines characteristics of an effective method according to different classifications and literature reviews. Nevertheless, an MPPT method must fulfill the following requirements.

Table 2-6 Characteristics of an Effective MPPT Method

Requirements
Tracking MPP regardless of PV array size, configurations, and cell technologies.
No need for periodic tuning that system dependent MPPTs might require because of non-uniformity of PV panel temperature, dust effects, damages of panel glass
Using minimum sensed parameters
Less difficulty in term of microcontroller programming, and the algorithm complexity, simplicity of hardware components
Grid-interconnection: utility side and PV system side should be considered regarding technical aspects
Fast convergence in varying environmental conditions
Effective in performance: reliable, work in different applications, and easy to implement
Detecting UPS and PSCs.
Free of prior training or previous knowledge of PVs or other system components.
Being cost-effective
Less oscillation around MPP

2.4.2 Designing an Efficient PV System

The planning for installation an efficient PV system requires to design the MPPT-based control system in the planning phase of the project. Practically, even in PV sites without any adjacent building, PSCs or USCs are inevitable due to clouds, dust, snow, or pollutions. PV system designing tools may or may not design MPPT control systems. In the case of ignoring PSCs, MPPT techniques are not applicable; thus, predicted power outputs cannot be accomplished. In the other case, the hardware and interfaces are provided by the software, usually picked from a database including commercially available MPPT control systems or defined by the system designer/engineer.

In term of having the option of choosing an appropriate MPPT method, the system planner/designer should make the decision about collecting a method from soft computing or conventional approaches. The efficiency of each method can be changed by adjustments a few technical features of system components and physical characteristics. Besides, even conventional methods can track the global point in most real-world conditions that cause more uncertainty in appointing exact MPPT method. The other factor is the redundancy and similarity in soft computing techniques that cause the making-decision process an arbitrary choice. The most important factor challenging MPPT classifications and efficiencies entitled to each technique is dependency of the method to various internal and external factors affecting the assessment. The following section and subsections identify one of those and show its impact on altering the efficiency.

2.5 Problems Associated with MPPT Methods

In a previous published paper [6], efficiencies of P&O method are assessed when the simulation model experiencing three different input patterns, respecting irradiance. We have shown that substantial alterations in an irradiance pattern marks in lower efficiency with a greater number for the iteration number (n). ANNEX IV illustrates the schematic of the simulation model tested, diagrams of the three input patterns, and the output results (voltage, current, and power) of the PV system. Table 2-7 provides a summary of the paper's results.

Table 2-7 Efficiency results

Scenarios	**Iterations**	**Efficiencies**
1	11372	95.3318 %
2	11366	97.4 %
3	11702	95.536 %

The results of this work indicate that to define efficiency for an MPPT method, the simulation must be implemented experiencing several irradiance shapes. In addition, applying unrealistic irradiance patterns to the Simulink model establish unrealistic efficiency results. In this regard, the reliability and accuracy of simulations presenting poor efficiency for the P&O method can be challenged. The fact that there are no standard irradiance patterns to evaluate accuracy of a simulation, the accuracy and reliability of the MPPT methods and their efficiencies are questionable. Testing multiple conditions and considering local irradiance data can assist system designers to pick optimum MPPT method required for the PV system. Moreover, the simulated irradiance patterns and their volatility should reflect real shading conditions based on the local climate data. In addition, a simple MPPT control system associated with the P&O algorithm can be used for PV applications demanding minimum equipment and devices.

As a result, it is argued that the efficiency percentage or the convergence speed related to any method can be altered when certain adjustments performed. In this manner, even conventional methods may perform a better efficiency than an EA-based technique. The fact is that there are no standard conditions to be considered for evaluating an MPPT method. Parameters of a PV installation can be adjusted based on the microcontroller used, control parameters chosen *I* or *V*, and configurations of PV arrays. Therefore, it reveals that choosing an MPPT algorithm from existence classifications does not guarantee a certain efficiency percentage, because of I) adjustments applied in experiments related to the classifications, II) initial values defined in EA-based and SI-based algorithms, and III) various PV system architectures. Furthermore, in a previous work, we argue that the previous perceptions about classification of MPPT methods are challenged by concentrating on technical characteristics of MCUs [48]. MPPT architecture is addressed as an important factor that is required to be considered to develop novel MPPT methods. In this perspective, PE approaches are frontiers comparing to soft computing MPPT techniques depending on their algorithms. In fact, instead of developing numerous redundant techniques, it is more sufficient to add new technical features to MCUs, for instance new sensing devices, or develop MPPT architecture. In this manner, system designers have opportunities to utilize technical characteristics of devices used in the PV system, so that designing a MPPT-based system will depend on the hardware used in the PV system.

CHAPTER 3 THE RESEARCH METHODOLOGY

3.1 The Research Methodology

The focus of this chapter is to describe the steps have been taken to implement the research methodology. Figure 3-1 depicts the main stages of the research methodology to create proposed ontology. The four stages of the research methodology represent the processes implemented from the beginning of the research project to evaluating the proposed ontology model.

- Stage 1) as depicted in the figure, the context of PV and research are studied in the first stage. In this early phase, we review possible research methodologies and scientific approaches. In addition, MPPT methods, optimization techniques, metaheuristic algorithm, PV system modeling, and simulation are investigated.
- Stage 2) in the second stage, class axioms and their relationships are defined. Searching for various concepts representing PV planning and MPPTs is the key aim in this step.
- Stage 3) the third stage of the research study the ontology model is designed and developed containing classes, data, and objective properties, as well as SWRL rules and queries.
- Stage 4) Evaluation of the proposed ontology is performed using a case study, NREL visitor parking. Available datasets help us to validate the ontology while semantically verifications of the ontology are undertaken using Protégé reasoning plug-ins.

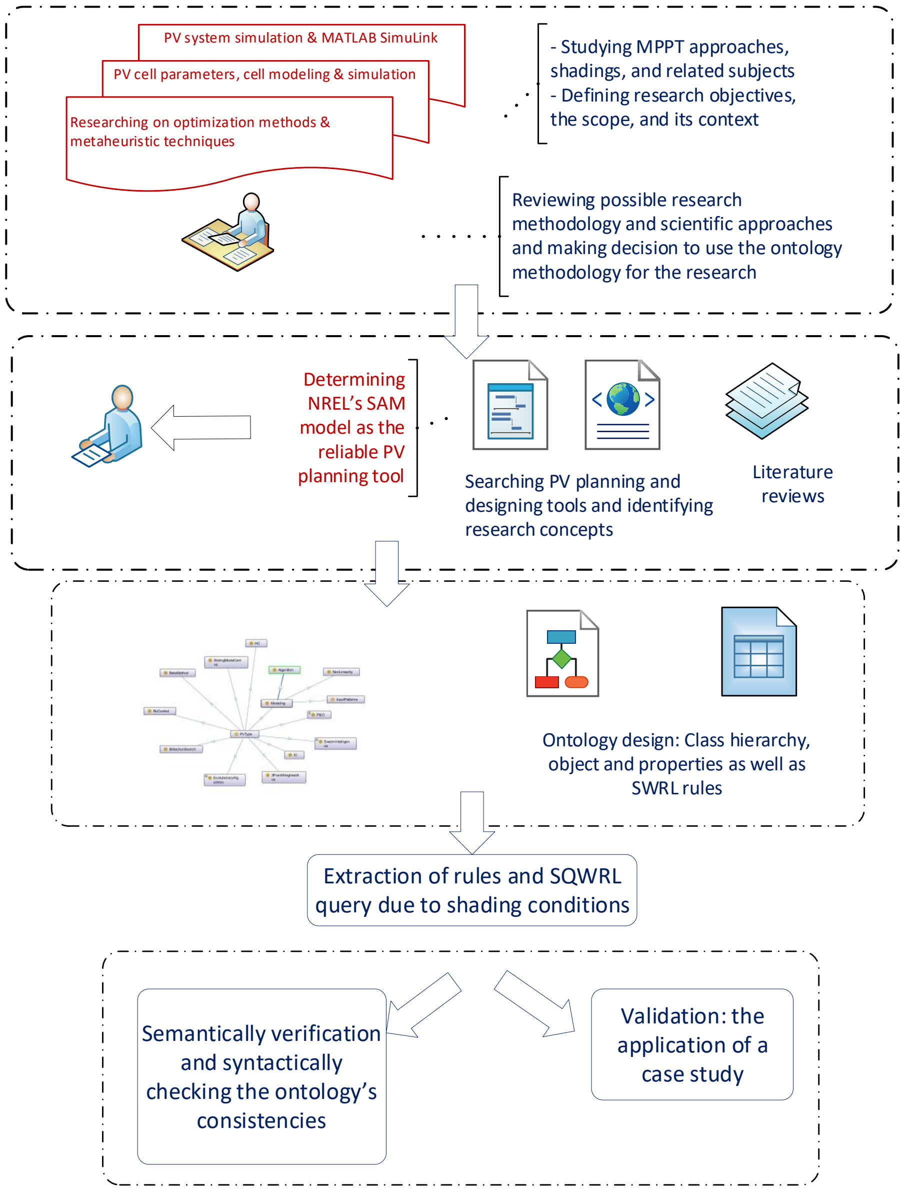


Figure 3-1 The research methodology

3.1.1 How the Proposed Model Built: The Research Implementation

Identifying OWL class axioms and their relationships are the most important processes in the executing phase (see figure 1-4). This sub-process is the prior step for determining the concepts needed for the knowledge-based model and developing the ontology. Figure 3-3 introduces these two main activities:

I. analyzing literature reviews searching for different concepts representing the subject matter and key factors of the PV domain

II. II) investigating PV planning tools and different PV design applications to find major concerns that PV planners and experts in the industry focus on.

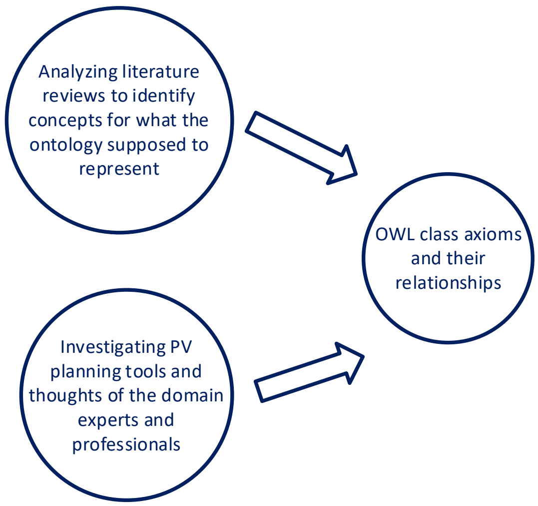


Figure 3-2 The two key activities leading to OWL class axioms

Defining notions in the PV system design and their interconnections with the PV project planning when shading occurs can assist us to set SWRL rules and provide reasoning for the ontology. Then the ontology can be developed using Protégé in this case. Ontology and the Semantic Web architecture play an important role in creating the proposed model. In the following sections, we review critical aspects of ontology methodology. Then, ontology languages, ontology engineering, ontology reasoning are overviewed. Further, we review the application of ontology in related works, especially in the energy sector and the PV domain.

3.1.2 Technologies Deployed in the Research

A summary of technologies deployed in the proposed model is displayed in table 3-1. These cutting-edge technologies and software applications are employed throughout the research for the literature review, modeling, and constructing the proposed ontology. MATLAB Simulink is used for the system modeling and simulation. SAM model is used to plan a project and estimate its hourly and monthly power productions. There exist two performance models used in SAM model: I) PVWatts which is a basic PV performance model, and II) PV-detailed that provides more precise information about PV performance.

Table 3-1 The key technologies utilized in the proposed model

Process or Field of Study	**Technology Used**
- Literature review	- EndNote X9.2
- Ontology language	- OWL
- Ontology editor	- Protégé (v.5.5.0)
- SWRL rules	- SWRLTab, Excel, and Notepad++
- Reasoner	- Pellet
- Query language	- SQWRL query
- Importing database to the model	- Cellfie, Excel, and Notepad++
- UML class diagrams	- Visio
- Ontology graphs	- OntoGraf, OWLViz
- BPMN diagrams	- Visio
- Simulation and modeling	- MATLAB Simulink (2019)
- PV planning software	- SAM model
- PV performance models	- NREL’s models and MATLAB PV model

W3C standard reasoners are used in different Protégé plug-ins for reasoning. Resource description framework (RDF) is used for representing entities and their relationships. Resource description framework schema (RDFS) is the schema language for representing classes and properties. In addition, we employ unified modeling language (UML) using Visio to depicts the classes logical relationships and define the basic and fundamental reasoning rules.

3.2 Motivations for Using Ontology

The emergence of Semantic Web technologies required a need for an ontology web language in the early 1990s [73]. Further, computer science and artificial intelligence research also required a language capable of modeling disparate knowledge with different sources from distinct domains. Thus, ontology has been arisen as the most powerful machine processable language for representing domain knowledge. In the next section (3.3) and chapter 4, the Semantic Web and ontology-based solutions related to the research are described in detail. In the below subsections, we present the major reasons for utilizing ontology in the research.

3.2.1 Ontology Models vs Databases

Among the technologies deployed in the research (3.1.2), Protégé plays a major role in building our ontology. Protégé is a tool enabling us to create a model and to collect information [74]. In addition, as the same as a database, its application can help to design a system or artifact. The differences are:

- **I.** Protégé emphasises on a model, whereas in a database, the data is important. In a database, the model is the secondary [74].
- **II.** Protégé provides better modeling language that leads to inheritance relationships, constraint overriding, and expressing a web of relationships [74]. In contrast, a database provides a simpler modeling language which is optimized for speed.

Moving from data processing to concept processing in modern information systems has carried out as a semantic concept rather than data analysis [75]. In fact, the building and the application of an artifact identify the knowledge base that is required to analyze a design problem [76]. A knowledge base model, through which relevant information about MPPT methods can be used and shared, helps domain practitioners to deal with PV planning and designing obstacles. We propose a knowledge base model offering data and information required for designing an MPPT-based controller when planning the system. Constructing the knowledge base model conduct us to utilize ontology engineering and technologies offered by that. One of the main reasons for using ontology is the capability of the model made to deal with complex data forms regardless of the sources. In addition, we need a model that understand logic of the context and can extract various information from distinctive resources. Ontology allows a model to represent data and information with various repository and perform rules to support context-aware systems. Therefore, in our research context, it can provide potential alternatives and solutions to design a PV system efficiently and plan the project effectively. A comprehensive knowledge base model using reasoner can present a decision support system for effectively using the planning tools and software products.

3.2.2 Common Terminology

Ontologies provide a common terminology that is independent to the application of the domain they represent. These knowledge-based models can be used similarly by human and machine agents [77]. Besides, the application-independent characteristic of the model allows it to be utilized in different applications. Moreover, the use of formal semantics aids the data to be transferred between humans and machines by eliminating undesirable explanations [78]. This feature is especially crucial for the purpose of this research where various concepts about the designing and planning of a PV system are involved in the power conversion. These factors contain PV operation under shading conditions that require contextual information and weather data about the PV project and the system itself.

3.2.3 Checking for Uniformity

As Kontopoulos et al. [77] indicates "*Ontology models provide inference capabilities for consistency checking, derivation (i.e deriving implicit knowledge) and classification (Burger and Simperl, 2008; Hepp, 2008).*" This advantage of ontology-based solutions is especially suitable for a decision support model when trying to categorize the effects of a new environmental factor on shading into an existing class of components. It means that the proposed model can be improved, and new concepts can be added to its classes after constructing the ontology model.

3.2.4 Integrating Heterogenous Information

Ontology allows us to work with various data and information provided from different bases. In this regard, heterogenous data from multiple diverse sources are integrated, ensuring the interoperability for the data and process [79]. This fact will fulfill the objective of this research for creating a decision support system interconnecting various sources of information and data.

3.2.5 Reuse, Interoperability, and Sharing Info

Establishing a decision-making framework that represents the PV system domain can assist non-technical consumers to cope with the process of the planning. The framework, through which relevant information about the methods and solar module performances can be shared and reused. It will assist non-technical consumers including project managers, PV software designers, utility clients, and domestic customers to collect relevant data and select appropriate MPPT approaches as well as other technical parameters.

3.3 Ontology: Basic Notions and Definitions

An ontology is "*an explicit specification of a conceptualization"* that can be interpreted as formally describing a domain of interest through an abstract model [80]. In this way, the community of a certain domain can reuse and develop the shared knowledge constructed with alike terminology. Ontologies are agreements about share conceptualizations including conceptual frameworks for modeling knowledge and representation of specific domain knowledge [81]. They are known as specific frameworks of representational vocabulary and common terminology. They provide hierarchy form of specified classes and their relationships.

Interconnection across heterogeneous applications conveniently provides an understandable framework for developing ontologies and facilitate them with up-to-dated knowledge and elaborated semantics [77]. Ontology can deal with large volumes of data, share knowledge, and incorporate the relevant domain concepts as well as their associated relations [82].

3.3.1 Ontology Language and Ontology Engineering

Ontologies are formed utilizing explicit formal languages, known as ontology languages. While its counterpart, ontology (or ontological) engineering states the set of processes, methods, and methodologies for developing an ontology. The Semantic Web, introduced by Berners-Lee [83], to improve unstructured and/or semi-structured Web pages and documents into a structured, well-defined and meaningful content of Web data. The need for a common framework that enables data sharing among a community or an enterprise and provides interoperation between machines and humans have been the motivation behind the notion of the Semantic Web [84]. The Semantic Web is constructed based on a multi-layer architecture of technologies with conceptual hierarchies known as ontologies.

Among many ontology languages, Web Ontology Language (OWL) is the most popular. It has developed by researchers to handle complex semantics. It is capable of dealing with various classifications, properties, and constraints in variety of applications [85]. OWL language is the most dominant ontological language which is used by applications that need to process the content of information [85]. On OWL knowledge bases, structural inferences can be performed such as subsumption and identity [86]. This kind of inference is lack of accurate meaning for the semantics that is being represented in the OWL knowledge base. Therefore, to be able to infer new knowledge Semantic Web Rule Language (SWRL) has been proposed to deal with reasoning [87]. SWRL is considered as a rule language for the Semantics Web that enable us to include OWL with reasoning capabilities. Ontology editors have been emerged in recent years to assist practitioners with automatic development of ontologies. Difficulty in developing an ontology depends on the ontology language and methodology that are used by the ontology editor [73]. In this research, Protégé 5.5.0 is chosen due to its support to ontology libraries, use of OWL languages, and existence of valuable plug-ins. OWL2 developed later with the Semantic Web with formally defined meaning and can be used along with information written in RDF [88].

Unlike ontology language, an ontology engineering deals with processes, methods, methodologies and tools to develop an ontology [89]. Ontology engineering as a specific-domain modeling notion can be deployed for the decomposition of the collaborative of practitioners such as survey into different activities. In addition, it can validate the process to test whether it is likely to yield the desired results [15]. The ultimate aim of an ontology engineering is to provide a theory of the common terminology needed to construct a model of human problem-solving processes [15]. By analyzing structure of the problem in the real-world, one can provide a theory of all the concepts necessary for building the model. Hence, ontology engineering assists researchers with the design rationale of a knowledge base with sophisticated theories and technologies [15, 90].

3.3.2 Ontology Reasoning and the Plugins Used

Ontologies are created to represent knowledge, information, and data originated from the real-world sources. In this regard, there is a need for additional description techniques to ease these complex situations. Rule-based ontologies can establish defined rules and logics to interpret different context including structured and unstructured data [84]. Reasoning is the process of making implicit information explicit. Reasoning rules are different from if-then rules from programming languages. In fact, conditionals in programming are procedural and are executed in the exact order specified by the programmer. In contrast, reasoning rules are decorated so that they do not encode the control flaw. Researchers have developed reasoners to infer the ontologies.

W3C team standardizes the SWRL for expressing different conditions in real applications. SWRL includes a high-level abstract syntax in the sublanguages of OWL [87]. A model-theoretic semantics is given to provide the formal meaning for OWL ontologies including rules written in the abstract syntax [87]. In Protégé, reasoning over the ontology is performed by employing developed plug-ins such as HermiT, Pellet, FaCT++, etc. To develop the proposed model, we implement Pellet plug-in. Pellet provides an extensive support for reasoning with individuals which play an important role in our model [91]. Sirin et al. states that Pellet fulfill most of the latest approaches and optimization techniques provided in the DL literature. The paper introduces several features and capabilities indicating Pellet's competencies axiom pinpointing and debugging and integration with rules formalism. These unique technicalities and the convenience application of Pellet through several interfaces offer practical solutions for ontology reasoning.

A query language is used to extract information from OWL ontologies. SQWRL, developed by O'Conner et al., provides a concise, readable, and semantically robust query language for OWL [92]. It provides different and useful operators that support negation as failure, disjunction, counting, and aggregation functionality. SPARQL has been the only RDF query language used for many years, while it has no native understanding of OWL and operates only on its RDF serialization [92]. In the O'Conner's paper, SQWRL is described as a SWRL's built-in facility. Thus, "*it defines a set of operators that can be employed to construct retrieval specifications*" and "*no syntactic extensions are required*" [92]. The paper presents several queries to support its applications in different scenarios. An implementation of SQWRL has been developed in SWRLTab and SQWRLTab plugins in Protégé. They provides a graphical interface to set, edit, and run SQWRL queries and also provides a Java interface to execute SQWRL queries in Java applications [92]. It free and open-source and the interfaces applied in Protégé enable the user to implement SQWRL language easily. In this work, we implement Pellet as the OWL reasoner and Semantic Query Enhanced Web Rule Language (SQWRL) as the query language for our ontology model.

3.4 Related Works

As an understandable language ontologies have developed significantly in several domains including bioinformatics, renewable energies, smart buildings, telecommunications, law, construction, agriculture, and land economy [73, 93, 94]. Table 3-2 emphasizes the number of articles reviewed in different subjects about ontology technology.

Table 3-2 The number of articles about ontology technology

Main subject of the paper	Number of References
knowledge-based & philosophy	2
Ontology Design	7
Ontology Engineering	15
Ontology Languages	25
Overviews	15
Reasoning	8
Ontology & Simulation	1
Design Science Research	11
Ontology Evaluation	44
Reference Model	1
Total	**129**

Figure 3-3 provides a visual comparison of reviewed papers. As observed, ontology evaluation withdraws lots of attention in the research interest of ontology. Developing a Web-based application is the outcome of an ontology for the domain depending on whether an existing one need to be improved or a new ontology is created.

Browsing scientific databases proves that ontologies are applied in many applications: environmental assessment of enterprises [95], educational tool for sustainable development [96], an environmental decision-making in the domain of industrial symbiosis (IS) [97], data mining and evidence-based decision making [94], software quality assurance [98], information system re-engineering [99, 100], e-Business management [101], software quality models [102], metrics [103], supply chain integrated business processes [104], system engineering and communication [93].

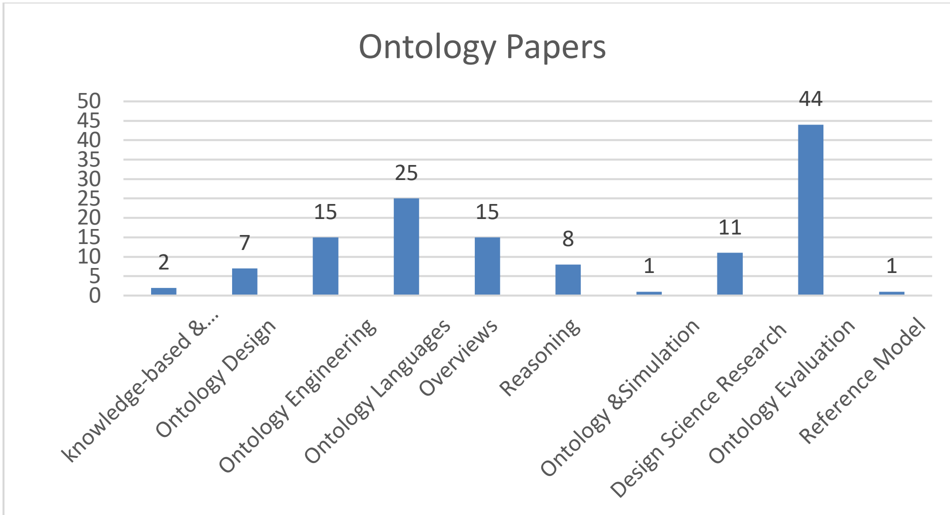


Figure 3-3 The visual comparison of articles about ontology

3.4.1 Applications of Ontologies in the Energy Sector and the PV Domain

Likewise, researchers in renewable energy domain have employed ontologies for modeling. Because of the field of this research, semantics in energy management and solar energy sector are overviewed in the followings. The notion of human and machine interaction establishes a unique collaboration between ontology and the domain of energy management and smart buildings. We collected a total of seventy papers in a searching for papers about applications of ontologies in energy-related domains. The purpose of this selection of papers was to understand the application of the ontology used and identify characteristics of ontology technologies employed. Table 3-3 indicates the collected articles about the application of ontology in energy sector; in addition, the chart bar for the visual comparison is provided in figure 3-4.

Table 3-3 The number of reviewed articles reviewed (ontology in energy sector)

Main subject of the paper	Number of References
Business	15
Classification & Selection	7
Education	5

Energy Management	6
Energy Policy & Enviro,	4
Knowledge Management	4
Product Description	1
Smart City	9
Smart Home	3
Software Engineering	6
Software Quality Assurance	4
Solar Sector	9
Wind Energy	7
Total	**70**

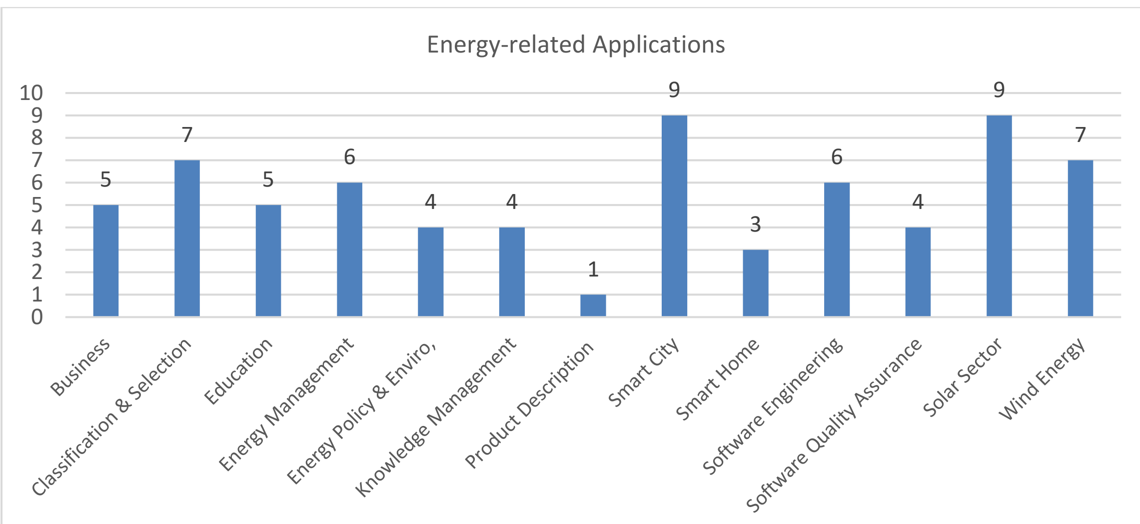


Figure 3-4 The visual comparison of articles about ontology applications in specific domains

In a related paper [105], an ontology is presented providing recommendations to increase efficiency for appliances. The presented ontology infolds knowledge of residential appliances and the energy consumed. In this way, related factors influencing the energy consumption can be analyzed and managed. Moreover, the ontology incorporates household information and family members' behaviour using appliances, to inform residences of their energy usage.

In a comparable ontology [106], the goal of the ontology (DogOnt) is to provide variety of options available for generating energy, depending on the building, the number of living residences, and the operating devices and/or appliances. Introducing a Home Energy Management System (HEMS) into user residences, [107] launches a system that allows the user to control the devices in the home network through an interface and apply energy management strategies to reduce and optimize their consumption. In the ontology, rules are applied to create the energy management strategies which makes this home gateway suitable for HEMS.

In the sector of Urban Energy Systems (UES), an ontology named SynCity introduces a platform for modeling urban energy systems [108, 109]. This OWL-based ontology characterizes components of UES domain including object classes representing the main parameters of an urban energy system [108]. The ontology consists of resources, infrastructure, and processes as the main categories of classes.

Specific ontology worked on PV, Photovoltaic Technology Ontology System (PV-TONS) [73], presents a PV ontology-based system assisting decision makers by recommending appropriate PV system configurations. It is a framework representing PV domain knowledge using OWL 2 [110] facilitating decision-making process. Although PV-TONS considers environmental factors and climate conditions, major parameters affecting power conversion and reducing the efficiency are overlooked. PV system performances are evaluated and estimated based on the simulation heavily depending on assumptions. In another work [77], an ontology is proposed for optimizing domestic solar hot water system selection. The proposed tool assists non-technical consumers with their needs to current information for choosing components of the solar hot water system and the installation costs in the form of an ontology formulated in OWL. The system configurations are computed based on various specific parameters, such as number of occupants, daily hot water requirements and house location [77]. From the best of our knowledge, there is no ontology engineered to facilitate MPPT-based PV system design.

3.5 The Research Methodology

To create a knowledge base reference model, two main activities are considered [15]: I) a comprehensive literature review, II) investigating PV planning tools and collaborating with the domain practitioners to identify characteristics and technical parameters associated with designing an efficient PV system. Literature review activities include processes that allow us to explore research interests, challenges, concerns, and knowledge areas from scientific point of views. On the other side, investigating PV planning tools and performing a survey can help us to understand technical challenges the industry deal with. Experts and professionals in the community can be asked to about essential factors affecting shading conditions and consequently PV performances. The architecture of the proposed Semantic Web model and its layers are explained in the followings.

3.5.1 Components and Software Platform Used

The idea of creating a “web of data” from unstructured and semi-structured group of Web documents is the emergence of the Semantic Web [83]. The Semantic Web in fact is “data about data” providing metadata so that various layers of technologies can be used. The architecture of the Semantic Web and its stacked layers are presented in figure 3-5 [111, 112]. As shown, several languages are used to create the Semantic Web. The technologies from the bottom to the top are currently standardized and accepted to build Semantic Web applications [113]. The bottom layers contain technologies providing basis for the Semantic Web and known as hypertext Web technologies. The middle layers, standardized Semantic Web technologies [110], allow us to build semantic web applications. RDF is a framework for creating statements. It enables to represent information about resources in the form of graph. Its schema (RDFS) delivers basic terminology for RDF and creates hierarchies of classes and properties. OWL extends RDFS by adding more constructs to describe semantics of RDF statements. It enables to state additional constraints and restrictions of values, or characteristics of properties.

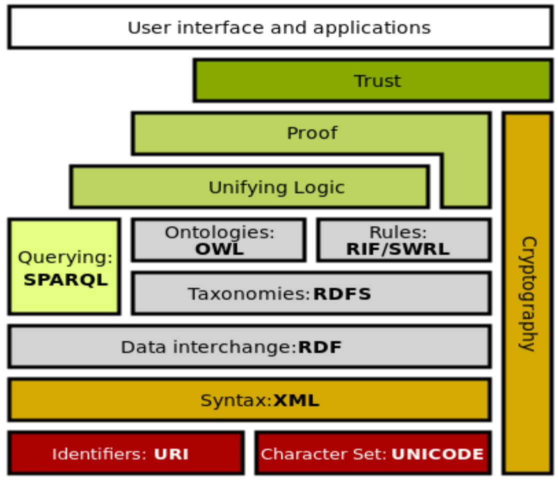


Figure 3-5 The Semantic Web architecture (source [112])

It is based on description logic and brings reasoning power to the semantic web [114]. OWL is an expressive ontology language that builds on top of RDFS and provides formal semantics. Differences between RDFS and OWL is about the decoration of classes and properties. RDFS does not differentiate between properties based on the range and all the properties are declared in the same way. It can be used in fast and flexible data modeling and efficient automated reasoning. Although, OWL is a modeling language in the classical sense. It has many advantages compared to the modeling languages that came before it, UML. OWL can be expressed in more human readable formats. A semantic query language such as SQWRL is used for databases. It can be used to query any RDF-based data including statements involving RDFS and OWL. Querying language is necessary to retrieve information for semantic web applications [87, 115]. The main components of an ontology are I) concepts, usually presented by classes of objects, II) attributes, which refer to features that the objects have, and III) relationships between the concepts, typically represented by properties.

3.5.2 The Semantic Web Stack of the Proposed Model

The Semantic Web Stack (figure 3-5) demonstrates the architecture of layers and languages and how technologies are arranged to make the knowledge base model possible [113]. These standardized technologies are used to build the Semantic Web of the proposed model. Complying with the standard architecture, Figure 3-6 portrays the Semantic Web and the components of the software platform in a detailed six-level layers.

Semantics, notions, and data related to PV planning and MPPT methods are gathered and extracted from available data sources in the PV domain. Logical relationships, interconnections, and rules expressing those connections are defined in the next level. Then, we extract rules based on these contextual knowledge areas defined in each domain. The decision support system and the application of the model is made by adding the rules and queries allowing the end-users to extract information from the ontology. The final level is to unify the logic and to prove that the semantic model represents what it has been made for.

The endeavors performed in several processes of creating the ontology model for PV systems can be utilized for other renewable energy resources applying the engineering design like solar energy. MPPT methods are used in wind farms so that the methodology of building the MPPT database can be transferred for making an ontology model in the wind energy sector. Furthermore, the architecture of the framework and its layers facilitate the process of planning projects in other renewable energy resources that rely on the engineering design.

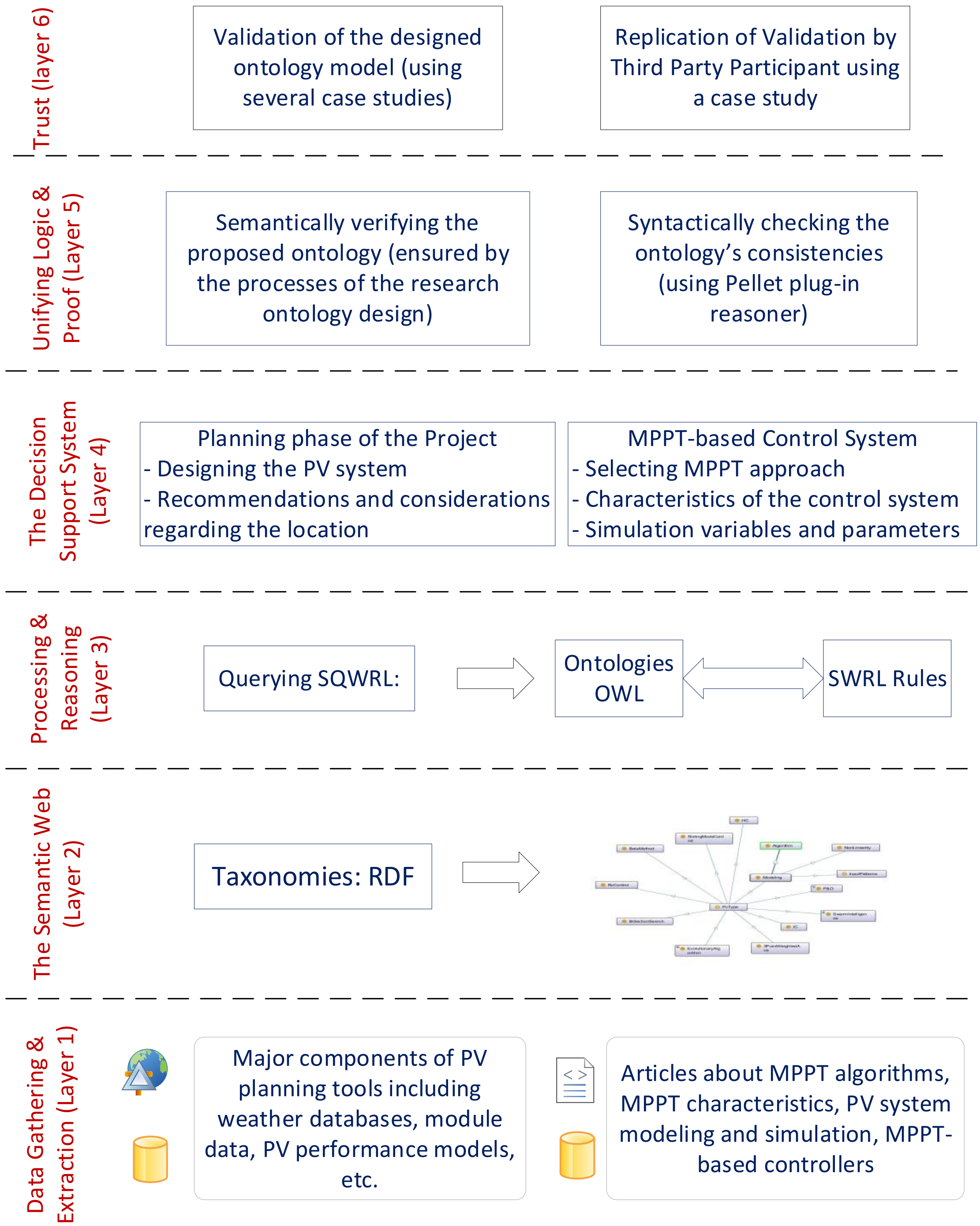


Figure 3-6 The Semantic Web architecture for the proposed decision support system

CHAPTER 4 DESIGNING THE PROPOSED ONTOLOGY

The process of building ontologies is often anarchistic because each development team usually follows its own set of principles, design criteria, and steps in the ontology development process [9]; so that few domain-independent methodological approaches have been reported. These methodologies start from the identification of the purpose and need for the domain knowledge acquisition [9]. The provided information by ontologies could be very subjective due to the fact that ontologies heavily depend on the level of knowledge of experts and the sources, in case of being constructed manually or automatically [116].

Ontology is one of the optional solutions to deal with massive amount of data originated from distinctive repositories [117]. There are three different approaches for constructing ontologies; single approach, multiple ontology approach, and hybrid approach [118]. The single ontology approach shares the vocabulary and the terminology to specify the semantics. It cannot provide a perfect solution for information integration because it uses single global ontology for all sources [119]. The multiple ontology method each information source is described by its own local ontology. Combination of these two approaches forms the hybrid ontology approach. In this approach, local ontologies may share some vocabularies amount each other [119]. Regardless of the ontology classification, methodologies for designing ontologies are established by determining a set of criteria for analyzing them.

Zambrana et. al focused on conceptualizations, development, and validation for an ontology methodology [120]. Five questions are determined to assess the methodology:

- **I.** "*Are the ontology elements as concepts, relations, properties, etc. based on corpus work?*"
- **II.** "*Who are the intended users of the methodology?*"
- **III.** "*Does the methodology explicitly state which methods and techniques we should use to perform the different activities?*'
- **IV.** "*Does the methodology propose to perform a conceptualization activity?*"
- **V.** "*Is there a program associated with the methodology that facilitates the different steps to be taken?*"

In another paper, the strategy taken for identifying concepts and then creating them is one of the main aspects of developing ontologies [121]. Rizwan investigated twelve common methodologies based on six basic measures: 1) collaboration, 2) degree of reusability, 3) application dependency, 4) life cycle, 5) methodology details, and 6) interoperability [122, 123].

According to Zambrana [120] and relevant to PV planning, we need to take into account the following questions:

I. Who are the intended users of PV planning tools and consequently the proposed model?

II. Which methods and techniques are used to overcome shading conditions and perform MPPTs?

III. Is there a program associated with the methodology that facilitates the different steps to be taken?

Answering these questions establish a framework to identify important concepts and notions needed for the ontology model which is supposed to represent MPPTs in PV planning. Responding to the first question can assist us to define the functionality of the developed model. Our research objectives focus on the representative aspect of the model instead of fulfilling users' interests. Answering to the second question requires to recognize various factors involved in shading conditions and application of MPPTs. Moreover, PV planning and designing tools must be investigated for seeking further parameters the experts of PV sector deal with. The next section describes how we implement a method to achieve these goals.

4.1 Identifying Important Concepts for the Model

As the scope of the research defines, the context of MPPT methods and the related factors affecting PV planning need to be investigated. In this regard, we divide the context into a set of concepts linked to designing PV systems and the planning. The subsequent figure (4-1) presents these two main streams and the processes undertaken to define essential classes and semantics for the model.

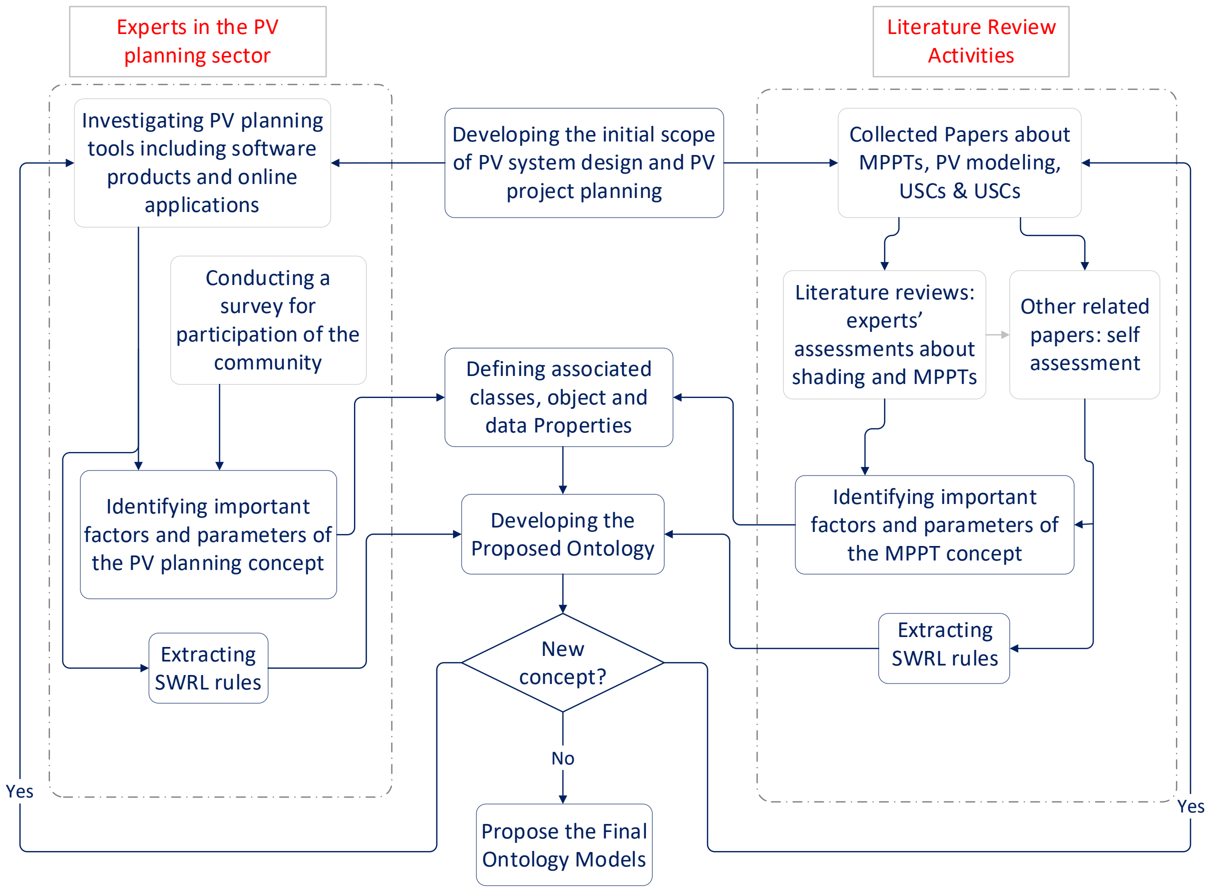


Figure 4-1 Identifying concepts for the ontology model

We implement three major steps to define key semantics for our ontology including the literature review, investigating planning software tools, and conducting a survey. The following sections explain how these processes can aid to characterize important classes and rules for the knowledge-based model. Also, extracting rules in the two main parts of the figure (4-1), respecting experts working in the PV sector and literature reviews, showcase its own background. The ultimate rules meant to extract two distinctive knowledge areas in the planning solar power projects, MPPT methods and shading conditions. Therefore, there is no conflict between the rules and each set can be performed differently.

4.1.1 The Process of the Literature Review

This process is the main approach for identifying concepts that accurately reflect every aspect of knowledge encompasses MPPT. We consider literature-review-oriented articles about the methods, shading conditions, and PV modeling and simulation as the main resources in this manner. We argue that a paper providing a literature review about a subject can be a source of representation for its context. In fact, literature reviews are performed by scientists and researchers with the intentions of encompassing every aspect of the subject matter. A literature review paper is known for its numerous references and representing various aspects of the research subject.

Table 4-1 shows our investigation in literature review papers for searching parameters and factors in the MPPT method knowledge base. These peer-reviewed papers reflect findings of many researchers. They are published while each and one of them include more than 150 references. In fact, the following table embody 6900 scientific resources representing the knowledge areas. Thus, class axioms defined in this manner can accurately contain concepts needed for representing the MPPT knowledge based.

Table 4-1 Papers investigated for identifying the OWL model class assertions

Knowledge Area	Number of Articles
MPPT methods and characteristics	27
Stochastic optimizations	13
Microcontrollers and PV architecture	6
Total	**46**

4.1.1.1 The Prior Process of MPPT Literature Reviews: A Self-Assessment Approach

In initial phase and planning phase of the research study, chapter 2-3, we comprehensively investigated MPPT-related papers to be able to provide scientifical contributions and novel approaches to the knowledge area. Therefore, many articles were reviewed that resulted in understanding the concept of MPPT approaches and many factors associated with them. Table 4-2 depicts the number of articles reviewed in the subject of MPPT methods.

Table 4-2 The number of articles about MPPT techniques

Main subject of the paper	**Number of References**
GWO	9
Conventional	7
DE	16
Hybrid	6
Heuristic-based	11
PSO	7
MPPT method reviews	13
ANFIS	9
ANN	2
FL	12
PV architecture-based reviews	6
PE-based methods	26
Total	**124**

Figure 4-2 shows the visual comparison of the papers reviewed in the self-assessment process of investigating for the concepts that comprehensively represents the MPPT domain.

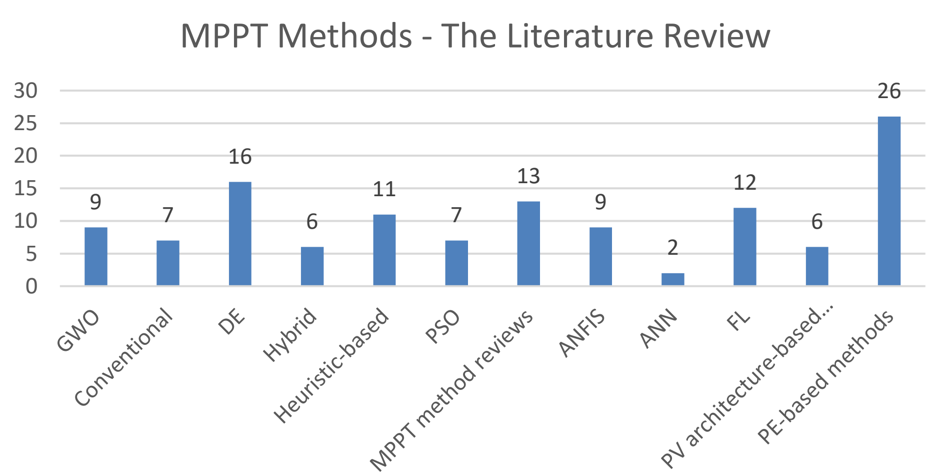


Figure 4-2 The visual comparison of articles about MPPT methods

The following table provides the main aspects of the most notable MPPT approaches found in papers concerning the research interests.

Table 4-3 The most notable MPPT algorithms in each MPPT classification

MPPT Method	**Algorithm's Information**
Conventional Methods	
P&O	The popularity of the P&O method among PV system designers is undeniable. It is widely used for stand-alone and grid-connected applications and can be implemented in analog circuits or cheaper digital elements [11]. Its application is as simple as checking recent and last output power and then the related voltages to increase or decrease the reference voltage by using an appropriate duty cycle.
HC	The HC operation is fundamentally the same as P&O; except, rather than iterating the voltage or current, it updates the working purpose of the PV exhibited by perturbing the duty cycle, $d(k)$, by a settled step size, towards rising power [124].
IC	The algorithm of the MPPT depends on dP/dV, which is equivalent to zero for the maximum power point. It is proposed to enhance the tracking precision and dynamic execution under quickly changing conditions. The algorithm begins with the cycle by finding the value of $V(t)$ and $I(t)$ at time t and comparing the instant conductance with IC, the GP is tracked [124].
Computer-based Methods	
DE	There are four operations: initialization, mutation, crossover, and selection. In a PV system with control parameter of the duty cycle, DE is implemented using two parameters. The duty cycle, modulated by the control system, is considered as the target vector. After initialization of the duty cycle, the associate powers of the PV are obtained. Then, the greater power is selected as the best solution. Therefore, the corresponding duty cycle is saved as the best duty cycle [55]. The DE algorithm continue this to make the duty cycle's donor vector. The donor vector crossover with target vector to generate the trial vector. The powers related to these duty cycles are measured from the input of DC-DC converter. Comparing these values to the power for each initial and the higher associated duty cycle is replaced by the previous duty cycle for the next generation. Then, the

	algorithm repeats the same operation processes for the next generation to approach to a desired ΔP.
PSO	PSO is a global optimization algorithm for dealing with problems on which a point or surface in an *n*-dimensional space represents a best solution. In this algorithm, several cooperative agents are used, and each agent exchanges information obtained in its respective search process. Each agent, referred to as a particle, follows two very simple rules, i.e., to follow the best performing particle, and to move toward the best conditions found by the particle itself. By this way, each particle ultimately evolves to an optimal or close to optimal solution [64].
GWO	The social behavior of gray wolves are mathematically modeled by Mirjalili *et al* [44] to establish a new SI algorithm. The hunting technique of gray wolves are defined in three stages in [125]: I) tracking, chasing, and approaching the prey, II) pursuing, encircling, and harassing the prey until it stops moving, and III) attack towards the prey. The two important equations mathematically model encircling behavior of gray wolves: $\vec{D} = \left\vert \vec{C}.\vec{X}_P(t) - \vec{X}(t) \right\vert$ and $\vec{X}_{(t+1)} = \vec{X}_P - \vec{A}.\vec{D}$ where t indicates the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_P$ is the position vector of the prey, and $\vec{X}$ indicates the position vector of a gray wolf: $\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a}$ and $\vec{C} = 2.\vec{r}_2$. where $\vec{a}$ is in the range of [2, 0] and linearly decreased in the iterations, and $\vec{r}_1, \vec{r}_2$ are randomly chosen from 0 to 1.
FL	A feedback reference voltage is given to a PV Panel to track the desired photovoltaic voltage and the duty cycle is feed to the boost converter, so the PV panel operates at the MPPT point. Changes in reference voltage and duty cycle are outputs of the fuzzy controller and the inputs are the error and its change [126].
ANFIS	By varying two environmental factors a set of data is generated in simulation. Hundred sets of obtained data are then used to train the ANFIS network for the purpose of MPPT. DC-DC boost converter is designed to be placed between solar PV module and load to transfer maximum power to load by changing duty cycle of dc-dc boost converter $(V_o/V_i)=(1/(1-D))$" [127].

Hybrid Methods	
Improved or Modified Model	These approaches are made by applying modifications, alteration, or provide improvements to the operations or processes of the algorithms used as fundamental approaches. These changes can be applied to the mathematical equations representing algorithms' functionalities, certain parameters, and factors of the equations. There methods are a little simpler that the hybrid methods unifying two different approaches.
Hybridized or Unified Methods	These tactics employ some features of an MPPT method and apply characteristics of another method using benefits of two methods for overcoming inadequacy of either approaches. Therefore, the final application includes processes from both techniques that are hybridized.
PE-based Methods	
TEODI	The eventual adoption of a PID controller instead of a PI controller allows the improvement of the phase margin and/or of the crossover frequency. It does not require measurement of the PV power, that is, it does not require multiplication of currents and voltages. It requires the sensing of the only output currents (or, in its dual implementation, of the only output voltages). Tracking based on a minimum number of electrical variables is preferable from a reliability point of view. It can be used with any topology of power converter. In grid-connected applications, the 100 Hz disturbances coming from the grid are not able to cause the failure of the technique [38].
DSP or MCU-Based Approaches	PV system configurations and distributed module-level converter architectures can overcome consequences of PSCs. In fact, distributed electronics might be the key for implementing diagnostic and prognostic actions at a module level. PV power optimizers can perform the MPPT function at a module level [128].

4.1.1.2 Exploring Literature Reviews about Shading Conditions and MPPTs

In this step of research, we investigate literature review papers representing important concept-related parameters and factors respecting shading conditions and MPPT approaches. As the scope of the research study indicates, articles focusing on various factors about shading in PV domain and MPPT approaches used to overcome the negative consequences are collected. The scope of the project defines that the affecting power estimations are associated to shading conditions and climate changes. As we discussed in the previous chapters, application of MPPT methods and related factors are investigated herein. In addition, it is stated that alteration in PV system design components and parameters can affect the results of the planning tools including software products and online plan/design applications. Therefore, the main factors that can mislead planning a solar power project are presented in two separate sections to define important elements in the planning. The following sections describe key concepts needed to be considered when using the planning tools and for designing the system. Table 4-4 represents the main subjects and the numbers of the articles reviewed for this manner. Figure 4-3 demonstrates the graphical comparison for the papers reviewed in each sector.

Table 4-4 The number of articles about shading

Main subject of the paper	Number of References
Dust	12
Ice & Snow	25
Parameters Estimation	5
Performance Models	26
PV modeling	11
PV under PSCs	21
Literature reviews about PV Modeling	10
SAM Simulation	13
Total	**123**

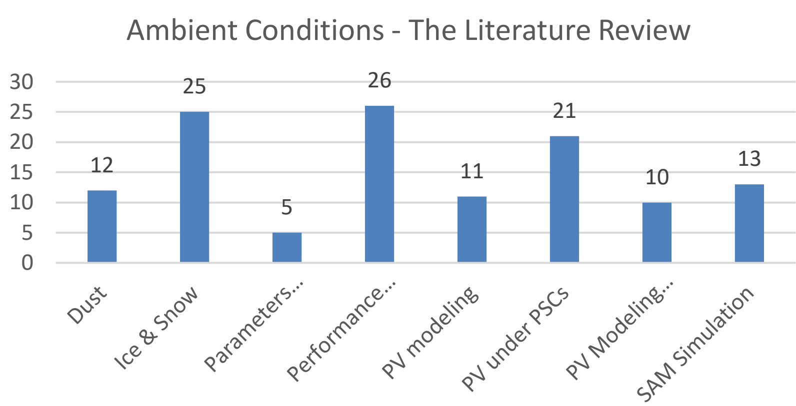


Figure 4-3 The visual comparison of articles about ambient conditions

4.1.2 The Process of Investigating PV Planning Tools

In the last 25 years, solar energy has become one of the main contributors among other forms of renewable energy resources. solar panels are used for converting solar energy to electricity. Globally, the contribution of PV systems to energy generation was approximately 14,000 MW in 2010 and is expected to be 70,000 MW in 2020 [4]. In Canada, the domestic market has been growing on average at about 26% per year since 1993 and about 48% since 2000 [129], demonstrating its popularity among domestic consumers. The system is simple and conveniently installed with little maintenance. As a result, residential and commercial users are motivated to install such systems for their utility needs. However, installing a solar energy production requires technical knowledge about the system model and parameters affecting the design so that the planning would not fail to operate properly. To overcome the system design obstacles for an effective planning, non-technical planners need a tool to plan the project and design an efficient system.

Typically, the planning software offers the system design providing system components and expected power outputs according to weather data and different parameters chosen during the process of planning. Due to the research methodology, planning tools and applications are investigated to identifying concepts that may be missed when reviewing academic papers. Therefore, it is required to rely on an accurate planning tool that is programmed with proper PV performance model and provide reliable outputs. Besides, the evaluation of the proposed ontology, we need to design a solar power project using a planning software. The following section describes requirements of such a tool.

A PV system planning tool, sometimes referred to and known as a designing tool, estimates the energy production and cost of solar plant projects. The accuracy of these data defines the correctness of power estimations, especially in locations where various environmental factors involved. In addition to meteorological databases, solar panel and inverter’s databases are needed for the planning. There are online applications and software products freely available for the planning. They allow project managers, utility consumers, technology developers, and researchers to easily predict the electricity output of a system and evaluates the system performance. These planning tools provide performance predictions and cost of energy for grid-connected projects based on installation and operating costs and system design parameters selected from databases and data libraries. These tools provide decision-making support systems through which the planning can be achieved efficiently.

For the case of submitting a reliable planning software to be used as a case study later, 31 design related commercial and open-source PV software tools were nominated by using Google search (ANNEX I). These websites provide PV or solar energy system planning or designing. Although some of programs offer financial reports and estimate profits and associated cost with the system designed, the system performance and the output power were measured for choosing them.

The level of accuracy and availability of their technical information were examined in their help pages, technical references, manuals, software presentations, and demo videos as well as commercial emails received from the providers. The following bullets present criteria and overall considerations for the selection:

- **I.** Is a PV design or planning application included on the website?
- **II.** Is the trial version run and executed completely?
- **III.** How reliable and accurate were related databases and meteorological data?
- **IV.** What type of PV model is used in the simulation?
- **V.** What type of technical and scientific information are presented?

The final list consists of nine online software programs and applications were selected (see table 4-5). The National Renewable Energy Laboratory (NREL), the national laboratory of the U.S. Department of Energy, and the National Research Council (NRC), and the government of Canada's largest research organization, offer free of charge PV designing services. The other software producers (ANNEX I) provide software products based on customers' need so that trial versions of their programs include a few technical features instead of indicating which PV performance model are used. Except PVWatts, which offers an online support, the rest of the list fulfills the research considerations and meet technical requirements expected from such products. The eight installed programs are shown in the next table (4-5).

Table 4-5 The final list of most reliable PV planning tools

Software	Provider	URL
PVWatts	NREL	http://pvwatts.nrel.gov/
HOMER Pro x64	HOMER Energy	https://www.homerenergy.com/homer-pro.html
RETScreen Expert	NRC	http://www.nrcan.gc.ca/energy/software-tools/7417
PVsys 6.7.0	NREL	http://www.pvsyst.com/en/
SAM	NREL	https://sam.nrel.gov/
Polysun	Velsa Solaris	https://www.velasolaris.com/?lang=en
Solar Pro 4.5	Laplace Systems	http://www.laplacesolar.com/photovoltaic-products/solar-pro-pv-simulation-design/
PVSOL 2018	Valentin Software	https://www.solardesign.co.uk/
PV perform mod	NRC	https://www.nrcan.gc.ca/energy/software-tools/19228

4.1.2.1 Planning A PV Project: The Application of SAM Model

The NREL's model employs an accurate PV performance model, capable of detecting PSCs and other related DC losses. The developed performance model is called the System Advisor Model (SAM). According to the SAM's website [130], it is a "*performance and financial model designed to facilitate decision making for people involved in the renewable energy industry: project managers and engineers, policy analysts, technology developers, and researchers.*" Due to objectives of the research, the financial model, and other sorts of renewable energies are excluded from the model. In addition, SAM contains a basic PV performance model, called PVWatts that offer a rough estimation of planning. In the case study, this feature helps us to compare the application of the two models to verify the importance of the accurate performance model. Performances of these apparatuses need to be validated using real cases for which the calculated data can be compared with actual measured data. In a comprehensive study [131], performances of three utility scale PV systems and six commercial scale systems are analyzed and compared by NREL including the key providers of our list (table 4-5). As quality-controlled measured data shows [131], all performance modeling tools achieve annual error within ± 8% and hourly root mean squared errors less than 7% for all PV projects. Furthermore, it is indicated that using SAM the annual error with respect to measured data presents about 2% less error. The study indicates that the estimated power outputs containing reports, diagrams, CSV files, and additional forms of provided data can be reliable more than the rest of the list. As a result, SAM model is considered and used for investigating additional concepts that might add any new classes to the knowledgebase model. Moreover, SAM simulations are used for the ontology evaluation later due to the accuracy of its PV performance models.

According to the website [130], SAM calculates the electrical output power of a grid-connected PV system consisting of solar panels and inverter. SAM's performance models run hourly simulations to compute the output power that their summation indicates the total annual value of the power output. SAM applies two performance models, the PV-detailed and the PVWatts, to calculate the power outputs. The PV-detailed model uses separate module and inverter models. It models the effect of temperature on the module performance with the option of applying shading conditions and other losses in the system [132]. This model provides more accurate power output results. It is used for estimation of energy produced by the system. Furthermore, the effects of PSCs are applied in the simulation when this performance model is chosen. The PVWatts model is an implementation of NREL's popular online PV calculator. According to [133], it models a grid-tied system using a few basic inputs and makes assumptions about module and inverter characteristics. In this case, the model provides the planning that can be used for a preliminary project analysis without knowing the type of equipment you plan to install. PSC is not considered when SAM simulation is run applying this performance model. Consequently, the systems which are designed using PV-detailed model provide more accurate power estimations due to accurate the performance model chosen. Eliminating shading conditions will result in calculating the power production when the system generates fewer energy. Figure 4-4 demonstrates the application of SAM model for planning a solar power project.

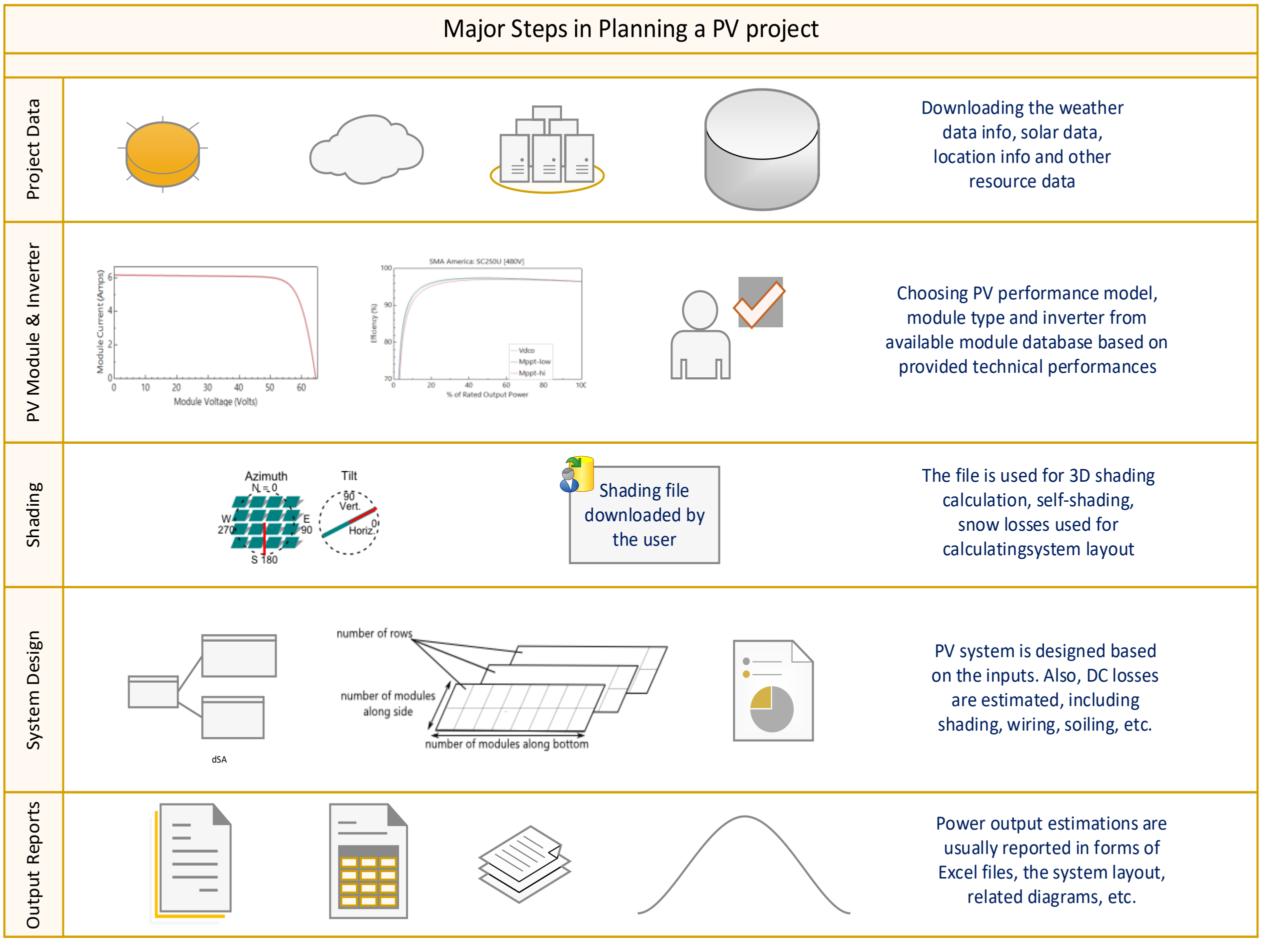


Figure 4-4 The application of SAM model for planning a PV system

4.1.3 Conducting a Survey: Identifying New Concepts

In the ontology engineering process, the collaboration with the domain experts and practitioners familiar with MPPT applications, plays a significant role to ensure that MPPT-On provides a reliable technical knowledge base for designing a PV system. Major steps in the SAM model, as the most reliable planning software, represent important design concepts and planning concerns that experts and industry leaders take into account. As stated in the previous section, we need the collaboration with PV domain experts to identify important factors affecting PV performances. They are essential for defining classes, data properties, and object properties of MPPT-On. Conducting a survey enables us to identify if there is any important concept or knowledge areas that has not been recognized in the previous approaches. Therefore, the survey is considered as an additional source of data for finding semantics. At the end of survey, the answers are reviewed to find any new notions.

4.1.3.1 The Questionnaire

The survey was designed to include three groups of questions concerning: 1) partial shading conditions (PSCs), 2) PV system modeling and simulation, and 3) MPPT approaches. Twenty-nine questions were prepared in total. Questions can be found in ANNEX II. The survey can be performed using the following link:
https://sondages.uqo.ca/index.php/456359?lang=en.
The consent form (ANNEX III) outlines objectives, confidentiality, the publication of results, data protection, voluntary participation, the contact information of the researcher, the supervisor, and the research ethics committee as well.

4.1.3.2 Results and Analysis

The results are used to define any concept that are not when investigating PV planning tools. Table 4-6 presents the results of the survey and answers provided by the participants to the first group of the questions.

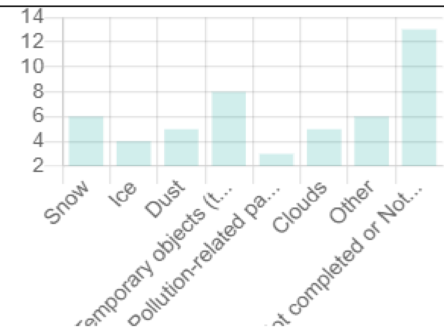
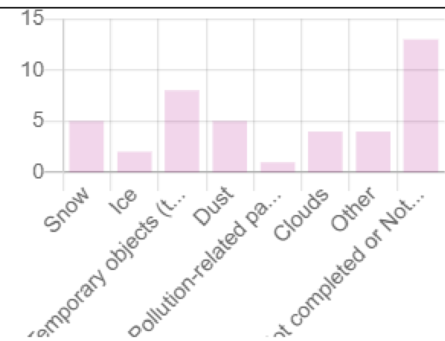
Table 4-6 Results of the Yes/No questions in each section in the questionnaire and statistics of responses

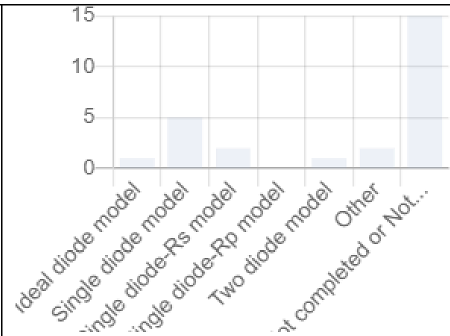
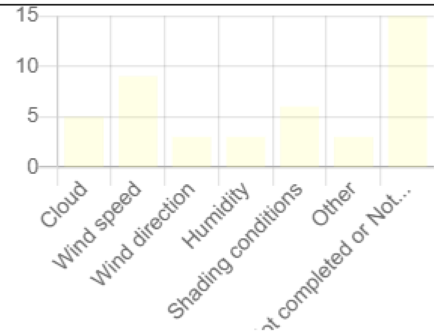
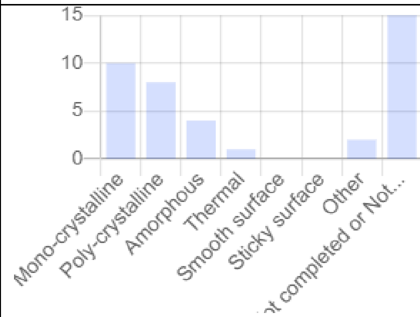
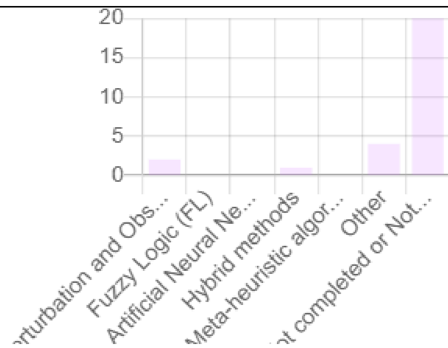
Shading	Yes	No
1. Is the effect of partial shading conditions (PSCs) considered in your PV system design?	25	1
2. Do you consider the physical properties of the particles causing shading conditions? (for instance: size, shape, and weight of particles)	20	5
5. Do you use the same PV model for PVs under uniform and partial shading conditions?	11	2
6. Do you apply specific irradiance patterns to model the PSC?	9	4
7. Do you calculate the overall efficiency for the PV system?	9	3

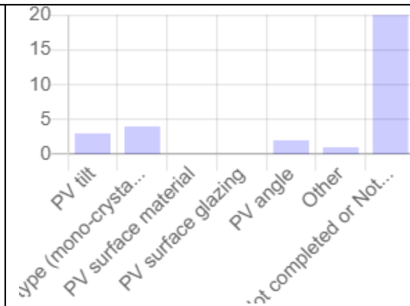
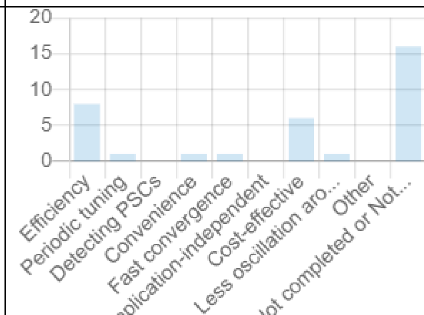
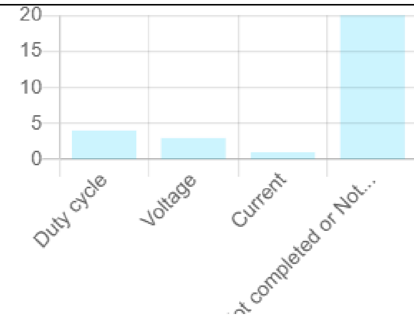
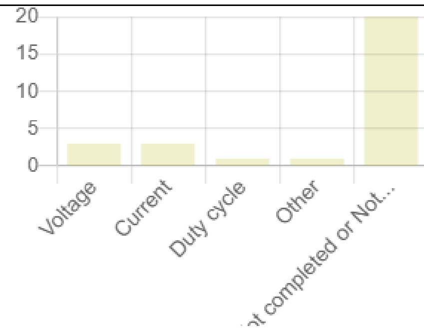
8. Does the irradiance input used for the simulation represent real-world shading conditions?	9	3
PV System Modeling and Simulation		
11. Does the configuration of PV arrays affect your PV system model?	9	2
13. Do you involve weather databases for modeling the system?	9	2
14. Do you apply the same shape, pattern, and variation for the input variables of your model (temperature and irradiance) regardless of environmental conditions?	3	8
16. Do you determine the technology type of the PV used in the model?	9	2
18. Do you apply site locations in your design?	10	1
MPPTs		
20. Is an MPPT method used in the design?	6	4
22. Do you consider PV system architecture when choosing an MPPT method?	6	4
28. Do you determine the type of microcontroller used in the simulation?	2	4

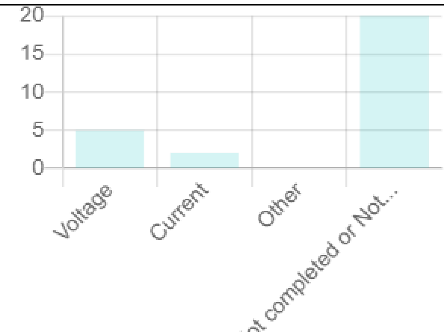
The second sets of the questions focus on shading conditions. The number of participants and their answers are provided in table 4-7.

Table 4-7 Charts and statistics concerning various factors

Shading	Results
1. Which external factor(s) is (are) included in the design? [Snow, Ice, Dust, Temporary objects (trees, buildings...), Pollution-related particles, Clouds, Other]	
2. Which external factor(s) do you think affect the efficiency of the PV system the most? [Snow, Ice, Dust, Temporary objects (trees, buildings...), Pollution-related particles, Clouds, Other]	
PV System Modeling and Simulation	

<table>
<tr>
<td>1. Which PV cell model is used in the simulation? [Ideal diode model, Single diode model, Single diode-Rs model, Single diode-Rp model, Two diode model]</td>
<td>
</td>
</tr>
<tr>
<td>2. What ambient condition(s) is(are) considered in the model? [Cloud, Wind speed, Wind direction, Humidity, Shading conditions, Other]</td>
<td>
</td>
</tr>
<tr>
<td>3. What type(s) of technology is(are) defined in your design? [Mono-crystalline, Poly-crystalline, Amorphous, Thermal, Smooth surface, Sticky surface, Other]
Split cell, PERC, and lapped cell, bifacial</td>
<td>
</td>
</tr>
<tr>
<td>4. Which MPPT classification is chosen? [Perturbation and Observation (P&O), Fuzzy Logic (FL), Artificial Neural Networks (ANN), Hybrid methods, Meta-heuristic algorithms, Other]</td>
<td>
</td>
</tr>
</table>

5. Which PV characteristic(s) is(are) involved in your design when selecting an MPPT method? [PV tilt, PV type (mono-crystalline, poly-crystalline, amorphous), PV surface material, PV surface glazing, PV angle, Other]	
6. In your opinion, which parameter could be considered as the most important factor when choosing an appropriate MPPT method? [Efficiency, Periodic tuning, Detecting PSCs, Convenience, Fast convergence, Application-independent, Cost-effective, Less oscillation around maximum power point, Other]	
7. What is(are) the control parameter(s) in your design? [Duty cycle, Voltage, Current]	
8. What is(are) the reference factor(s) in your design? [Voltage, Current, Duty cycle, Other]	

9. What is(are) the sensed parameter(s) in the PV control system? [Voltage, Current, Other]	

The third segment of inquiries were designed enabling PV practitioners to express their overall thoughts and recommendations. The following bullets and answers are bulleted here:

- Do you have any recommendation or suggestion concerning PSCs?

  “Calculate the detailed I/V curves and take the lower limit voltage of the inverter (for MPP tracking) into account.”

  “There are two big factors, the purpose of the PV system, Stand-Alone, Generator offset or Annual harvest. (storage or no storage). Also, the cost of energy you are comparing to and the cost of installation. If you have PSC issues, but can mitigate by increasing PV capacity economically, then it is a nonissue.”

  “I use Helioscope for design of solar systems, along with 'fudge factors' for snow losses - for example 90% losses due to snow, in January for a 10-degree ballast system on a rooftop, in Edmonton.”

  “Storage batteries efficiency can be increased dramatically by adding a few ml of water-based Battery Equaliser to each cell, when battery is new, and on a regular top up basis over the now upgraded (up to 3 times) battery life.”

  “Mitigate PSCs by shifting to more optimal locations when possible.”

- Which simulation or modeling tools do you use? Please briefly explain why.

  “MATLAB”

  “SAM, free software, easy to use.”

  “Helioscope - best mix of price, automatic layout and shading analysis/optimization tools, familiarity, ability to export to CAD, and ability to do 3D renderings to show customers.”

"Helioscope. It is very high quality, easy to use, and vetted by NREL."

- Do you have any recommendation or suggestion about PV system modeling and simulation when selecting an appropriate MPPT?

  "We use the one-diode model for the PV module I/V curve. We calculate the combination of I/V curves as sums of voltages and currents, of each sub-module by our own algorithms. We call submodule a set of cells protected by a by-pass diode. Programmed in Pascal/Delphi"

  "After calculating the I/V curve of the shaded array, we use the higher MPP point within the Voltage MPPT range. Or the intersection of the I/V curve with the Lower voltage limit of the inverter if this is higher."

  "Models are only an estimate, when you try to make them too accurate, they end up producing undesired results and thus do not get used."

  "Select an inverter and thus MPPT size that encompasses all modules in the same plane and does not mix modules on different planes."

- Do you have any recommendation or suggestion about MPPT approaches, algorithms, etc.?

  "I simply select an inverter whose manufacturer I get along well with that I believe to be reputable. Also needs to be suitable for the site conditions, for example have a voltage that matches the building voltage - 600Vac 3 phase, for example."

Reviewing answers reveals that concepts recognized by the other two approaches, literature reviews and PV planning tools, reflect the most notions required for the ontology.

4.2 Defining Classes of the Model: The OWL Model Assertion Axioms

Prior activities for searching notions and semantics led us to categorize the identified concepts in several super classes including weather data, PV module, PV planning, ambient condition, and MPPTs. These knowledge areas reflect concepts needed for a model that supposed to represent MPPT and ambient conditions.

4.2.1 Weather Data

PV energy productions strictly depend on the climate in which they operate. In one side, shadings situations, and the other side, weather conditions demonstrate the importance of ambient situations in a PV project. One of the imperative factors that affects shading conditions the most is irradiance. We include irradiance database herein duo to its relationship with the other elements of this class. Snowfall and cloud data are crucial for calculating power losses. Therefore, their databases are vital for power estimations. These databases help to forecast shading times and compute power productions accordingly. In addition, they provide structured data that PV planning tools need for estimating energy productions. To comprise further climate-related data in the proposed model, we need to add temperature, humidity, and wind to the ontology model. Humidity and wind speed have direct impact on the effect of temperature and consequently PV performances. These environmental factors can increase or decrease the severity of other ambient conditions such as dust and snow. Figure 4-5 illustrates dependency of climate conditions to weather data. Air quality also influences system productions because of accumulations of polluted particles on PVs.

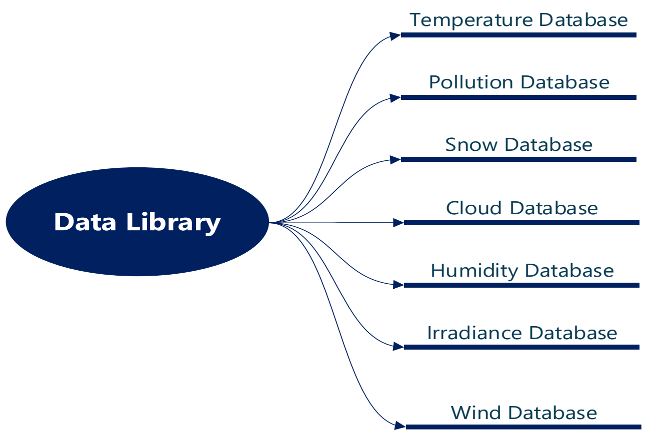


Figure 4-5 The key concepts respecting weather data considered

4.2.2 Concepts Related to PV Module

In this class, we search for important elements of PV modules that can influence the system efficiency. There are many concepts involved, as it is the main concept of the proposed model. The properties consist of PV technologies, tilt angle, and glazing. These physical characteristics alter ambient conditions and as a result change power efficiency in the PV system. Figure 4-6 displays major items involved in the class of PV module.

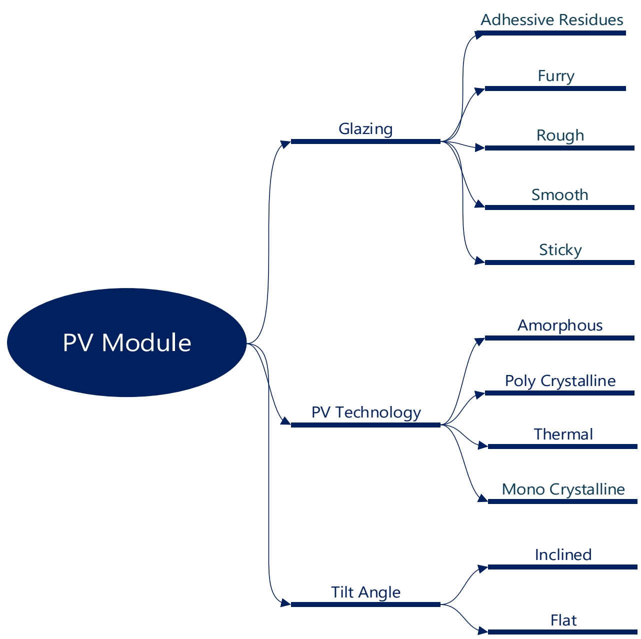


Figure 4-6 Major elements of a module

4.2.3 Concepts in PV Planning

As described in the research presentation, the proposed model deals with only shading conditions as the main sources of DC losses in PV systems. In fact, other sources of DC losses have much less impact than shading. These system-related losses contain soiling, reflection, bifacial, DC wring, module mismatch, DC power optimizer loss, diodes, and connections. We need more data to describe the shading conditions. Shadings can be described by their conditions, affects, the sources created them, and in many cases, the object that cause them. Figure 4-7 shows subject matters that are vital in a planning software including PV performance model, application of the system, power output reports, the software used, and components of the designed system. This means that by investigating characteristics of shading and system-related losses, a complete list of important factors will be assigned to the proposed model.

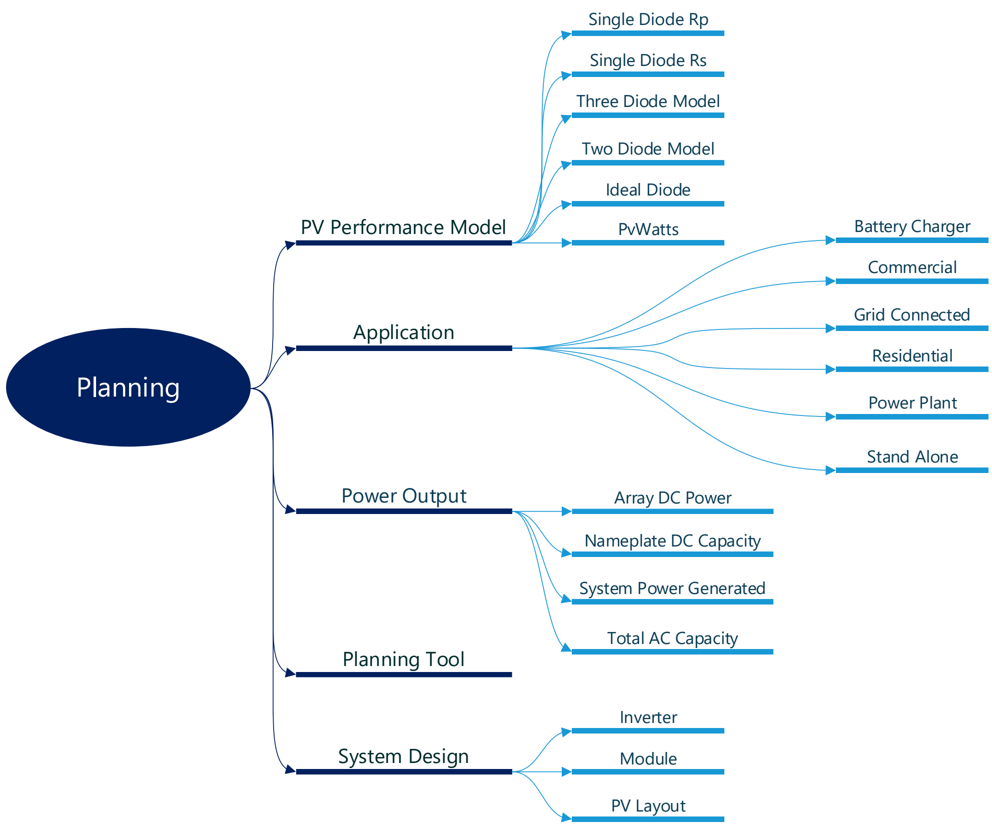


Figure 4-7 The important notions and considerations about the planning

4.2.4 Ambient Conditions

Ambient conditions are the main reason for implementing MPPT methods. The location of a project indicates several features of the project including its climate and geographic parameters. The context of ambient condition is categorized into the shading and the climate.

Interrelationships between several classes can be related through them. Figures (4-8 and 4-9) present shading and environmental aspects perceived as class axioms for the ontology model.

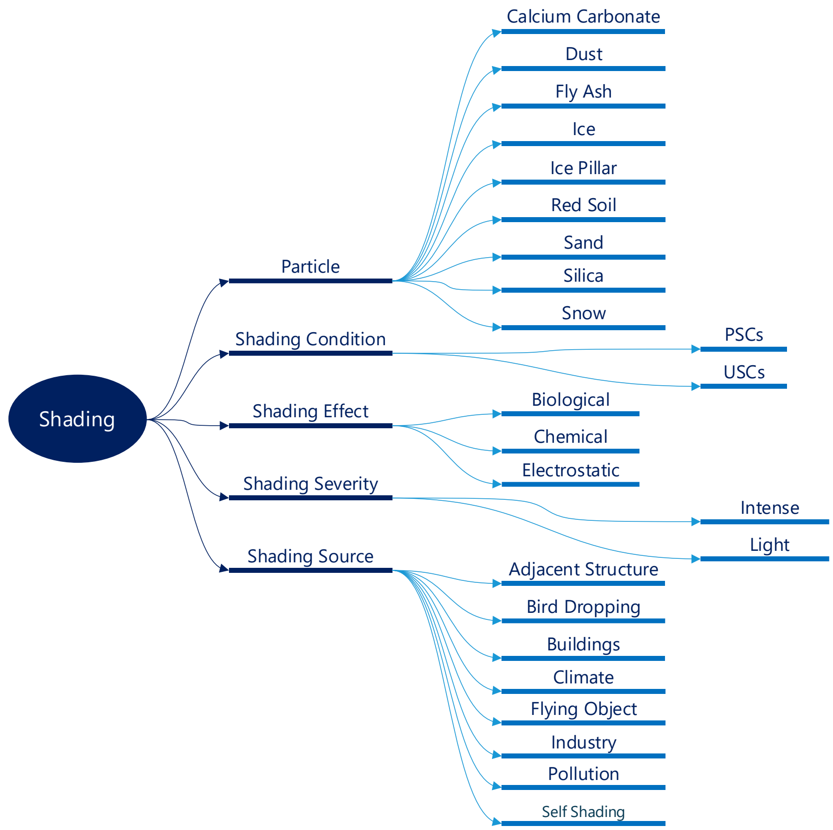


Figure 4-8 Key semantic concepts concerning shading in PV systems

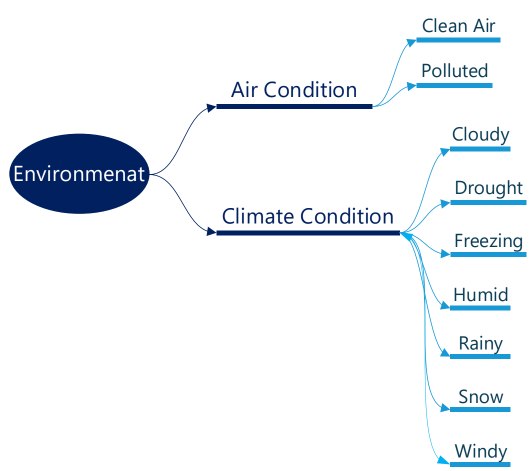


Figure 4-9 Key elements concerning environmental conditions

4.2.5 Notions of the MPPT Concept

Designing an efficient PV system will result in installation an efficient PV system. From the design perspective, the contextual data are divided into three sections: 1) MPPT characteristics, 2) MPPT approaches, and 3) MPPT control systems. As perceived, this classification of semantics represents the complete framework of every aspects about PV system design. It means that the proposed ontology consists of the information required for designing a PV control system.

MPPT characteristics can be used for each one of MPPT methods, though some of them may be used to describe specific MPPT classifications such as periodic tuning and oscillation around GP. Several measures such as implementation, complexity, and convenience are utilized to evaluate the application of an algorithm and the technical features of the MPPT method. Furthermore, we define the technical parameters of an MPPT-based control system in this set.

Classifications of MPPT approaches help us to categorize methods with similar characteristics in the same class assertion in the ontology. Conventional methods, soft-computing, hybrid, and PE-based methods were introduced in chapter two as the main clusters representing different MPPT methods. However, the subclasses of soft-computing methods are only depicted. AI-based and Metaheuristic methods are parental class of many methods. They are not displayed in the figure due to brevity. The main notions are illustrated in figure 4-10. MPPT-based controller is the class that its data properties and the object properties complete the information needed for the class assertions.

As it was described in chapter 2, designing an MPPT-based control system requires specification of its technical features. Depending on the microcontroller used in control system, technical characteristics are defined. Thus, semantics of this class are based on attributes of the hardware. We define technicality of the control system respecting important parameters of the algorithm executed. Duty cycle, reference parameter (*V*, *I*, or *P*), initial values, sensing parameter (*I* or *V*), PWM, and other essential variables are defined through data properties in the ontology.

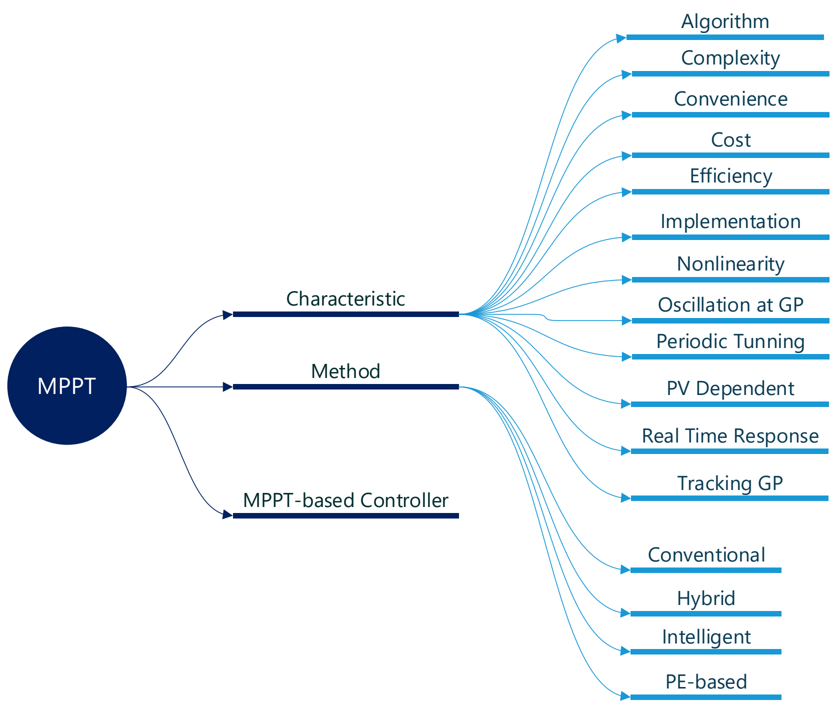


Figure 4-10 Main concepts associated with MPPTs

4.3 Defining Properties and Attributes: The PV Planning & MPPT

The next step after identifying concepts of the model is to define data properties and object properties related to each stream of the proposed model. In the planning sector of the model, we defined four main classes for representing important concepts: I) ambient conditions, II) data library, III) PV module, and IV) power output. Figure 4-11 presents a graphical view of a few data and object properties for the planning. In the other side, there are five major branches representing MPPT knowledge area: I) algorithm, II) method, III) characteristics, IV) control system, and V) simulation. Figure 4-12 portrays several attributes defined in each class. Defining properties and attributes of concepts in the ontology model enable us to understand relationships between classes and different variables introduced in the model. These relationships can help us to construct the ontology model in next phases.

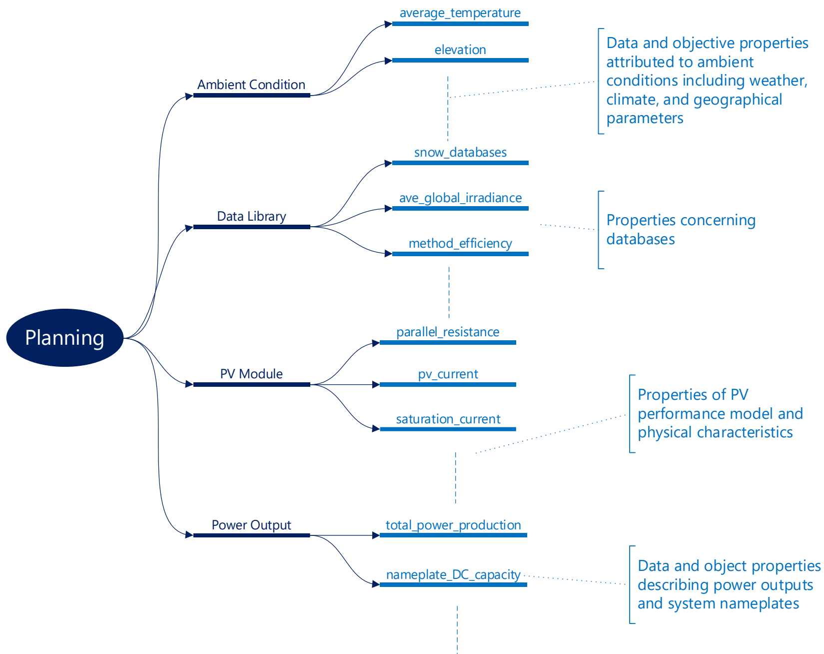


Figure 4-11 A graphical view of a few data and object properties for the planning

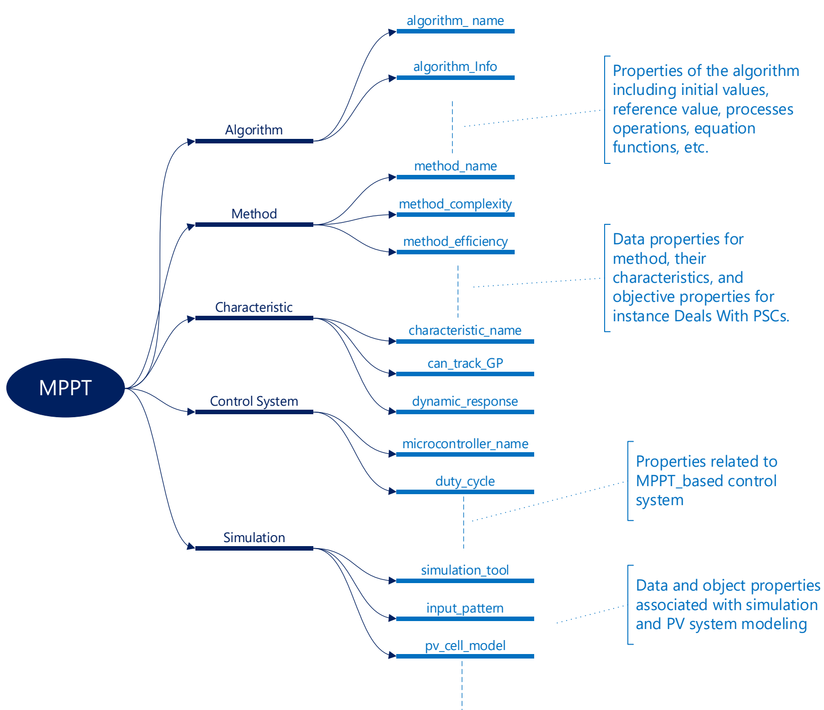


Figure 4-12 A graphical view of a few data and object properties for MPPT

4.3.1 Relationships and the Representation of Concepts

For each previous section, we need to signify the attributes and the function that relates two different concepts or classes. Each instance in a class is described by a data containing its value and type. The data define attributes and properties of a variable in the domain. We use UML diagram to demonstrate classes, attributes, and their relationships. Data type, the visibility, and the name associated with each attribute describe several features of a class or a subclass as well as any instance or variable in the class. The relationship between two classes can be explained using four different line types in the software. Inheritance and composition types are chosen to I) present the inheritance of the all attributes and methods of the subclass (parent class) and II) demonstrate no existence for a subclass outside its class. Further, numerical constrains and the number range for them can be specified for every relationship. The defined classes, attributes, and their relationships are used later for designing the ontology and reasoning with further considerations. UML diagram shows the relationships of the factors and valuables affecting the planning of a PV project reflecting ambient conditions. The RDFs correlated to the knowledge area of MPPT methods are defined by graphically displaying them. Figure 4-13 depicts a graphical representation of the key concepts and their relationships concerning MPPTs.

Figure 4-14 shows the UML diagram of important concepts associated with planning a PV project. These factors affect the power efficiency and the power estimation reported by a planning tool. This figure helps to define RDFs leading to data properties, object properties, data values, data type, and restrictions about every concept.

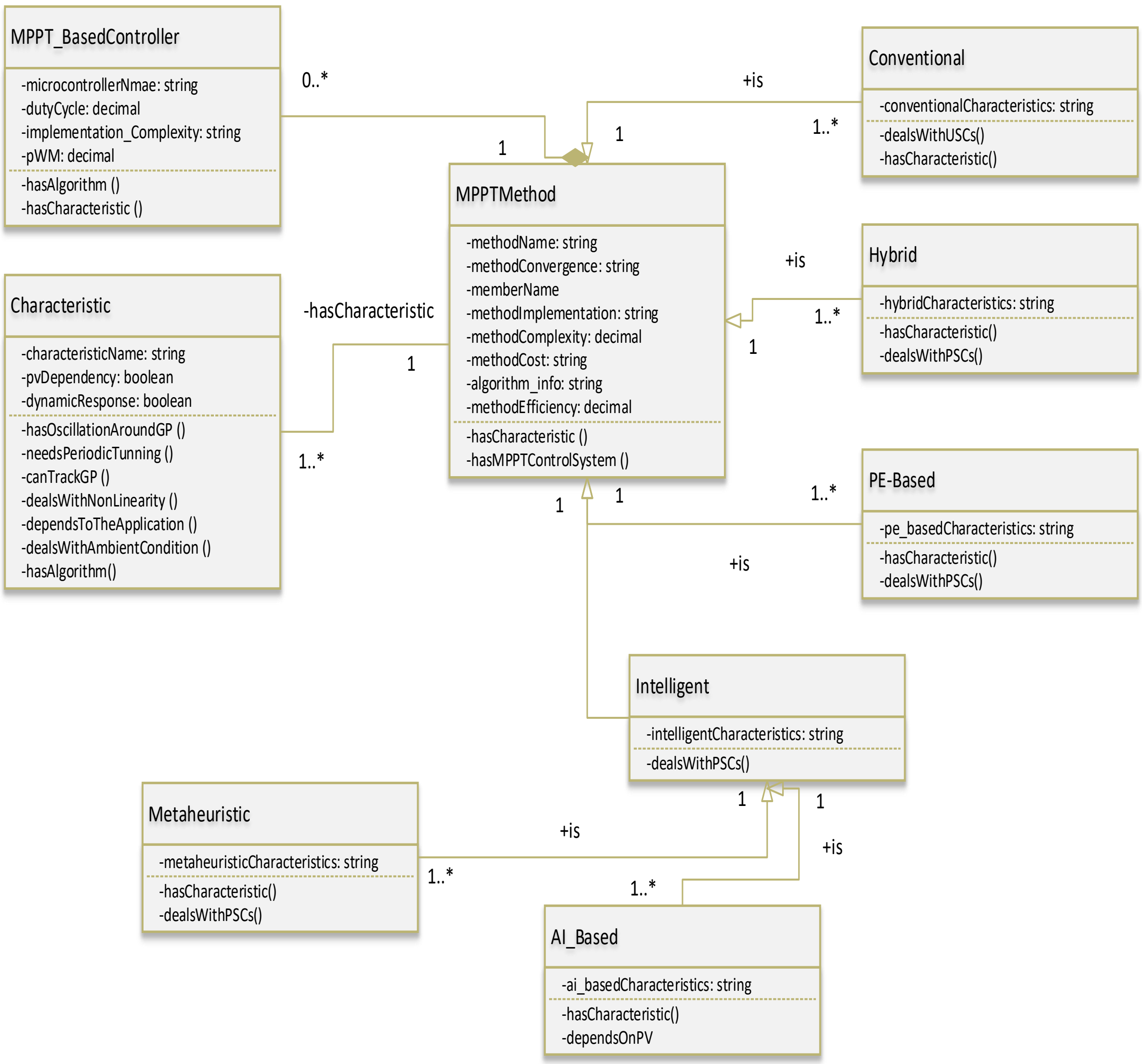


Figure 4-13 UML diagram of the key concepts for MPPT methods

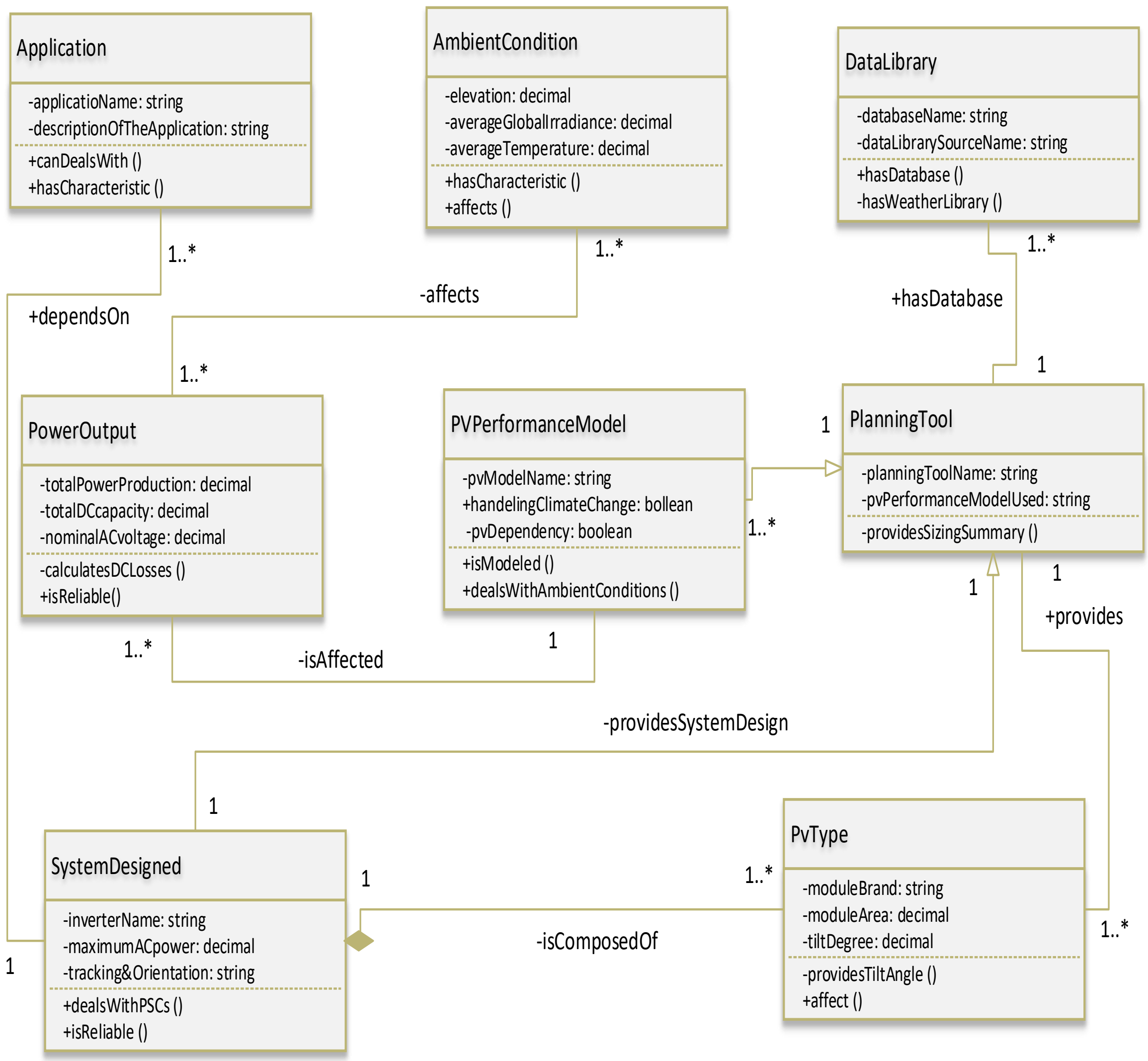


Figure 4-14 UML diagram of the key concepts about the planning

4.4 Integration of the Identified OWL Axioms to the Model

Weather data, PV module, PV planning, ambient conditions, and MPPT are the domains that the proposed model aim to represent. As perceived in the previous sections, numerous OWL axioms are recognized. These semantics are included in the model in the terms of classes, sub-classes, object properties, data properties, and individuals. We identify them using the criteria presented in the next table (7-8).

Table 4-8 Considerations and criteria for identifying concepts to build the ontology

Process	
Literature reviews	-What measures are used to evaluate an MPPT method? -What are the characteristics of an algorithm in an MPPT method? -How an MPPT technique is implemented through an MPPT-based controller? -What are the technical parameters of a PV control system?
PV planning tools	-Is there any factor or parameter recognized in the software rather than what has been found in literature reviews (concerning shading conditions) -Are there any knowledge domains that can be added to the main classes of weather data, PV module, PV planning, ambient conditions, and MPPTs? -What are the steps taken to calculate power outputs?
The survey	-What are the concerns among design experts and industry professionals regarding PV planning? -Is there any variable or parameter related to ambient conditions and MPPTs that has not been identified in other resources?
Self-assessment	-Define the parameters, values, variables, and factors affecting PV shading? -Define the main characteristics of MPPT algorithms, especially optimization techniques, AI-based algorithms, and PV modeling, and PV system simulation
Knowledge Areas	
Weather data	-What are the key elements of a data library in a PV planning software? -What are the relationships between PV shading and weather data? What are the important factors?
PV module	-What are the physical characteristics of PV module that can be influenced by ambient particles?
PV planning	-What are the major criteria to evaluate power estimations of a PV planning software as accurate values? -What are the PV modeling approaches used in the planning simulation? -What are the databases?
Ambient conditions	-What is the environment related factors affecting PV performances? -Which particles influence the impact of shading conditions? -Does the impact is worsened or relieved by any changes in the climate condition?
MPPTs	-What are the well-known MPPT methods? -Which characteristics are considered as crucial for technical purposes?

	-What are the technical parameters of the MPPT controller that must be included in any PV engineering design? - Is there any parameter or factor of PSC and USC modeling that can affect the efficiency result of a PV system simulation?

Table 4-8 describes the questions and goals which we considered for identifying important concepts and notions, that supposed to be represented by the ontology model. As explained in section 4.1 and highlighted in table 4-8, there are four crucial processes for finding and classifying knowledge areas, including literature reviews, PV planning software tools, the survey, and self-assessment analysis. In each process, we had desire to answer the inquiries stated in the table (4-8). Likely, in each knowledge area, we have attempted to fulfill the concerns and highlight the important semantics based on the questions indicated in each category.

CHAPTER 5 DEVELOPING THE ONTOLOGY MODEL

5.1 Constructing the Ontology

In this phase, the aim is to develop the proposed framework. In this regard, the ontology model is built, and the rule-based system is defined. We identify semantics and different concepts related to MPPT methods in the PV domain. Ontology technologies have been applied to develop the knowledge base system and build the ontology. There are several ontology methodologies for developing an ontology including Methontology [134], On-To-Knowledge [12], NeOn [135], and Horrocks Ontology Development Method [136]. While these methodologies have been employed in several knowledge base domains, we need to apply a method that offers convenience technologies working with many software environments. Ontology Development 101 is the well-known and most practiced methodology for developing ontologies [14]. This methodology presents technologies to build an ontology from starting point. It applies OWL language and conveniently implemented in Protégé-OWL editor that includes several compatible plug-ins for different applications. Herein, the concept of Ontology Development 101 is adopted for developing MPPT-On. In the methodology, four main activities need to be defined [14]:

- **I.** Different terms in the domain and relations among them
- **II.** Concepts (classes) in the domain
- **III.** Hierarchy arrangement of the concepts (sub-classes and classes relationships)
- **IV.** Constraints, values, and properties values.

There are key concepts used in Protégé including individuals, classes, and properties. Individuals are known also as instances can be referred to as being ‘instances of classes.’ Classes contain all the individuals that are categorized in a domain of interest. Classes may be organized into a superclass or sub-class hierarchy, which is also known as a taxonomy [83]. A class represents a concept in the domain or a collection of elements with similar properties. Properties are binary relations on individuals connecting two individuals together. Properties describe attributes of instances of the class and relations to other instances. Object properties are relationships between two individuals. Data properties describe relationships between individuals and data values. Annotation properties can be used to add information (metadata-data about data) to classes, individuals, and object/data properties.

This methodology requires understanding concepts and knowledge areas associated with the domain that its terms, classes, and hierarchies supposed to be defined. The purpose of determining each term and the relationship among them reflect the semantics in the developing ontology. Defining classes and hierarchies of classes identify concepts in the domain so that elements with same properties are recognized as a class. Relationships between various classes construct a hierarchy that may illustrate subclass-superclass hierarchies as well. A subclass is a subset demonstrating an under-branch in a class. Defining properties, values, and constraints of a class describe attributes of instances of the class and relations to other instances [14].

As defined in [137], "Protégé is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies." It is an ontology development environment that allows to create, upload, modify, and share ontologies. It supports OWL 2 Web Ontology Language and description logic reasoners like Hermit and Pellet [137].

We implement the following steps to construct our ontology:

I. Creating the class hierarchy

II. Defining the OWL properties: defining their type (functional, transitive, symmetric, reflexive, etc.), and defining their domain/range as per need.

III. Describing and defining the classes created for example restrictions (axioms).

IV. Invoking reasoner, checking the consistency of the ontology, and creating the inferred view.

V. Creating certain individuals by assigning certain OWL properties.

VI. Running the reasoner and check it.

The next sections illustrate three views of main aspects of the designed ontology, MPPT-On:

I. Classes and subclasses

II. Object properties

III. Data properties

5.1.1 The OWL Class Axioms

Figure 5-1 shows a part of the screen displaying super-classes and subclasses. The right figure presents a section of the classes determined with regards to the PV planning, while the left figure depicts classes representing MPPT methods.

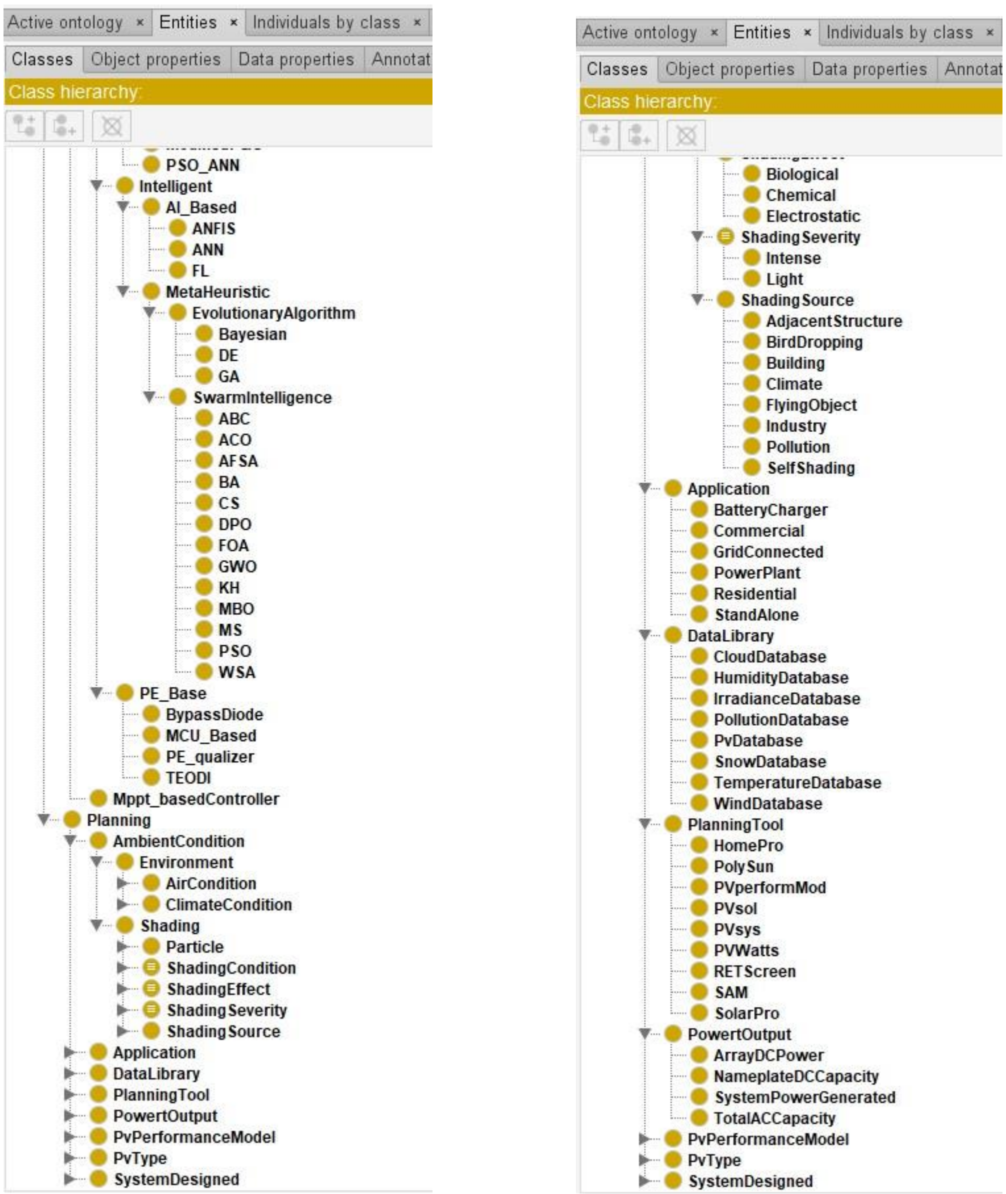


Figure 5-1 A part of the class hierarchy page defined in Protégé

5.1.2 Creating Object Properties

The following figure (5-2) demonstrates two snapshots of object properties designed for MPPT-On. The right figure displays a part of the MPPT-On with object properties about MPPT characteristics. The left figure relates to attributes describing PV planning tools.

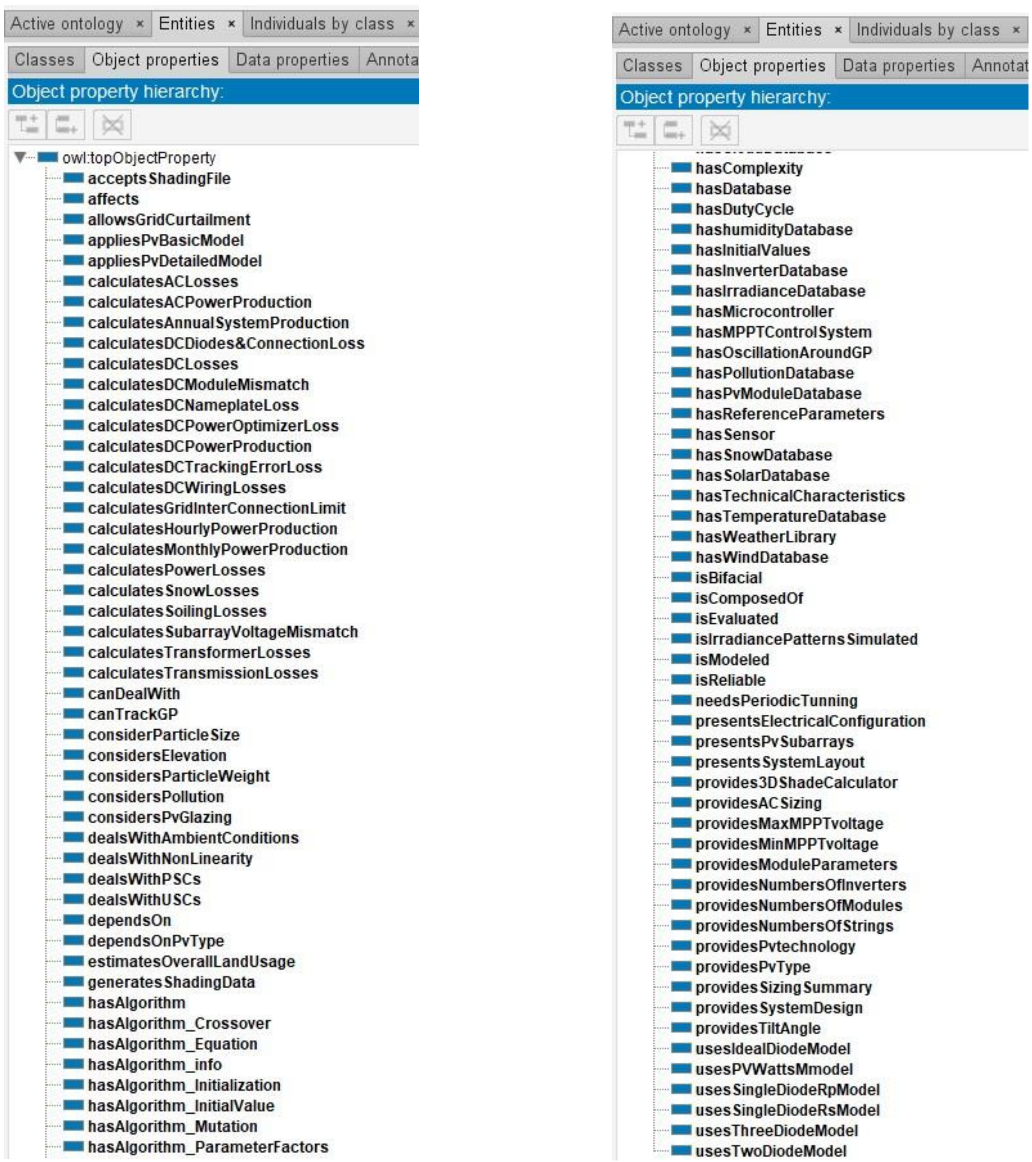


Figure 5-2 Two images of some the object property hierarchy defined in Protégé

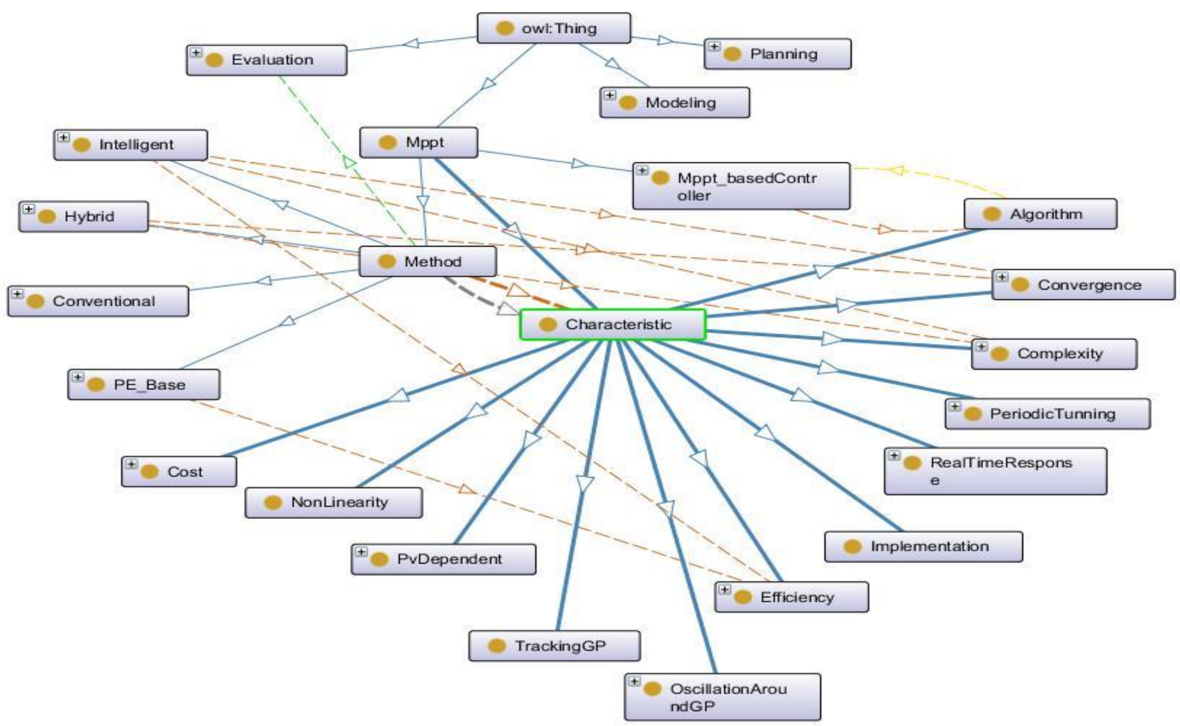
5.1.3 Determining Data Properties

Figure 5-3 depicts two images of data properties defined for MPPT-On. In the left image, it is attempted to display parts of the data properties representing algorithms' attributes. The right figure demonstrates a section of data properties respecting PV planning.

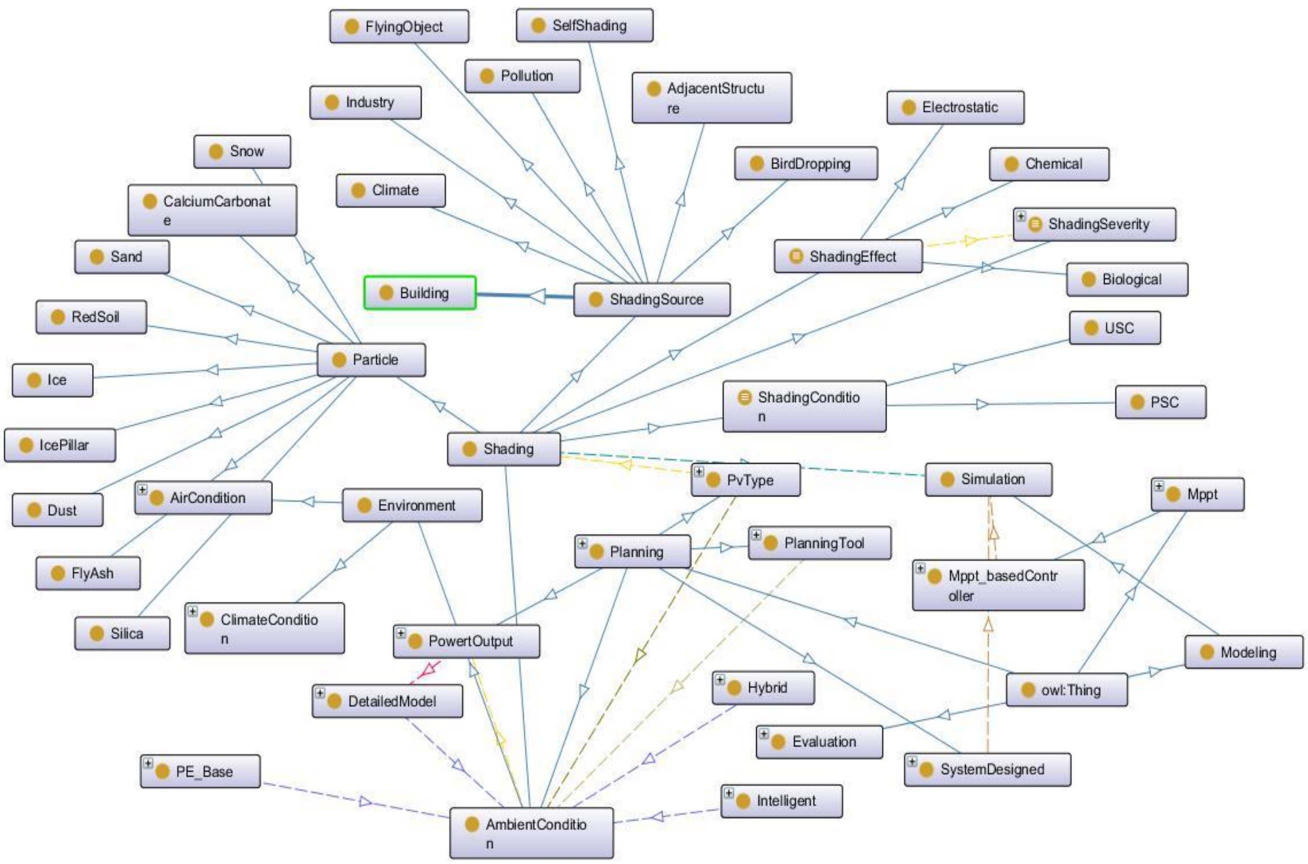
Figure 5-3 Some of the data properties related to the proposed model built in Protégé

5.1.4 Visual Presentation of the Ontology in Protégé

Using OntoGraf plugin, figure 5-4 illustrates the main classes of the designed ontology in Protégé. These two figures represent several classes defined in the MPPT knowledge area and the PV planning. As described, we incorporate ambient conditions including climate related factors in the planning section of the ontology. Graphical representations in both figures demonstrate relationships in the two main sector of the model, the MPPT and the planning. Both figures main classes related to these concepts. Using several plugins, we can illustrate a variety of graphical visualizations showing different relationships of each class in MPPT-On.



(a)



(b)

Figure 5-4 Two snapshots of graphical representation of super-classes (a): MPPT, (b) PV shading

5.2 Structure of Rules and Queries for the MPPT Database

In this case, SWRL rules are designed to provide information about the MPPT-Based controller. These technical and physical characteristics are essential for the PV system designed by a PV planning software. During the processes of identifying class axioms, three areas were detected as the main resource of concepts in the context of MPPT:

- **I.** MPPT methods
- **II.** MPPT characteristics
- **III.** MPPT control system.

MPPT methods represent knowledge base about the algorithms, different techniques, parameters involved, mathematical approaches employed, and related variables. Searching techniques used for tracking GP and functions as well as their parameters are the intentions of any research endeavors about MPPT methods. Unlike these notions, MPPT-linked semantics without physical or technical features are classified in the sector of MPPT characteristics. These classes represent criteria and measures that an MPPT approach can be compared with the another. The third key knowledge area in the context of the MPPT domain belongs to the hardware of an MPPT-based control system. Technical features and physical properties of the controller are embodied in this stream. These properties are defined in the ontology so that the important properties of an MPPT method can be obtained. Figure 5-5 outlines these data properties from which the SWRL rules are extracted.

The prioritized numbers shown in the figure states how important is the SWRL rules. In other words, defining rules for MPPT algorithms alone can be useful for the MPPT database. PV planners can present the information of the method algorithm to the system designer for technical purposes. The following sections elaborate these SWRL rules explaining what they are and how they can be used.

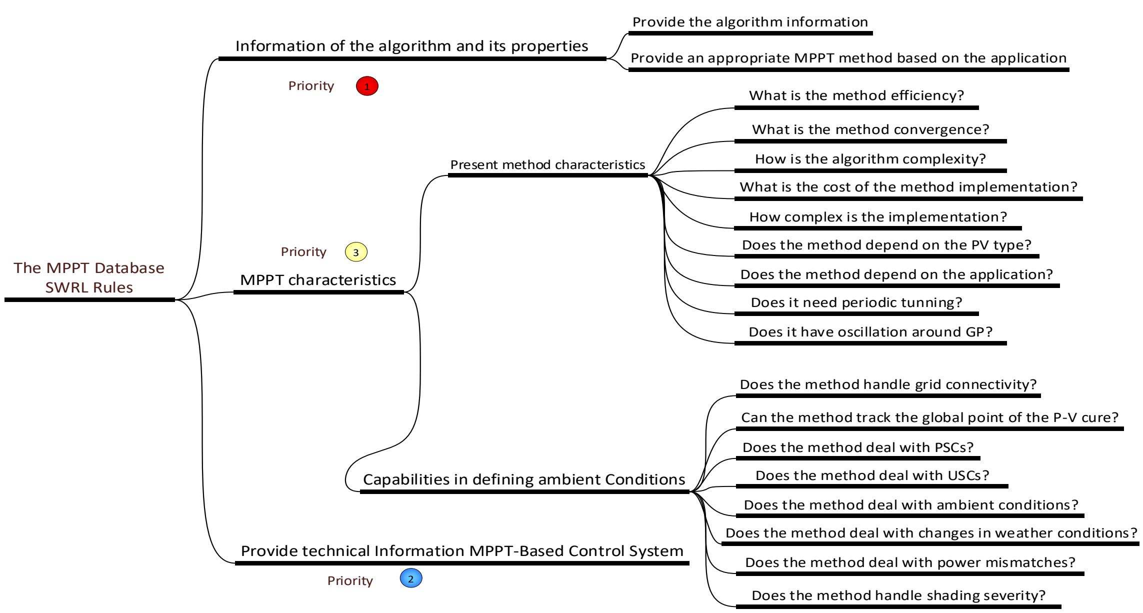


Figure 5-5 Structure of the SWRL rules for the proposed MPPT database

5.2.1 Rules for MPPT Methods

An MPPT method or technique is recognized based on the algorithm used. It means the mathematical approach employed by the method determines variables and parameters needed for the method. Usually, several processes of the mathematical approach are implemented through the algorithm. Properties of the methods define information needed for them. In fact, SWRL rules are made to extract these data from the MPPT database (table 5-1).

Table 5-1 Extracted data from the ontology applying SWRL rules, MPPT methods

Class Assertion	Data Properties and Object Properties
Algorithm	algorithm initial value, algorithm initial parameter defined, algorithm operation processes for metaheuristic methods and swarm optimizations (initialization, crossover, mutation, selection), population size, reference parameter defined, algorithm searching technique, crossover rate, functions and equations used, AI characteristics, metaheuristic characteristics, intelligent method characteristics
Method	method name, method classification name, method-related object properties

5.2.2 Rules for MPPT Characteristics

This group of SWRL rules assists PV project planners to acquire information needed to compare various characteristics of a method with other techniques. Table 5-2 shows the type of info obtained from the ontology with regards to MPPT characteristics.

Table 5-2 Extracted data from the ontology applying queries, MPPT characteristics

Class Assertion	Data Properties and Object Properties
MPPT Characteristics	Method cost, convergence, efficiency, implementation, PV dependency, application dependency, periodic tuning, oscillation around GP, complexity, grid connectivity,
Ambient Conditions	Tracking GP, handling shading conditions (PSCs and USCs), can handle power mismatch,

5.2.3 Rules for MPPT-based Controller

SWRL rules in this regard aid PV designers and engineers to deal with technicality of an MPPT-based control system. If it is not included in the system designed by the PV planning tool, the technical recommendations related to the controller are offered by MPPT-On. Furthermore, SWRL queries provide all technical data needed for such systems. The following table (5-3) presents some of the data properties and object properties about MPPT controllers.

Table 5-3 Extracted data from the ontology applying queries, MPPT controller

Class Assertion	Data Properties and Object Properties
MPPT-based control system	Controller input variable, duty cycle, power at MPP, PWM, microcontroller name, algorithm information

5.2.4 An Example of a SWRL Query for an MPPT Method

The defined SWRL rules can produce different reports associated with MPPT methods. The aid of this database is to provide technical recommendations and design information needed for an MPPT controller. SQWRL queries are employed to define various rules and extract information from the MPPT database. SWRL rules, in fact, act to evoke knowledge out of the ontology model instead of manipulating data or changing values of a class assertion and produce new class assertions. The application of a SQWRL query and its results are shown in the following figure (5-6). In this example, the SWRL query lists all recommended MPPT methods included in the database. There is a query for presenting conventional MPPT methods in the SQWRLTab:

- *ConventionalMethod(?c) ^ hasOscillationAroundGP(?c, ?oscillation) ^ dealsWithPSCs(?c, ?psc) ^ canTrackGP(?c, ?gp) -> sqwrl:select(?c, ?oscillation, ?psc, ?gp)*

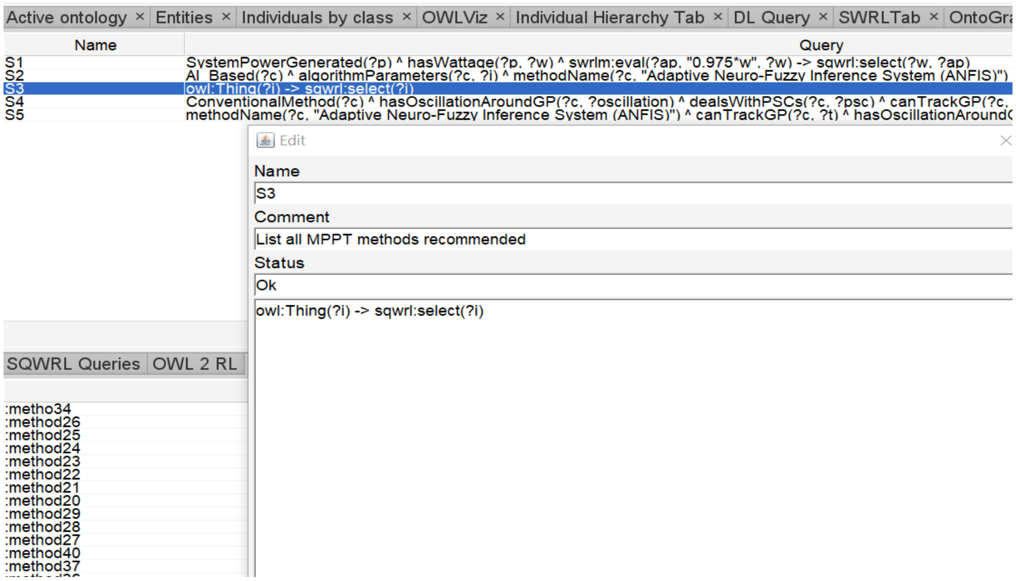


Figure 5-6 A query for presenting conventional methods and the characteristic of oscillation around GP

5.3 SWRL Rules for Shadings and Tilt Angles

SWRL rules extraction regarding shading conditions are determined concerning accumulation of different particles on a module. These rules are the focus of this work with regards to ambient conditions. We consider the factor of tilt angles affecting shading conditions, although this factor is design-related concern. These two factors represent environmental parameters and design-related item that a planning tool offers. Snowfalls and accumulations of different particles on solar panels creating shadings impact PV performances significantly.

The SWRL rules are used in MPPT-On to adjust power estimations given by any planning software. The usual attempt would be to determine rules to manipulate power data outputs based on some adjustments according to environmental factors. However, shading conditions depend on weather data and environmental factors that their impacts on module performances need to be investigated. In this work, we set up rules for snow and polluted particles that are the main source of shading conditions in many cases. Aside from particles, which is an environmental factor, there is a system design related factor that affects the performances. The role of a module’s tilt angle on the energy production has been investigated in many papers. Hence, inclination and its effects on power degradation are reviewed to establish SWRL rules and SQWRL queries. Determining the impacts of snow, dust, and tilt angles are the major aspects considered for rules extraction and queries in the paper. In the next two sections, the SWRL rules and queries are defined based on accumulation of snow and different particles as well as tilt angles. These rules help PV project planners to make required adjustments for the power estimations reported by the planning tool.

5.3.1 The Effects of Different Particles

The impacts of dust and snow depend on weather conditions of where the solar panels are installed. For many locations, the effects of snow, dust, and/or either of them are not considered because they are not environmental or climate concerns for those sites. However, there are many geographical locations where the energy productions can be noticeably influenced by snowfalls or accumulations of different environmental particles.

We characterize the rules for snowfalls based on the decreases in output productions. However, snow crystals and conditions of snowfalls are not assessed in our rules. With regards to particles, the same trend is performed. Factors affecting dust deposition on a solar panel can be divided into four categories containing dust properties, environment and weather conditions, module properties, and the installation design [138]. These elements are outlined in the following table.

Table 5-4 Considered particles and their impacts on PV performance

Ref.	Particle Type	Effect on PV Performance
[139]	Dust and Sand	2-2.5% decrease of power (Turkey)
[140]	Airborne Dust	At least 33.5% decrease in efficiency
[141]	Cement Dust	80% drop in PV short circuit voltage (deposition of 73 g/m^2)
[142]	Dust	6-13% decrease in output power (Cyprus)
[143]		Average of 4.4% daily energy loss that could increase to 20% in dry conditions (Spain)
[144]		50% reduction in the power for the panels exposed without cleaning for six months (Saudi Arabia)
[145]		2.78% daily reduction for silicon solar panels in short circuit current

[146, 147]		10% power reduction after 5 weeks of the exposure (UAE) and 10% in module efficiency (Qatar)
[148]		5-6% decease in module efficiency (Palestine)
[149]		16–29% degradation of energy yield of 7 different PV modules without any cleaning procedure for 18 years (Australia)
[150]		11% reduction in the energy production (5 g/m^2 dust deposition)
[138]		15-21% decrease in the short circuit current
		2-6% reduction in the open circuit voltage
		15-35% degradation for the efficiency
[151]		About 15% losses with periods without rain (either textured or non-textured glasses module surface)
[152]		5% or more annual energy losses
[153]	Sand	About 4% reduction in PV voltage (multi-crystalline PV)
	Red Soil	About 7% decrease in voltage (multi-crystalline PV)
	Ash	25% PV voltage reduction (multi-crystalline PV)
	Calcium Carbonate	5% reduction in PV voltage (multi-crystalline PV)
	Silica Gel	About 4% reduction in PV voltage (multi-crystalline PV)
[154]	Snow	50% lower than evaluated PV energy
[155]		0.3-2.7% decrease in annual yield
[156]		4.25% yearly energy loss
[157]		1-5-5.2% of one year's production
[158]		Snow depth >1" cause 45% of daily loss, and <1" cause 11% daily loss [for 30° module angle] Snow depth >1" cause 26% of daily loss, and <1" cause 5% daily loss [for 40° module angle]
[159]		1%-12% annual energy production losses
[160]	Cloud	77% reduction in power output

5.3.2 The Effects of Tilt Angles on a PV System Performance

Tilt angle is a fix factor and irrelevant to ambient conditions. However, their impacts and the attention expressed by experts in the PV community encourage us to include this factor in the proposed ontology. We setup several SWRL rules associated with it due to its influential role in snow shedding and its impact on the duration of snow coverings on PVs. Their impacts on PV performances are outlines herein (table 5-5).

Table 5-5 Impacts of tilt angles on PV system performances

Ref.	Inclination	Effect on PV Performance
[161]	25° tilt angle	Power is 5.6% to 17.3% higher than 6° tilt depending to the site plant (Turkey)
[162]	45° tilt angle	17.4% energy loss per month for south-facing panels (Egypt)
[152]	23° tilt angle	70% losses in winter months
	40° tilt angle	40% reductions in winter months
	0° tilt angle	18% losses in generation
	24° tilt angle	15% losses (annually estimated)
	39° tilt angle	12% losses (annually estimated)
[163]	Dual axis	Produce about 30% more electricity than the tilted system
[158]	30° tilt angle	Snow depth >1" cause 45% of daily loss, and <1" cause 11% daily loss
[158]	40° tilt angle	Snow depth >1" cause 26% of daily loss, and <1" cause 5% daily loss

5.4 MPPT-On: The Proposed Ontology Model

The developed ontology model (MPPT-On) is available in the following link:
https://github.com/khof01/ontology
The above link consists of two versions of MPPT-On. The first file (MPPT-On_V6.1) presents MPPT methods and the SQWRL queries extract information about MPPTs including the control system. ANNEX XI depicts two screenshots of the MPPT database included the ontology. This database consists of important characteristics of well-known MPPT methods. In fact, technical data and info related to an MPPT database are added to the ontology as individuals and queries are defined accordingly. While the second file (MPPT-On_V6.2) represent SQWRL queries that provide info needed for corrections of power outputs reported by the planning tool. The following figure (5-7) shows how the ontology is appeared in the Protégé.

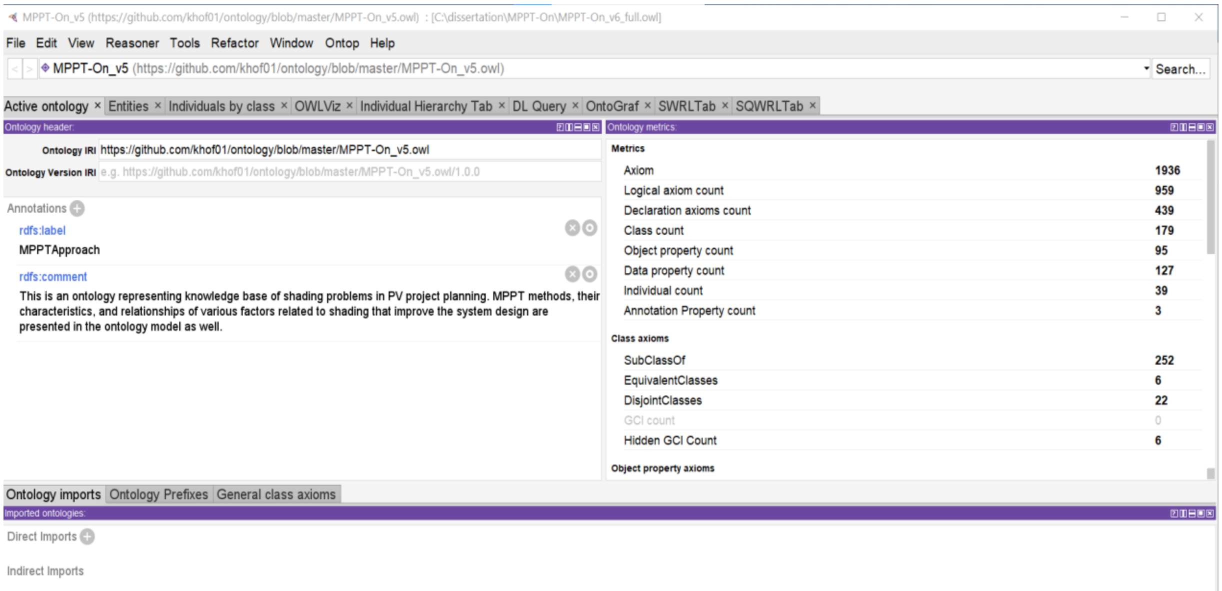


Figure 5-7 The view of MPPT-On in Protégé

Figure 5-8 depicts technical characteristics and functionality of the developed ontology. The ontology model represents notions and semantics related to the MPPT knowledge area and PV shadings. The defined SWRL rules and SQWRL queries extract information from the model. Table 5-6 outlines the ontology metrics, appeared in the figure, consisting of numbers associated with the axioms.

Table 5-6 MPPT-On metrics

Ontology Metrics	**Characteristic**	**Number**
Metrics	Axioms	2457
	Logical axiom count	1515
	Declaration axioms count	443
	Class count	179
	Object property count	96
	Data property count	125
	Individual count	44
	Annotation property count	3
Class Axioms	Sub-class of	252
	Equivalent classes	6
	Disjoint classes	22

Object Property Axioms	Functional object property	9
	Object property domain	94
	Object property range	8
Data Property Axioms	Sub-data property of	4
	Functional data property	28
	Data property domain	124
	Data property range	124
Individual Axioms	Class assertion	44
	Data property assertion	795
Annotation Axioms	Annotation assertion	499

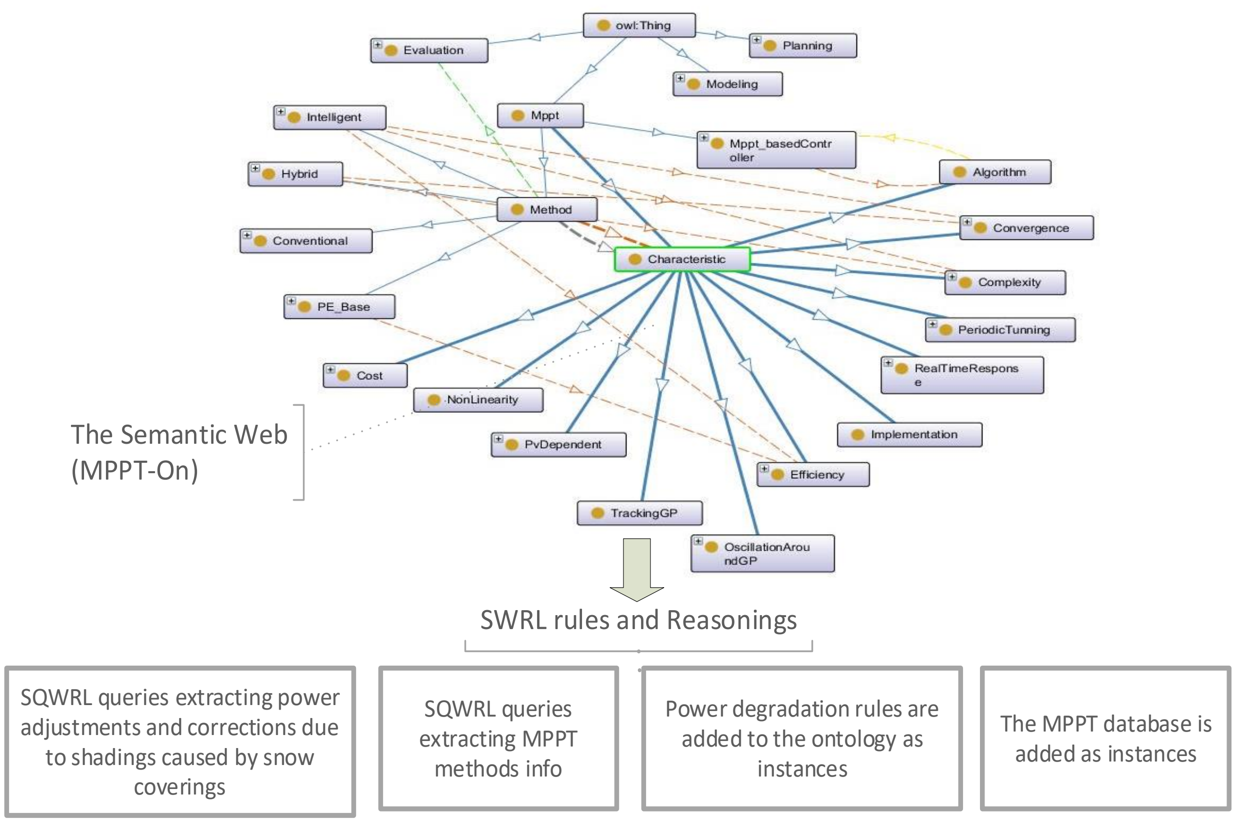


Figure 5-8 Characteristics of the developed ontology

5.4.1 The Application: How the Decision Support System Works

Figure 5-9 depicts the application of MPPT-On and how it can be employed. When a PV project is planned, using a software tool for instance SAM, the output reports and the designed system are presented by the software. Applying the proposed model and considering various environmental parameters of the PV site, we can make the decision to implement the appropriate SWRL rules for the project. The application of MPPT-On evaluated in the next chapter allowing us to demonstrate how the decision support system works.

The functionality of the decision support framework follows the layers of the Semantic Web architecture adapted for the proposed model (depicted in Fig. 3-6, P61). In the following figure (5-9), some layers of the original structure have been combined or not included, for brevity and simplicity.

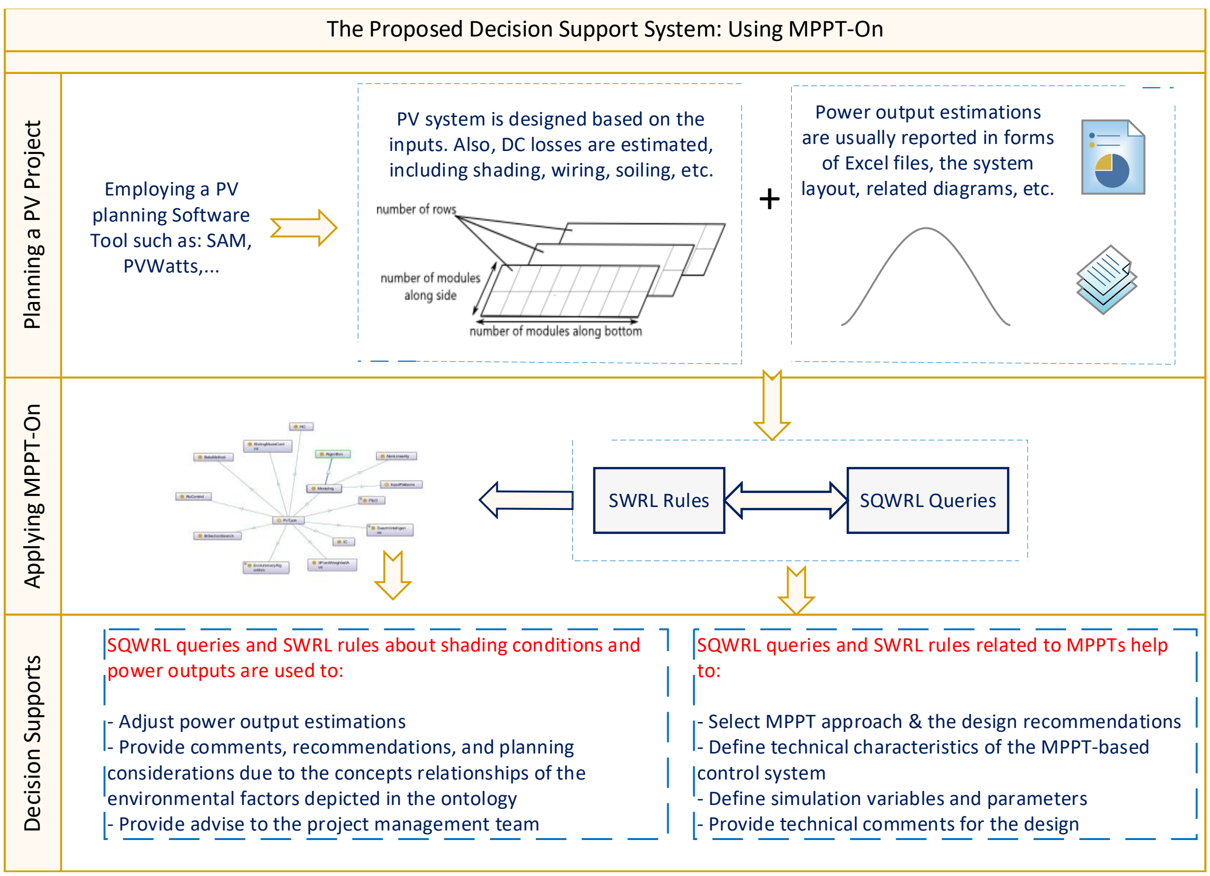


Figure 5-9 The application of the proposed model (MPPT-On)

In fact, the unifying logic and trust layers were eliminated in figure 5-9, as the intention is to demonstrate how the ontology works and how the application should be performed to benefit from the framework. The section of Planning PV Project in the above figure is the process of data gathering and using information and data about the project. Applying MPPT-On represents the Semantic Web and reasoning layers presenting relationships between various factors about shading and PV MPPT-based control system. In the last layer of the figure, we utilize the SQWRL queries and SWRL rules for different purposes of improving power estimations or PV design recommendations.

CHAPTER 6 THE ONTOLOGY EVALUATION: RESULTS AND ANALYSIS

The evaluation of an ontology is as important as developing it. Evaluation can be deemed as an approval for the application of a developed ontology. It indicates that how suitable the ontology model is for which it is supposed to used. The term evaluation includes two distinctive concepts known as verification and validation [16].

Verification demonstrates technical characteristics of the ontology assuring syntactic correctness and clearness of the knowledge base model [73]. On the other hand, validation reflects that whether the ontology represents semantics and notions of the phenomenon that it has been designed for [17]. The two main aspects of evaluation are described in detail in the next sections.

6.1 Verification of MPPT-On

As indicated in chapter 5, MPPT-On has been developed from the scratch using Ontology Development 101 [14]. The methodological guidelines utilize the OWL language that can be applied to Protégé-OWL editor and conveniently applicable for our purpose of the proposed ontology. In the ontology engineering process, collaboration with the domain experts and practitioners familiar with MPPT applications, play a significant role to ensure that MPPT-On provides a reliable technical knowledge base for designing a PV system. The proposed ontology is developed from scratch, then consultation with PV domain experts is recommended [164]. The methodology that has been used for identifying semantics and their relationship fulfill this criterion. Figure 6-1 shows the two key sub-processes that have been introduced in the executing phase of the research during the ontology design. These processes can prevent many unexpected anomalies. The implemented method literally guarantees the correctness and completeness of the concepts defined for the ontology. Semantically verification of the ontology is ensured considering the research ontology design process. In this regard, semantic verification is mainly performed by exploring PV planning software tools, although we include the results of the survey. For syntactically verification of the developed ontology, it is checked using Pellet plug-in reasoner incorporated in Protégé 5.5. The use of the reasoner eliminates anomalies in the ontology.

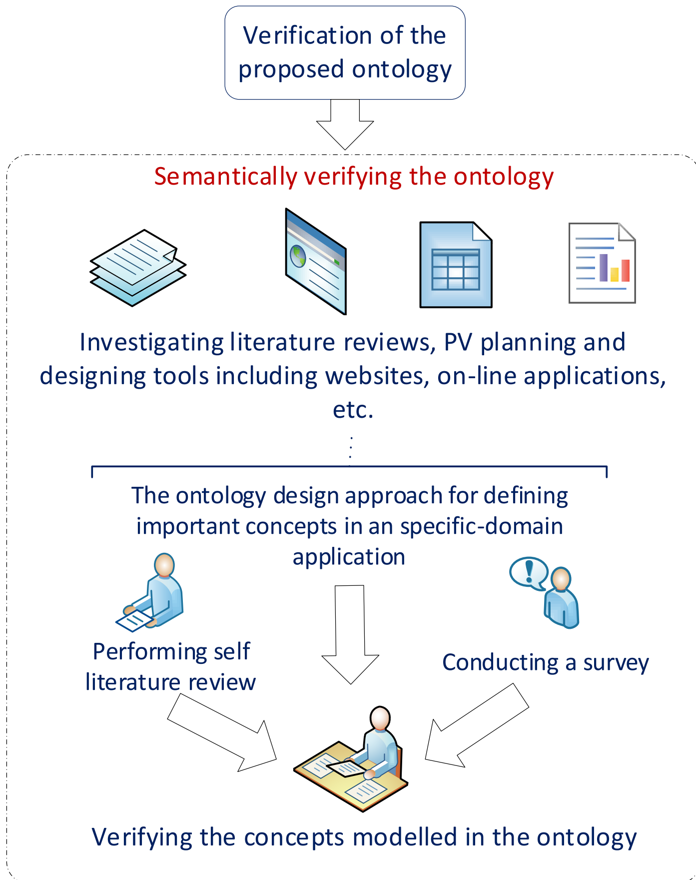


Figure 6-1 Verification processes of the proposed ontology MPPT-On

6.2 Validation with a Case Study

The consistency of the proposed ontology is assured when anomalies considered acceptable due to the compliance with reasonable thresholds. MPPT-On is semantically validated by a case study. We verify the proposed ontology by comparing results of two systems: 1) a system which is planned by support of the MPPT-On and 2) a system without using technical recommendations. The following Figure demonstrates the validation processes including syntactically checking and using the case study (figure 6-2).

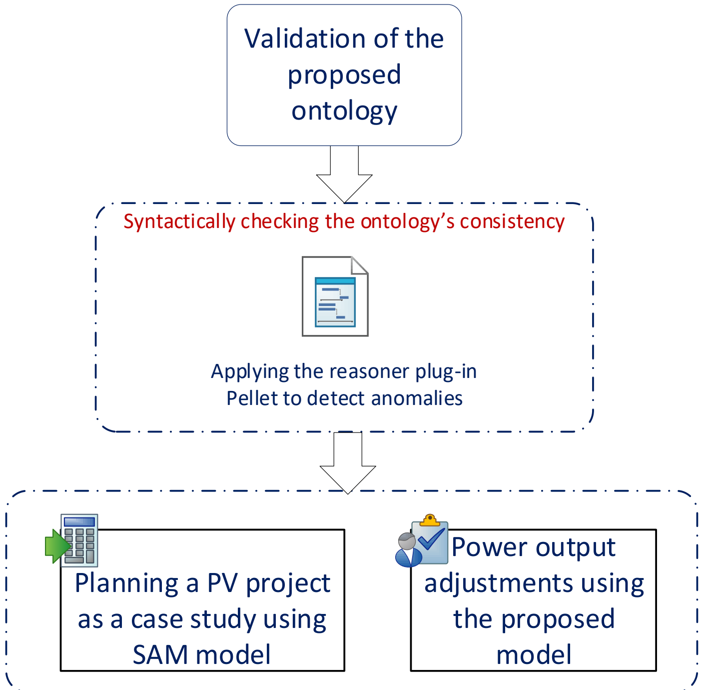


Figure 6-2 Validation processes of the proposed ontology: using the case study

The results of using SQWRL queries, for correcting SAM's power estimations, and SAM's output results are compared with the actual measured power outputs. Therefore, if the application of the proposed ontology demonstrates significant corrections for the estimated power productions, the validation process of the ontology is fulfilled.

In order to validate MPPT-On, we need a PV case study with real data that its measured hourly power productions are available as well as its weather data including snow data for a year. NREL provides 9 PV case studies for which measured performance data are available for the community to be used [165]. The systems consist of three utility-scale (greater than 10 MW) systems and six commercial-scale systems (75-700 KW). Onsite measured snow data for the year 2012 can be used as inputs for these projects. One important advantage of using these PV systems is that if there is any system failure or an outage, it is reported in the project description provided by SAM [165].

6.3 NREL's Visitor Parking: Datasets and Technical characteristics

The benefits of providing a covered parking lot and producing electricity are the reasons many businesses and organizations install PV systems. NREL installed a 524-kW PV system covering their visitor parking, designed and installed for NREL by SunPower in 2011 [18, 165]. The information about 9 PV systems used as case studies are available publicly at:
https://sam.nrel.gov/photovoltaic/pv-validation.html
The PV project is located at Golden, CO, with the geographical information shown in here:

Table 6-1 The PV System Geographical Information

Project Name	Latitude	Longitude	Elevation	Location
Visitor Parking	39.74° N	105.18° W	1,829 m	Golden, CO

SunPower measured the system performance data for the entire year of 2012. AC powers were measured at each of the inverters and reported hourly in kilowatt-hour. The total system output was calculated by adding the output power at each inverter. In addition, inverter outages and system shutdowns were identified and removed from the analysis from the analysis [165]. In this case, June 27- July 23 were removed because both inverters were shutdown, and August 19- September 18 were removed because one inverter experienced an outage (as indicated in the report). The 2012 weather data from the Solar Radiation Research Laboratory (at NREL) is used to simulate the case study as the measured data for the project are collected and available for this year [166]. February 29, 2012 is removed from both gathered dataset by SunPower and the SRRL dataset because it is a leap. This is done to prevent for missing data and obtain accurate model in SAM. The measured data, collected form the PV site, are publicly available to the PV community. NREL provides 9 PV systems to validate its model, SAM, to quantify SAM's ability to predict performance for these systems. Datasets related to the 9 PV case studies can be downloaded from SAM website: https://sam.nrel.gov/photovoltaic/pv-validation.html (NREL PV Validation 2013). Technical characteristics, the electrical system summary, and the array layouts of the case study are shown in figures (6-3 and 6-4) [167].

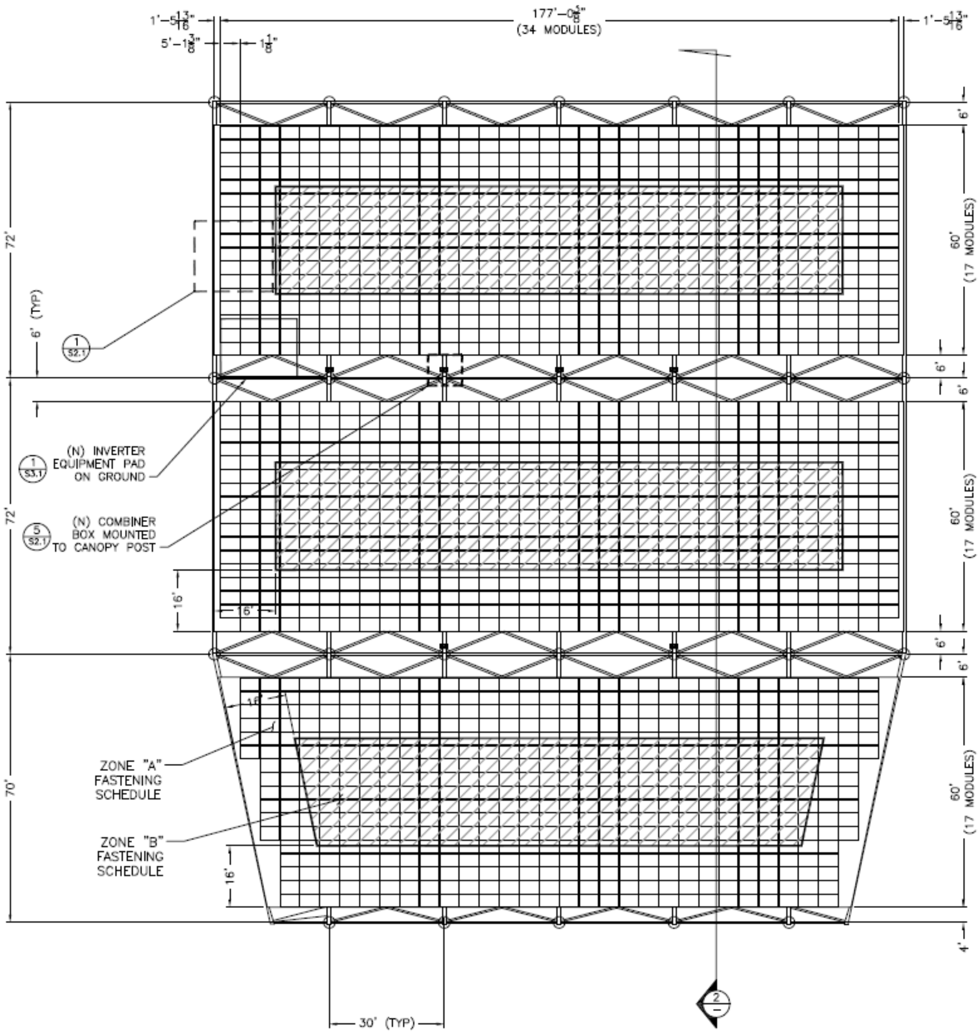


Figure 6-3 Array layout of NREL parking lot structure (source: [167])

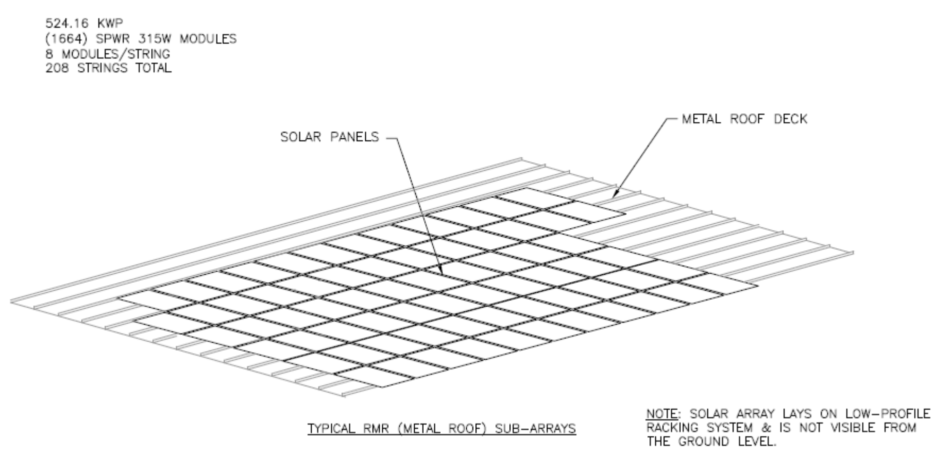


Figure 6-4 Electrical system summary of NREL visitor parking PV project (source: [167])

6.3.1 The Planning of the Case Study Using SAM Model

The application of the SAM model and the simulation results for the NREL's visitor parking are presented in ANNEX VI. The output report files of the simulation are available in: https://github.com/khof01/ontology. The subsequent processes present the steps taken in the SAM software to plan NREL's visitor parking.

6.3.1.1 The Weather file and the Data Library Used in the Simulation

To start a PV project and weather conditions at a project location, SAM requires a weather data file. A weather data file can be chosen from a list, downloaded from the Internet, or created the file using existing data. From SAM's Solar Resource Library, the latest weather files from the NREL National Solar Radiation Database (NSRDB) are downloaded and added to the solar resource library. The NSRDB is the best source of data for locations in the United States, Canada, Central and South America, Sri Lanka, India, Nepal, Bhutan, Bangladesh, and part of Pakistan, Afghanistan, and Myanmar, and western Southwest Asia [168]. It provides access to the latest weather files as both single year and typical-year (TMY) files. Using the NSRDB, TMY weather files of the locations are added to the SAM's library. Table 6-2 provides weather data associated to the location of the case study. The data include weather files downloaded, weather related and solar data.

Table 6-2 Data library for the case study (NREL's visitor parking garage at Golden, CO)

Solar Resource Library	
Weather file downloaded	Golden_co_39.749672_-105.216019_psmv3_60_tmy
Data Source	NSRDB
Annual Averages from Weather File Data	
Global horizontal	4.51 kWh/m^2/day
Direct normal (beam)	5.51 kWh/m^2/day
Diffuse horizontal	1.55 kWh/m^2/day
Average temperature	8.4 °C
Average wind speed	2.5 m/s

Maximum snow depth	Not available

6.3.1.2 PV Module: The Performance Model and the Database

This step of the planning tool is about the PV module selection and its data containing performance model, module characteristics at reference conditions, physical characteristics, and the model parameters. These parameters can be employed by the system designers for modeling and simulation purposed. The module data also indicate technology and PV type, brand name and manufacturer of PVs. The system planner and SAM's users may know which PV name and model they need for their system or may arbitrarily pick one of the listed PVs. The PV performance model chosen for the simulation is one-diode R_{SH} model which is comparable with CEC performance model [169, 170].

Figure 6-5 depicts the *I-V* curve of the module chosen (SunPower SPR-315E-WHT-D) at the standard test condition (STC), total irradiance = 1000 (W/m^2) and cell temperature = 25 °C. The values determined in the module database can be observed in the following figure. The bending point of the curve indicates the important point of a PV characteristic. In the case of performing one PV or when there is no ambient alteration or mismatch with other PVs, this point is occurred at about 80% of the open circuit voltage (V_{OC}).

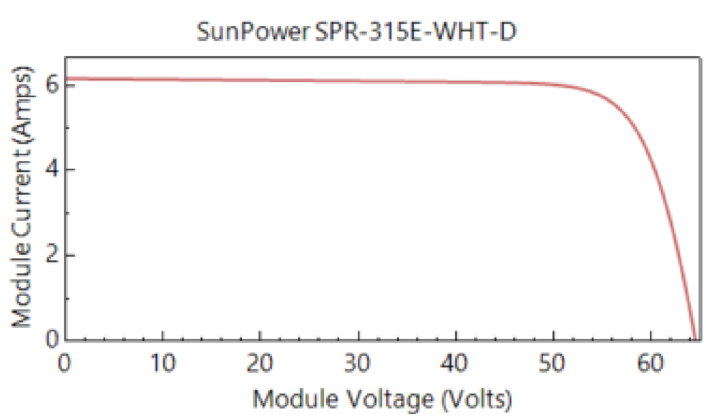


Figure 6-5 The *I-V* characteristic of SunPower SPR-315E-WHT-D module (source: SAM 2020.2.29)

SunPower SPR-315E-WHT-D is selected as the PV module from the database in SAM for the case study. As a result, the PV system is designed based on technical characteristics of the selected module. Its physical and technical characteristics are introduced in the following table (6-3).

Table 6-3 Module data used in the case study (source: SAM)

Physical Characteristics	
Module name	SunPower SPR-315E-WHT-D
Technology	Mono-c-Si
Length	1.599
Width	1.046
Number of Cells	96
Module area	1.631 m^2
Bifacial	No
Module Parameters	
Nominal efficiency	19.3177%
Maximum power (P_{MP})	315.072 (W_{dc})
Maximum power voltage (V_{MP})	54.7 (V_{dc})
Maximum power current (I_{MP})	5.8 (A_{dc})
Open Circuit Voltage (V_{OC})	64.6 (V_{dc})
Short circuit current (I_{SC})	6.1 (A_{dc})
Nominal operating cell temperature	46 ℃
Ideality factor (A_{ref})	2.58002 (A)
Photocurrent at ref. (I_l or I_{PV})	6.14394 (A)
Reverse saturation current at ref. (I_O)	$8.05e^{-11}$ (A)
Series resistance (R_S)	0.339337 (Ω)
Parallel or shunt resistance (R_{sh} or R_P)	529.162 (Ω)

In our SAM simulation, we choose this brand because of two reasons: I) our MATLAB/Simulink models demonstrating shading conditions (chapter 3) uses module data (SunPower SPR-X20-250-BLK) with almost similar characteristics presented by this module from the same brand, II) the module performance and its technical characteristics allow our simulation to design a system similar to the project installed in the NREL site.

6.3.1.3 Inverter

Performance mode and its technical concepts of the inverter in system design are out of the scope of this research. Nevertheless, an inverter is an important component in a grid connected PV system in most practical applications. Besides, a few input values defined in the inverter database determines MPPT's technical parameters. Although inverters' technical parameters are excluded from the model, its data complete the final report of the case study and need to be in the system design. The main technical information of the inverter chosen, SMA America: SC250U [480V], are presented in the following table (6-4).

Table 6-4 The data about the inverter chosen for the system (source: SAM)

Variable	**Value**
Max. AC power	250 (kW_{ac})
Max. DC power	259.023 (kW_{dc})
Power used during operation	2.064 (kW_{dc})
Power use at night	75 (W_{ac})
Nominal AC voltage	480 (V_{ac})
Max. DC voltage	480 (V_{dc})
Max. DC current	700.062 (A_{dc})
Min. MPPT DC voltage	330 (V_{dc})
Nominal DC voltage	370 (V_{dc})
Number of MPPT inputs	1
Max. MPPT DC voltage	480 (V_{dc})

6.3.1.4 The Designed System

SAM model provides the sizing summary of the designed system after the last two steps. This includes DC sizing and electrical configuration, tracking, and orientation of the system. Table 6-5 presents the sizing of the system designed for the NREL's visitor parking garage. In the program, we ask the model to estimate the sizing in one subarray configuration.

Table 6-5 The system designed by SAM model for the case study

Parameter	Value
Number of inverters	2
DC to AC ratio	1.05
Desired array size	524 (kW_{dc})
Nameplate DC capacity	524.280 (kW_{dc})
Total AC capacity	500 (kW_{ac})
Total inverter DC capacity	518.046 (kW_{dc})
Number of modules	1,664
Number of strings	208
Total module area	2,714 (m^2)
Modules per string in subarray	7
Strings in parallel in subarray	238
String V_{OC} at ref. conditions	452.2 (V)
String V_{MP} at ref. conditions	382.9 (V)
Tilt angle	8 (deg)
Azimuth	165 (deg)
Ground coverage ratio	0.3
Max. DC voltage	480 (V_{dc})
Min. MPPT voltage	330 (V_{dc})
Max. MPPT voltage	480 (V_{dc})

Otherwise, SAM may report that the string voltage in a subarray exceeds the inverter maximum rated voltage at reference conditions or indicates that the voltage is below the operating rate of the inverter. In that case, it is the user’s optional choice to change the number of modules in each string and number of the strings in parallel in subarrays to match with the total number of modules. The adjustments need to comply with the minimum and maximum voltage rate of operating voltage of the inverter chosen for the system.

6.3.1.5 Shading and the System Layout

In this part of the planning, shadings of any objects located adjacent to the PV arrays are applied to program. The file can project the external objects such as buildings and trees or any other structures. Therefore, the 3D shade calculator imports shade data for each subarray designed for the system. In addition, self shading for fixed subarrays and one-axis trackers can be included herein. Module aspect ratio, module length, and module width play a significant role in this case. There exists an option in this section of SAM model for estimating snow losses whereas the weather file includes snow depth data. Losses are calculated for each subarray and at the end of the simulation, this loss is reported among other DC losses. If the location of the PV project includes snow database, the final estimations of power outputs represent reliable calculation of the productions and a major correction step has been taken. However, weather databases for most locations can not provide snow depth data.

6.3.2 The Simulation Results and Output Reports

SAM provides various output reports including monthly and annual summaries, data tables and graphs, time series, and PDFs. The followings categorize them into three sorts of outputs that can assist our model users to realize to which part of the model they refer to. ANNEX VI shows a few screenshots of the previous steps implemented in SAM. The SAM simulation file is available in the following link.
https://github.com/khof01/ontology
In the next sections, the output reports and hourly power estimations and weather conditions are investigated. Snow depths and freezing temperature can cause severe PV shadings that will result in decrease in energy production.

6.3.2.1 A summary of monthly energy production and energy losses

Table 6-6 presents, DC and AC power estimations of the output simulation result for the case study, NREL's visitor parking. These summaries aid the system designers and planners to predict energy productions prior to installing the project. However, they can be used as predefined data for the decision-support system that the ontology model provides. In another word, these valuable data assist and educate even the ontology user of this work to adjust the final parameters more effectively. Figure 6-6 shows powers generated in each month of the year.

Table 6-6 DC Power production and AC power generated by the system

Time stamp	PV array DC energy | (kWh)	System AC energy | (kWh)
Jan	43477.2	41250.9
Feb	52362.2	49830
Mar	72329.9	68897.1
Apr	74228	70655.8
May	83477.9	79503.7
Jun	84844.9	80974.1
Jul	81067.9	77318.9
Aug	73849.5	70380.1
Sep	68799.6	65641.6
Oct	57866.6	55106.5
Nov	45962.8	43714.8
Dec	39818.3	37775

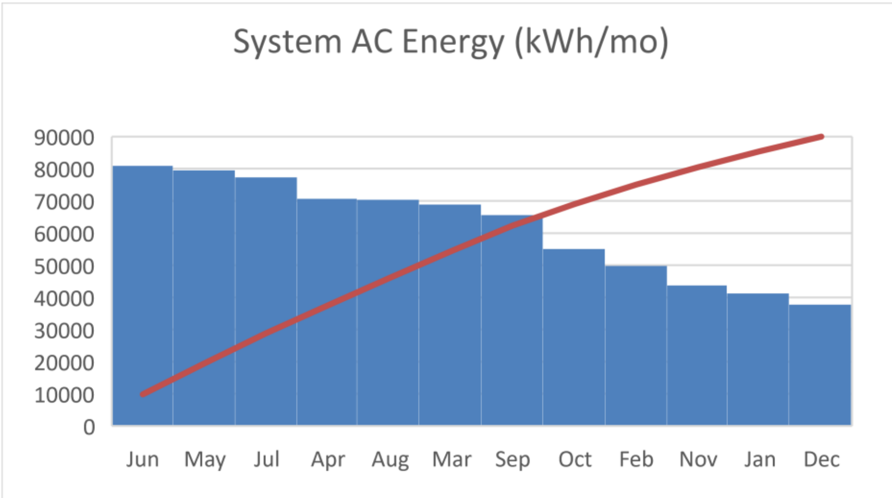


Figure 6-6 The Pareto chart of the power generated by the system in each month

6.3.2.2 Data tables and statistics

Table 6-7 outlines numerous data that are useful for system designers and planners as it contains PV model parameters, losses, and several single values of AC and DC energy production. The data can be exported to an Excel file and save as CSV format.

Table 6-7 Data generated from the simulation of the case study in SAM

Data	Value
Annual AC energy gross (kWh/yr)	748548
AC connected battery loss- year 1 (%)	0
AC inverter efficiency loss (%)	2.21122
AC inverter night tare loss (%)	0.0877539
AC inverter power clipping loss (%)	0
AC inverter power consumption loss (%)	1.53301
AC inverter thermal derate loss (%)	0
AC performance adjustment loss (%)	0
AC wiring loss (%)	1
AC wiring loss (%)	1
AC wiring loss (kWh)	7485.48
Annual DC energy (kWh/yr)	778085
Annual DC energy gross (kWh/yr)	814239
Annual DC energy nominal (kWh/yr)	848069

Annual Energy AC (year 1) (kWh)	741048
Annual GHI (Wh/m2/yr)	1.65E+06
CEC 6-parameter: Adj	22.3781
CEC 6-parameter: Il	6.14394
CEC 6-parameter: Io	8.05E-11
CEC 6-parameter: Rs	0.339337
CEC 6-parameter: Rsh	529.162
CEC 6-parameter: a	2.58002
DC inverter MPPT clipping loss (%)	0
DC mismatch loss (%)	2
DC mismatch loss (kWh)	16284.8
DC nameplate loss (%)	0
DC nameplate loss (kWh)	0
DC snow loss (%)	0
DC tracking loss (%)	0
DC tracking loss (kWh)	0
DC wiring loss (%)	2
Energy yield (kWh/kW)	1413.46
Inverter clipping loss AC power limit (kWh/yr)	0
Inverter clipping loss DC MPPT voltage limits (kWh/yr)	0
Inverter nighttime loss (kWh/yr)	682.8
Inverter power consumption loss (kWh/yr)	11928.1
Inverter thermal derate loss (kWh/yr)	0
Lifetime daily AC loss- year 1 (%)	0
Lifetime daily DC loss- year 1 (%)	0
DC wiring loss (kWh)	16284.8
DC power optimizer loss (kWh)	0
DC power optimizer loss (%)	0
DC performance adjustment loss (%)	0
DC module deviation from STC (%)	3.98911
DC diodes and connections loss (kWh)	4071.19
DC diodes and connections loss (%)	0.5
DC connected battery loss- year 1 (%)	0
Capacity factor based on AC system capacity (%)	16.9189
Capacity factor (%)	16.1354
Subarray 1 DC diodes and connections loss (kWh)	4071.19
Subarray 1 DC mismatch loss (kWh)	16284.8
Subarray 1 DC nameplate loss (kWh)	0
Subarray 1 DC tracking loss (kWh)	0
Subarray 1 DC wiring loss (kWh)	16284.8

Subarray 1 Gross DC energy (kWh)	814239
Subarray 1 Total DC power loss (%)	4.4402
Sun position time offset (hours)	0.5
System nameplate DC rating (kW)	524.28
Transformer load loss (kWh/yr)	0
Transformer loss percent (%)	0
Transformer no load loss (kWh/yr)	0
Transformer total loss (kWh/yr)	0
Transmission loss (%)	0
Transmission loss (kWh)	0

There are many options of generating different output reports resenting statistical values for various parameters, hourly or monthly data. Figure 6-7 depicts a view of these reports, for brevity they are not presented in a complete form.

	Mean	Min	Max	Sum	Std Dev	Avg Daily ...
All						
Hourly Data						
AC wiring loss (kW)	0.8561	0.0005	4.7712	7499.1421	1.2606	0.0015
Absolute air mass ()	1.5208	0	24.7565	13321.9922	3.1188	0
Array DC power (kW)	88.8225	0	495.0367	778084.7951	129.859	0
Array DC power loss due to snow (kW)	0	0	0	0	0	0
Array POA beam ra...g and soiling (kW)	350.0028	0	2598.5874	3066024.3285	611.2875	0
Array POA front-si...ation nominal (kW)	368.424	0	2735.3551	3227394.03	643.4606	0
Array POA front-sid...lection (IAM) (kW)	501.154	0	2821.0023	4390109.3094	744.6701	0
Array POA front-si...ng and soiling (kW)	522.7052	0	2833.9252	4578897.2342	760.508	0

Figure 6-7 A snapshot of a section of the statistics from one of the output reports (SAM simulation)

6.3.2.3 Time series graphs

A PV planning tool needs to provide hourly data so that the time series values may be exported to other programs for analysis or compared with other data where distinctive parameters, values, or factors applied to the simulation. Figure 6-8 implies the time series graph of the system power generated by the PV system of NREL’s visitor parking installed in Golden, CO, the case study (generated in SAM).

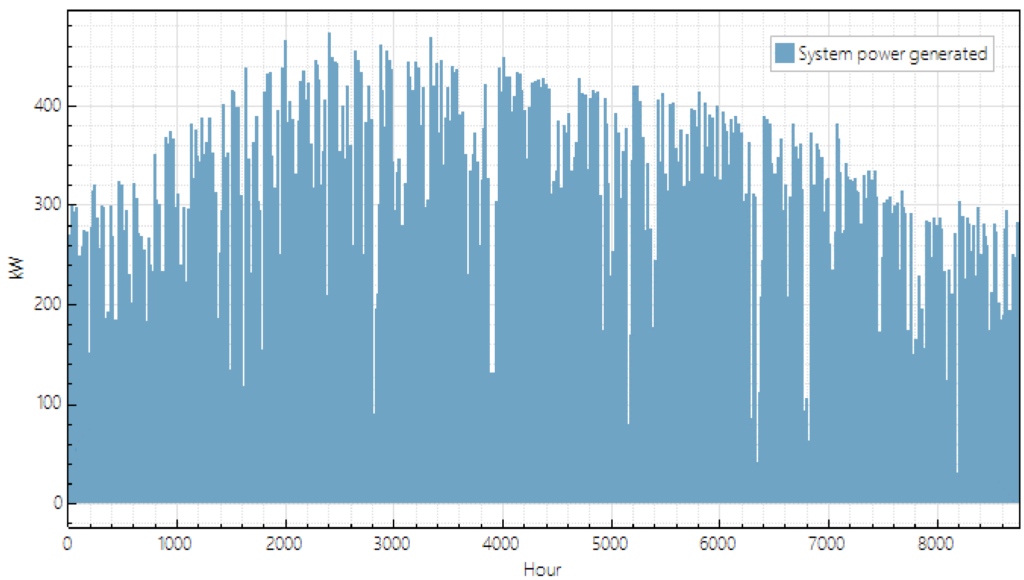


Figure 6-8 The hourly system power generated for the case study (SAM report)

The graph bar of the monthly system productions (figure 6-9) illustrates the estimations reported by SAM for the PV project (the exact values are presented in table 6-6, P122).

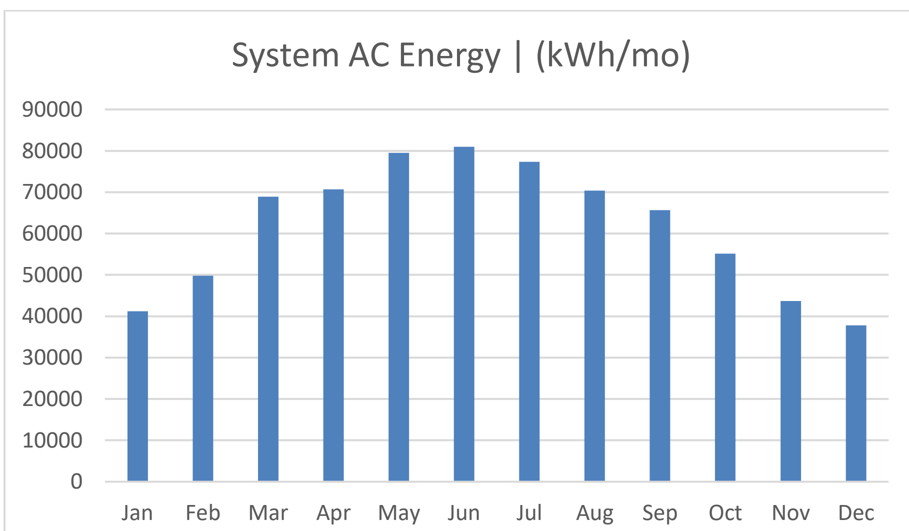


Figure 6-9 System power productions estimations simulated by SAM

However, we need the monthly data productions for the months expecting shading the most (due to snowfalls, clouds, or ice pillar, etc.) to analyze the estimated powers considering weather conditions and snowfalls effects. This can help to effectively use the ontology model for adjusting the output results of the PV planning tool, herein SAM model.

6.4 Results Analysis of the Case study

6.4.1 Investigating Ambient Conditions of the Location

There are six criteria pollutants for which the United States federal government has launched several standards in the Federal Clean Air Act and its amendments [171]. Among the pollutants carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), lead (Pb) are concerned directly to protect sensitive members of the population, though there is a criterion for particulate matter that can affect the results of this research. Two standard size fractions are considered for this measure: $PM_{2.5}$ and PM_{10}. These measures have been set to protect such factors known as “visibility in scenic areas” [171]. Therefore, they might affect the results of PV power productions due to PSCs or USCs. The standard level of $PM_{2.5}$ has been set at 15 µg/m^3 (averaged over 3 years). This level has been set at 150 µg/m^3 for PM_{10}.
As observed in figure 6-10 (Table 3, P8 [171] and Table 2-2, P9 [172]), the NREL site experiences no exceedance of particulate matters of both $PM_{2.5}$ and PM_{10} for years 2012 and 2018 which is the most recent data available. The pollution data indicate that particles with the source of air pollution cannot affect the PV productions for the NREL site plant. Hence, there is no power corrections or adjustments for power outputs estimated by SAM with the source of airborne for the project.
According to the installation plan, the project of NREL’s visitor parking consists of the installation of a solar electric system on the metal rooftop of an existing building. The PV site location including vicinity map and site map is shown in figure 6-12 (NREL site, Golden, Colorado).

AQS Site Number	Site Name	2017 O$_3$	2017 PM$_{10}$	2017 PM$_{2.5}$	2018 O$_3$	2018 PM$_{10}$	2018 PM$_{2.5}$
08-001-0008	Tri County Health (TCH)			2		1	1
08-003-0003	Alamosa - Municipal Bldg.					1	
08-005-0002	Highland Reservoir	2			7		
08-005-0005	Arapaho Community College (ACC)			1			
08-005-0006	Aurora - East	1			3		
08-013-0003	Longmont - Municipal Bldg.			1			2
08-013-0012	Boulder Chamber of Commerce (CC)			1			
08-013-0014	Boulder Reservoir	1			5		
08-031-0002	CAMP			4	1		5
08-031-0013	National Jewish Health (NJH)						1
08-031-0026	La Casa			2	1		1
08-031-0027	I-25: Denver			2			1
08-031-0028	I-25: Globeville			1			1
08-035-0004	Chatfield State Park	2		2	10		3
08-041-0013	U.S. Air Force Academy (USAFA)				2		
08-041-0016	Manitou Springs				1		
08-041-0017	Colorado College			1			1
08-045-0012	Rifle - Health Dept.				1		
08-059-0006	Rocky Flats - N.	3			16		
08-059-0011	NREL	5			10		
08-069-0009	Fort Collins - CSU			1			1
08-069-0011	Fort Collins - West	3			8		

AQS ID	Location	2011 O$_3$	2011 PM$_{10}$	2011 PM$_{2.5}$	2012 O$_3$	2012 PM$_{10}$	2012 PM$_{2.5}$	Violation O$_3$
08 001 0006	Commerce City			1				
08 001 3001	Welby	3			5			
08 003 0001	Alamosa Adams State Coll.		2			4		
08 003 0003	Alamosa Municipal Building		2			5		
08 005 0002	Highlands Reservoir	5			6			X
08 005 0006	Aurora East	4			2			
08 013 0003	Longmont Municipal						1	
08 013 0011	South Boulder Creek	4			4			
08 031 0002	CAMP				1		1	
08 031 0014	Carriage	2			5			
08 031 0025	DMAS				3			
08 035 0004	Chatfield State Park	9			15			X
08 041 0013	U.S. Air Force Academy	3			2			
08 041 0016	Manitou Springs	2			3			
08 045 0012	Rifle				1			
08 051 0007	Mt. Crested Butte Realty					1		
08 059 0002	Arvada	6						
08 059 0005	Welch	6			6			X
08 059 0006	Rocky Flats N	8			19			X
08 059 0011	NREL	10			13			X
08 059 0013	Aspen Park	1			5			
08 067 7001	SUIT-Ignacio	1						
08 067 7003	SUIT-Bondad	1						

Figure 6-10 Sites with exceedances of the ambient air quality standards for Colorado (Source:[171] Table 3)

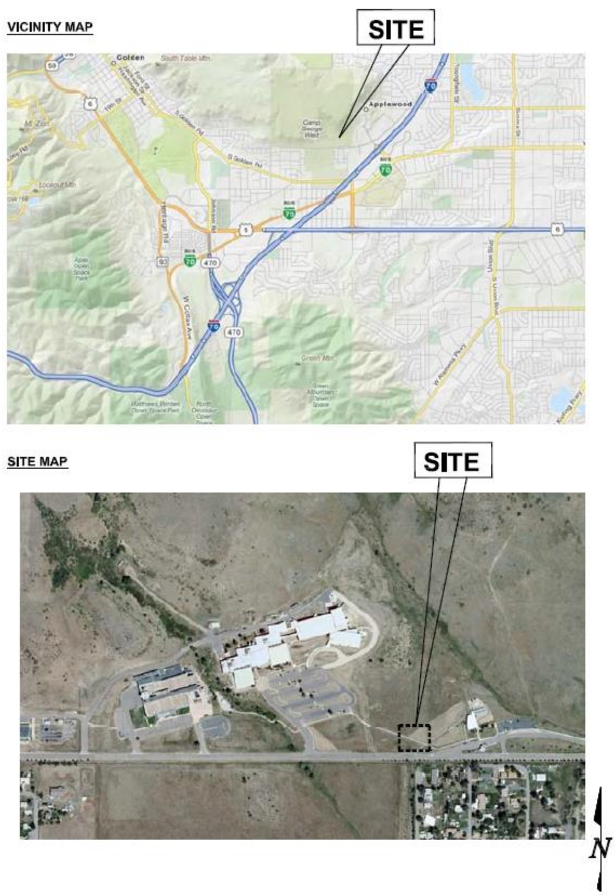


Figure 6-11 NREL parking lot site map

The attempt of investigating the neighborhood of the case study is to perceive if there are any significant ambient factors that could possibly influence power generations of PVs located at the roof of the NREL visitor parking. Therefore, we search for possible environmental-related elements such as nearby industries and sources creating shading conditions for PV arrays. The fact that the site is in an urban area with no source of industrial pollutions, we discuss the ambient conditions and investigate the results based on the effects of snow.

6.4.2 Reviewing the Weather File

Making decision about choosing relevant query to be used for power adjustments requires analysis of the weather file for the months that we expect PV shadings due to snowfalls. We review the weather file for the months from October to April of the year 2012 to detect snowy days. Temperature of these days also need to be investigated in order to perceive whether snow is wiped out from PV surfaces. High temperature for the upcoming hours or days after the precipitation means that snow shedding will be happened. Therefore, snow has a minimum impact on PV energy generations. By reviewing the weather files, we detect temperature and snow data to determine durations of PV shadings. The following diagrams (figures 6-12 to 6-18) depict snow data and temperatures for the seven months that we forecast snowfalls.

Figure 6-12 shows average temperatures and snowfalls for the month of January 2012. As the temperature shows, Jan 10-12 and 16-18 demonstrates temperature below -5 Celsius. In addition, snow starts on Jan 7 and ends on Jan 11 so that PV arrays experiencing accumulation of 6, 4, 2, and 12 (cm) of snowfalls. Also, there is about 1 (cm) of snowfall for Jan 17-18 and Jan 1st, and temperatures are below zeros in these three days. Temperatures in the rest of the month especially after snowfalls help PVs to melt the snow and perform in their standard operating temperature.

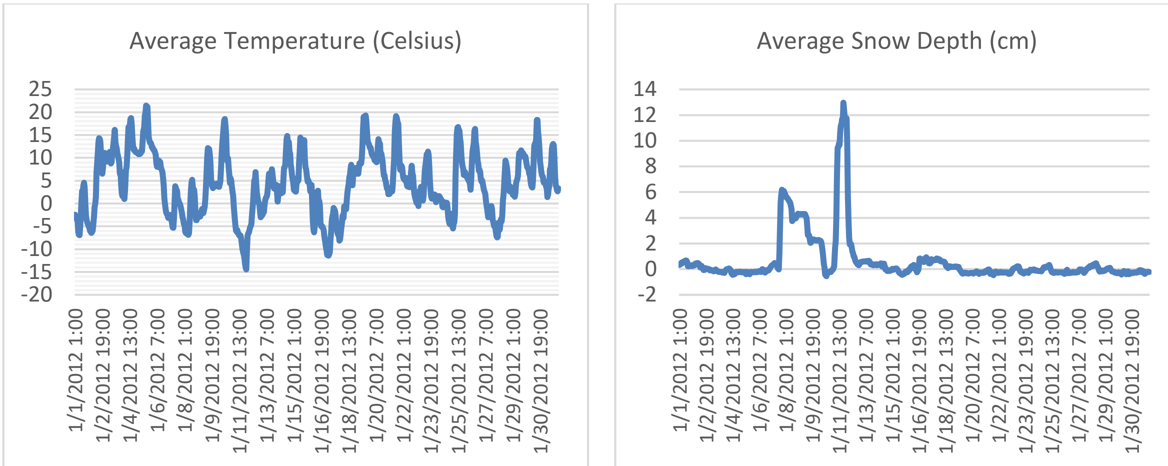


Figure 6-12 Bar charts for average temperature and snowfalls for the case study (Jan 2012)

Figure 6-13 depicts bar charts for average temperature and snowfalls for the month of February 2012 for the location of the case study. As shown, there is enormous number of snowfalls in this month for consecutive days, Feb 3-26 for about 50 to 10 (cm). Temperatures are mostly below zero with a few days of extreme cold for Feb 8, 11, and 12th.

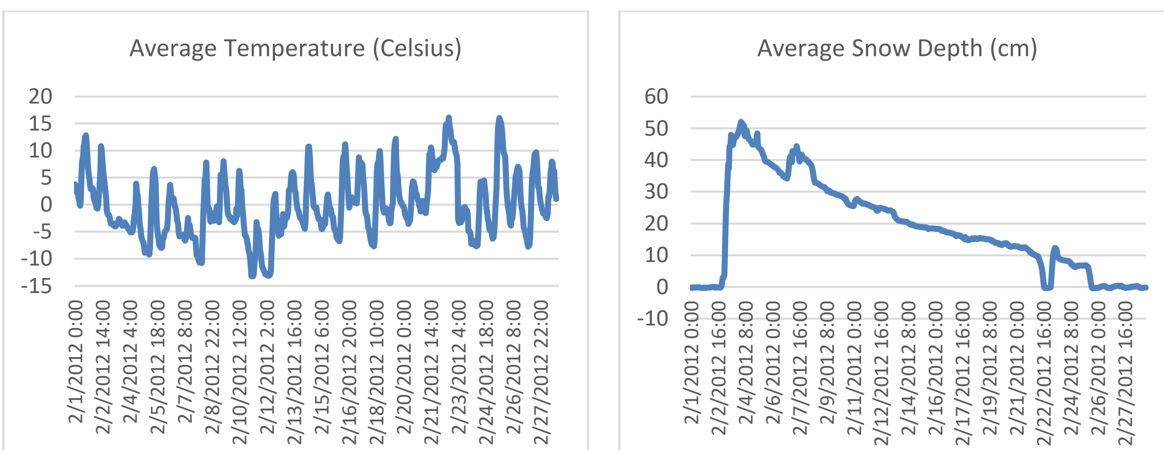


Figure 6-13 Bar charts for average temperature and snowfalls for the case study (Feb 2012)

In the following bar chart diagrams (figure 6-14), the temperature and the snowfall of March 2012 illustrate fewer alterations in temperature and more specifically in snowfalls with exceptions of Mar 2-3 (about 0.4 centimeter of snow), Mar 7-8, and Mar 20th with temperature about -5°C.

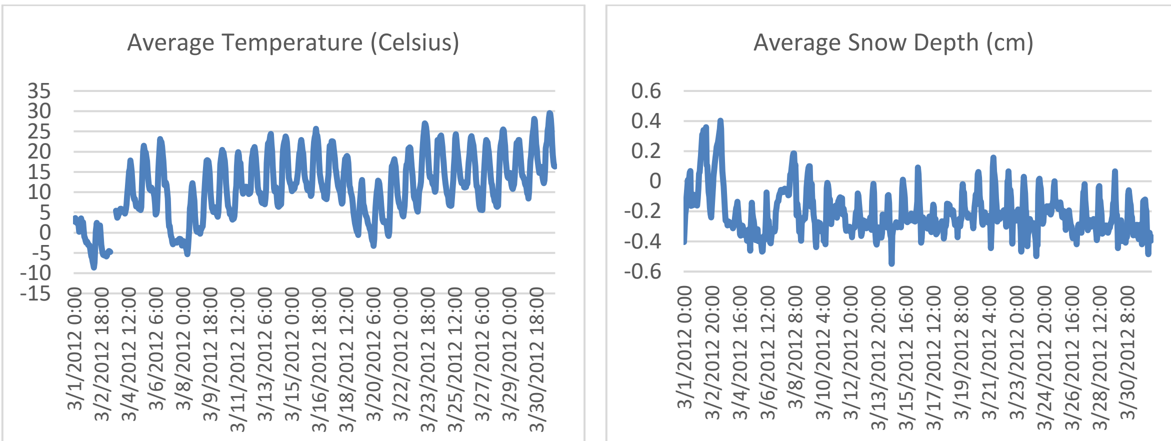


Figure 6-14 Bar charts for average temperature and snowfalls for the case study (Mar 2012)

Climate conditions of the PV site are expected to demonstrate average temperatures above zero with no snowfall in April. However, Figure 6-15 presents two events of average snow depths of 4 and 2 centimeters for Apr 3rd and Apr 14th. The upcoming months are not investigated for this region as the climate condition are projected to be normal without any snowfalls for May and following months.

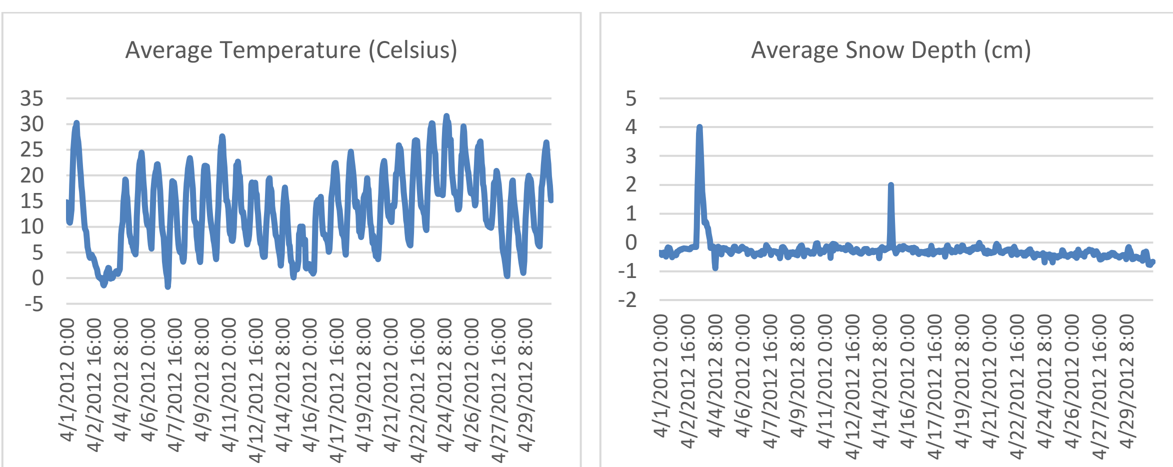


Figure 6-15 Bar charts for average temperature and snowfalls for the case study (Apr 2012)

As the weather approaches to the cold months starting October, we can expect snowy days. Respecting the weather conditions of the site, temperatures are mostly above 0℃ for October, except Oct 5-7 (less than 0℃) and Oct 24-27 (about -5 ℃). Further, there is a snow depth of 5 (cm) for a single day of 24th (figure 6-16).

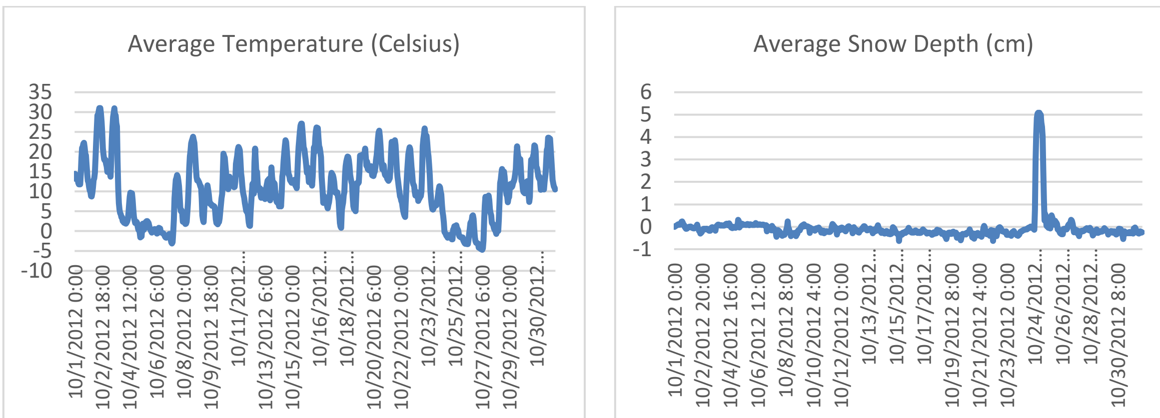


Figure 6-16 Bar charts for average temperature and snowfalls for the case study (Oct 2012)

Starting November, temperatures are dropped but not as much as to create new situations than October. PVs are covered by a slight amount of snow about 1 (cm) for Nov 10-11 and about 0.2 (cm) for Nov 26-27. The associated temperatures are about -10 ℃ and -5 ℃, respectively (figure 6-17).

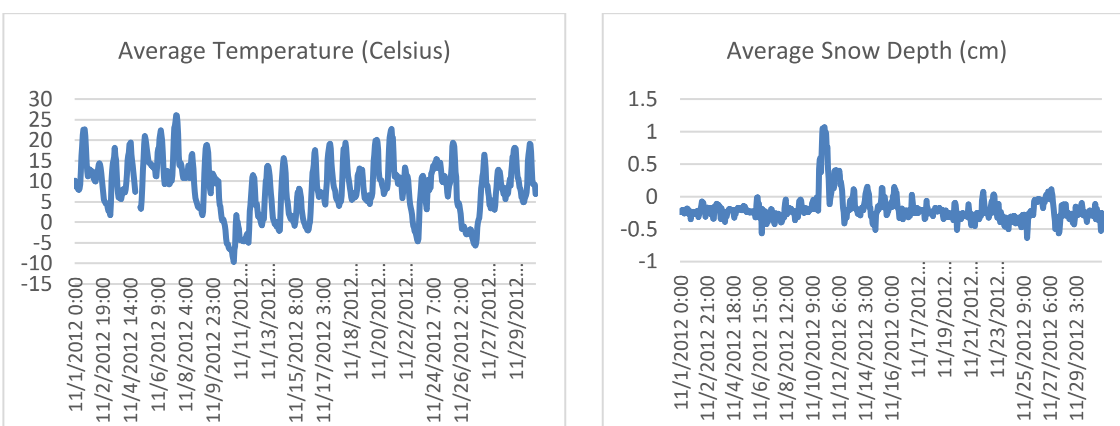


Figure 6-17 Bar charts for average temperature and snowfalls for the case study (Nov 2012)

These snow depths cannot affect PV performances because there are no shading conditions detected for the month of November. Therefore, we exclude this month of our investigation. Unlike November, the month of December delivers snowfalls and below zero temperatures for most days. As observed in figure 6-18, Dec 19-22 snowfalls of 6 to 2 centimeters are experienced by PVs and from Dec 25th throughout to Dec 31st snow depths of 8 (cm) to 4 (cm) for the four following days. Cold temperatures about -5 ℃ to -10 ℃ increase the severity of shadings created by the snow for Dec 19-22 and Dec 25-31.

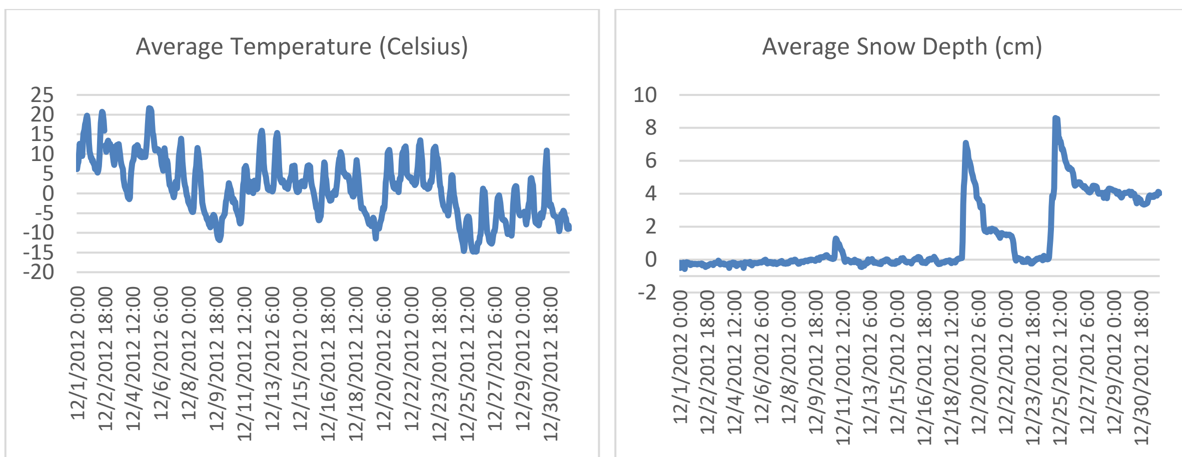


Figure 6-18 Bar charts for average temperature and snowfalls for the case study (Dec 2012)

Now, we investigate the power output reports of the SAM model for the months of shadings defined as October, December to April. The month of November is excluded as there is no snowfall occurred, and there is no panel shading. In these six months, PVs are operating under shading conditions in several days. So far, there are two sets of data: I) the results of SAM simulation including hourly power estimations and II) the hourly power generations measured onsite for the visitor parking (data is available in the SAM website[18]).

Figure 6-19 illustrates the two power outputs reported by SAM and measured onsite for the six months that the shading condition affects the output results. As depicted, the SAM model drastically overestimate powers for the months of February and December. SAM also overestimations power produced for the months of January and October as well.

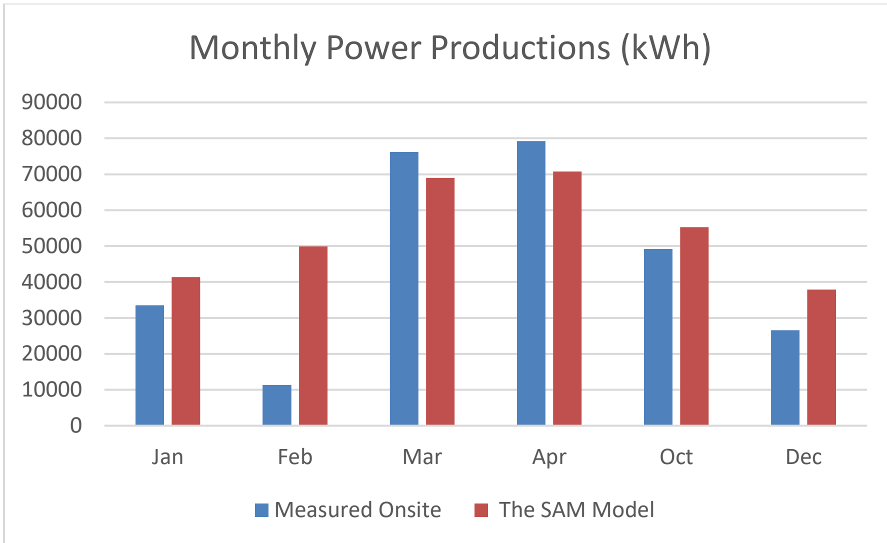


Figure 6-19 Power outputs reported by SAM and measured onsite for the visitor parking

In the next sections, we describe how to apply MPPT-On to the hourly powers simulated by SAM and then the results are compared with the actual data measured onsite for the case study.

6.5 Using MPPT-On

6.5.1 Shading Conditions and Associated Rules

Snow depths and the durations of snow covering PVs play significant roles in power generations in our case study. Reviewing the effect of snow in the previous sections help us to make decision about applying appropriate SWRL rules and queries for power corrections (MPPT-On the rules are available at: https://github.com/khof01/ontology). The durations of shadings created by snowfalls depend on a few factors that can affect snow coverings afterward. There are two major factors that cause snow covering much longer: I) temperatures for the following days after snowfalls, and II) PVs are not wiped out due to the site maintenance. Snow shedding may be occurred the day after the precipitation because of hot weather or any type of human activities. Therefore, we can predict two scenarios estimating durations of PV shadings: I) longer durations for PV snow coverings and II) shorter durations for PV snow coverings.

I. Scenario 1: Longer durations for PV snow coverings

In this scenario, we forecast for least duration of snow coverings for PVs that it means there is no shading experienced the day after snowfalls. Table 6-8 presents the days of shadings experienced by PVs in this case.

Table 6-8 Scenario 1: longer durations for snow coverings

Month	Days of Shading
Jan	Considerable amount of snow depths about 10 (cm) for at least 15 days, and 3 days with snow coverings less than 2 (cm)
Feb	More than 20 (cm) remains on PVs for at least 26 days
Mar	Snow coverings for 3 days due to previous snowfalls, light precipitations, and cold temperatures at the beginning of the month
Apr	3 days of snow depths of more than 2 (cm)
Oct	1 or max 2 days, more than at least 3 (cm)
Dec	12 days of snow coverings with depths of about 4 (cm)

II. Scenario 2: Shorter durations for PV snow coverings

Another option is to consider that snow remains on PVs for a couple of days (the duration is estimated according to the temperature of the upcoming days, respectively). Table 6-9 outlines the days when PV shadings occur due to snowfalls for the case study. Now, we can refer to the SWRL queries to select rules providing recommendations and adjustments needed to correct the calculated powers reported by SAM. We attempt to find the rules that help us to correct the power estimations respecting daily energy production and number of snowfalls. Searching for the associated SWRL rules in the ontology model reveals the following results.

Table 6-9 Scenario 2: shorter durations for snow coverings

Month	Days of Shading
Jan	12 (cm) snow coverings for at least 5 days and about 1 (cm) for two days
Feb	10 to 50 (cm) expected to remain on PVs for about 25 days

Mar	Small volume of snowfalls about 0.4 (cm) for two days
Apr	4 (cm) for one day that is not expected to remain on PVs more than a day and 2 (cm) for another day
Oct	Accumulation of 5 (cm) for 1 day
Dec	12 (cm) of snow remains on PVs for about four days 12 (cm) of snow accumulated in seven days

Reviewing the rules in the ontology model, the three rules are picked to be applied according to the snowfalls and associated shading conditions:

I. Rule P24 (Shading Condition 22) – The Effect of Snow on PV Energy

As figure 6-20 depicts the result of the SQWRL query, it recommends: 50% lower than evaluated PV energy. It means that for the days that PVs experience snowfalls, PV productions degrade 50% less than the usual values.

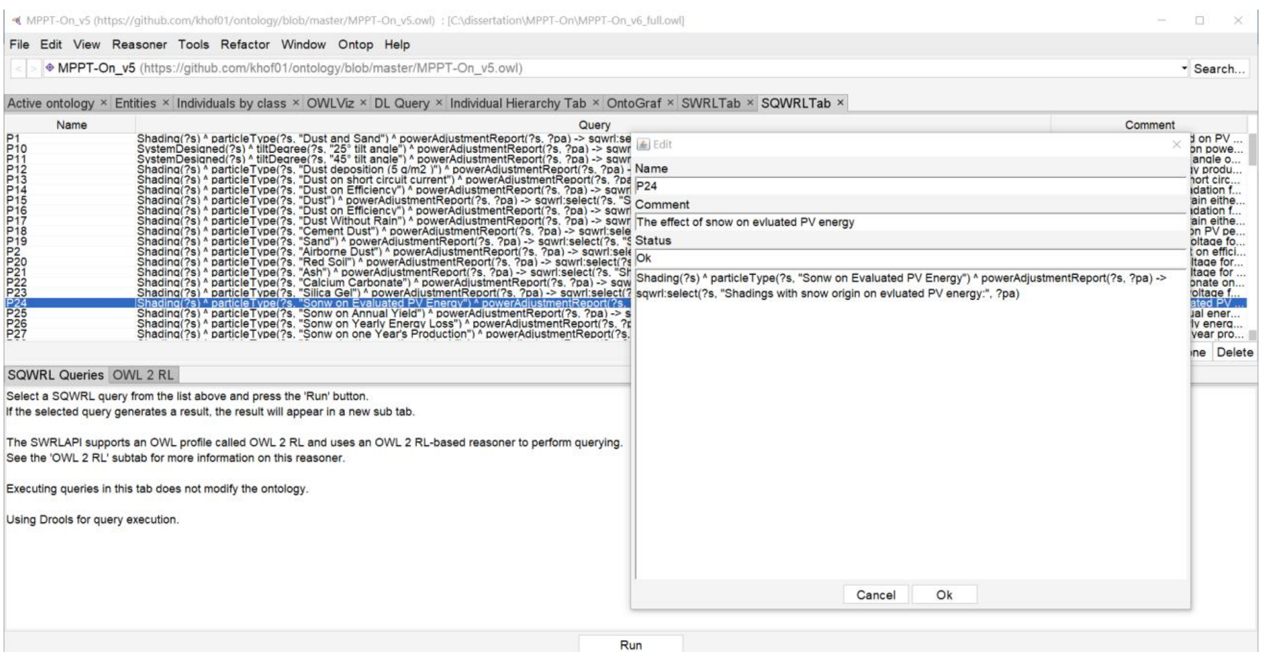


Figure 6-20 The SQWRL query, rule P24: the effect of snow on evaluated PV energy

The following bullet portrayed the rule 24, displayed in the figure (6-20):

- *Shading(?s) ^ particleType(?s, "Sonw on Evaluated PV Energy") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin on evluated PV energy:", ?pa)*

II. Rule P28 (Shading Condition 26) – Snow Depth More Than 1 Inch

Figure 6-21 shows the result and the application of rule 28 recommending that “Snow depth more than 1-inch cause 45% of daily loss for 30° module angle, and cause 26% of daily loss, and for 40°. Tilt angles are not considered as the main factor of changing parameters. The PV arrays are designed in a fixed angle (30°) in our SAM simulation for the case study.

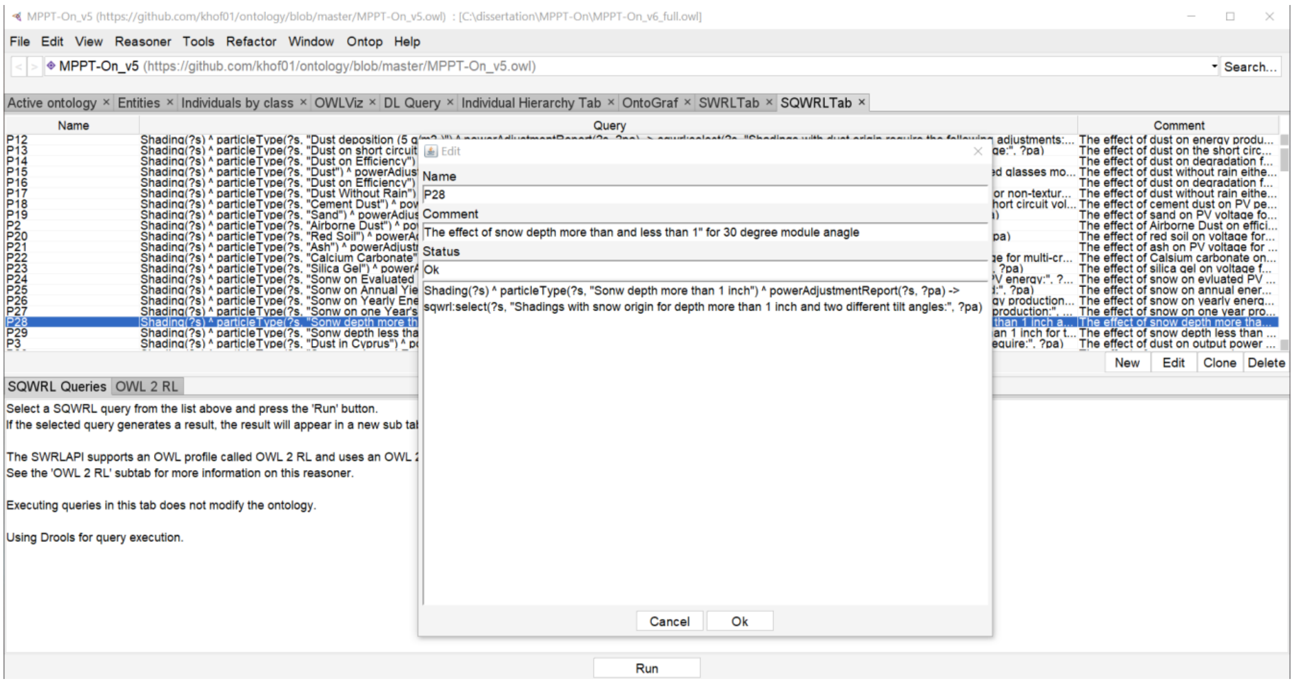


Figure 6-21 The SQWRL query, rule P28: the effect of snow depths > 1” on PV performance

The following bullet portrayed the rule 28, displayed in the figure (6-21):

- *Shading(?s) ^ particleType(?s, "Sonw depth more than 1 inch") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin for depth more than 1 inch and two different tilt angles:", ?pa)*

III. Rule P29 (Shading Condition 29) - Snow Depth Less Than 1 Inch

Applying rule 29 which is about snow depths of less than 1-inch cause 11% daily loss for 30° module angle and 5% daily loss for 40°. The following figure illustrates the result of the rule in the SQWRL TAB environment. Figure 6-22 demonstrates a screenshot of the query and the result.

The following bullet portrayed the rule 29, displayed in the figure (6-22):

- *Shading(?s) ^ particleType(?s, "Sonw depth less than 1 inch") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin for depth less than 1 inch for two different tilt angles:", ?pa)*

In the next section, we apply the recommended corrections to adjust power outputs estimated by SAM model.

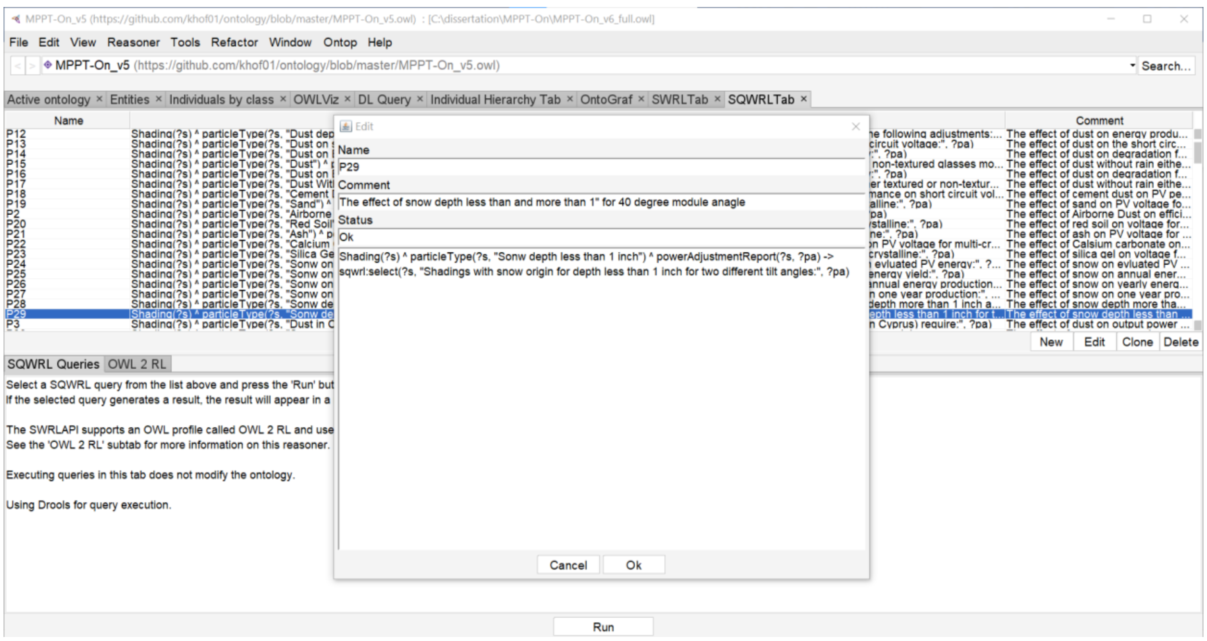


Figure 6-22 The SQWRL query, rule P29: the effect of snow depths < 1" on PV performance

6.5.2 Shading Predictions

To adjust the hourly power generations for the considered months, we identify the affected days in two scenarios for each month. Then, we correct power generations in the affected days by the percentages recommended by the rules. Yet, there are two predictions of shadings, two sets of data are generated considering I) longer durations of snow on PVs (ANNEX VIII), and II) shorter durations of snow coverings (ANNEX X).

Scenario 1: expecting extended durations for snow coverings

Respecting this perspective of shading, we predict that snow stays on PVs for a longer period of times due to below zero temperatures for upcoming days after precipitations. In addition, there is no snow removals at the site. Table 6-10 presents how we make the corrections for affected days in this scenario.

Table 6-10 Shading days, snow data, and related correction factors

Month	>1” Snow (45% power reduction)	<1” Snow (11% power reduction)
January	15 days (7th-22nd), 7th-12th important days	3 days (17th-19th)
February	26 days (3rd-28th) Full shadings	Nc* or N/A
March	29th Feb- 4th, 1st-2nd Full shading	3 days (2nd-4th)
April	3 days (3rd-4th,14th), check for full shading	Nc or N/A
October	(1st-5th), 24th-29th	Nc or N/A
December	13 days (19th-21st) full shading, (24th-29th)	11th

*Not Considerable

Scenario 2: considering shorter durations for snow coverings

Herein, we forecast for snow shedding due to higher temperatures for successive days after snowfalls. Hence, there PVs start generating electricity as soon as above zero temperatures occurred. We still predict that there is no snow removal because of site maintenance. Table 6-11 demonstrates the way we manipulate data in the Excel files of power output reports to correct them according to the ontology model.

Table 6-11 Power reductions associated with predictions of fewer days of shadings

Month	>1” Snow (45% power reduction)	<1” Snow (11% power reduction)
January	5 days (7th-10th, 11th)	2 days (17th-18th)
February	23 days (3rd-25th)	Nc* or N/A
March	N/A	3 days (2nd-4th)
April	1 day (3rd)	1 days (14th)
October	1-2 day (24th-25th)	Nc or N/A
December	10 days (19th-22nd, 24th-31st)	Nc or N/A

These two sets of data, considering two scenarios, demonstrate no significant results because there is no snow removal at the visitor parking site. Moreover, the cold climate condition of the site (Golden, CO) makes no differences between the two scenarios. Thus, we apply the first scenario predicting for a longer duration of PV snow coverings.

6.5.3 Adjusting Hourly Power Estimations

Herein, we apply MPPT-On for the hourly power estimations reported by the SAM simulation. The following steps reviews the important processes undertaken for the application of the proposed ontology, MPPT-On: 1) investigating environmental factors of the PV site, 2) studying climate conditions of the location**,** 3) indicting snowy days, 4) defining shading conditions due to snowfalls, 5) reviewing the SWRL rules and SQWRL queries for the applicable rules, 6) implementing the rules to the hourly results in the SAM's Excel files, 7) obtaining the hourly power estimation results of the MPPT-On application.
These items are described in detail in the followings:

I. Investigating environmental factors of the PV site

In the first step of the application, ambient conditions of the PV site plant are investigated to determine the environmental factors that may affect snowfalls. These factors can be detected as airborne particles due to pollution and air quality of the location. By referring to the MPPT-On, we can identify important environmental factors that influence shadings. Furthermore, their relationships with other elements of climate conditions of the site location can be defined. The ontology shows that airborne particles play an important role in affecting shading conditions. Therefore, the air quality of the site is investigated by exploring different elements of the environment, as described in section 6.4.1. For instance, the existence of a cement factory or being in a polluted urban area accelerate the effectiveness of snowfalls. Furthermore, we need to identify environmental factors that may be used for finding the applicable rules.

II. Studying climate conditions of the location

Complying with the previous step, climate and weather circumstances of the PV plant are studied to define whether snowfalls are effective. Defining cold months and temperatures for the effective months also help us to detect important parameters for shading. Furthermore, weather related elements including humidity, wind speed, and elevation of the environment can influence the impact of snow and consequently PV shadings. For instance, wind can blow away the PVs covered by snow or change the shading conditions and create partial shadings. In addition, humidity especially in high temperature makes the surface of a PV module suitable for airborne particles to remain on the surface causing longer shadings.

III. Indicting snowy days

By reviewing snow data, one can define the days and hours of snow in addition to the snow depths. Knowing the amount of snowfall enable us to detect shading status of PV panels. It defines whether a full shading occurred or not. In the case of full shading, there is no PV productions because of no irradiance reaches the surface of the PV module. At the end of this phase, we spotted the affected hours of shadings and their snow depths.

IV. Defining shading conditions due to snowfalls

This is the important step that identifies the hours that were affected by the snow. The data about snow depths, durations, temperatures, and severity of precipitations can help us to assess the shading conditions. Therefore, this phase of the application takes lots of efforts and attentions working with the Excel files. The weather and snow data allow us to detect the temperature of weather following snowfalls to forecast the duration of shadings. Regardless of no maintenance at the site for snow removal, high temperatures after snow create snow shedding on the PV surfaces. It means the shading duration is challenged when temperature rises afterwards of the precipitation. Full shading is one of the most fundamental aspect in assessing shading conditions. When snow depths are more than 6 or 7 (cm), sunlight cannot reach the surface of PV modules. In this case, there is no power generated.

V. Reviewing the SWRL rules and SQWRL queries for the applicable rules

By now, the amount of snow and the affected days and hours are detected in the Excel files of the SAM model. Thus, the ontology model and the defined rules are reviewed for the applicable queries. In section 6.4.4, these rules are presented concerning snow depths for the case study. Furthermore, there are many recommendations and suggestions with regards to the snowfalls defined in the ontology that aids the user to describe and explain the planning reports.

VI. Implementing the rules to the hourly results in the SAM's Excel files

The rules must be implemented to the hourly power estimations of the SAM model. These rules introduce correction factors needed for the affected hours of shadings. We have already identified the exact dates and durations of shadings for our case study. Thus, the correction factors are applied to the affected hours in the Excel files for the related months.

VII. Obtaining the hourly power estimation results of the MPPT-On application

Applying the correction factors to the affected hours, the Excel files presenting the application of MPPT-On are gained. These files include the hourly power estimations for the six months of predicting shading conditions due to snowfalls. The correction power estimations can be reported instead of the SAM model for the snowy days.

In the following section, we compare the two sets of data reported by SAM and MPPT-On to the actual data gathered from the visitor parking in 2012. It is shown that the application of MPPT-On for snowy days provide data that are close to the measured onsite.

6.5.4 Statistical Analysis of the results

There exist three sets of data reporting power productions for the NREL's visitor parking. The first set of data is the simulation results of the SAM model. Implementing the steps defined in the previous section generate the second sets of data files. The third sets of data are the hourly power productions for the visitor parking for the year 2012. The measured data file is available in the SAM website [18]. Now, the two sets of Excel files related to SAM and MPPT-On can be compared to the onsite data. Accuracy of the data reported by MPPT-On and how close the data is to the actual data demonstrate the effectiveness of MPPT-On and as a result validate it. The complete output reports and related files for the visitor parking can be found in the GitHub account: https://github.com/khof01/ontology

To project a better understanding of the results, we implement the t-test for the results comparing the application of MPPT-On on the SAM model with the measured powers collected onsite. To perform the t-test, the following processes are implemented:

I. The three sets of data, presenting hourly power productions for the 366 days of the leap year 2012, are made.

II. Hourly data with no power generations are removed from the data sets. We eliminate the data for nighttime hours, system shutdowns, and any type of system interruptions causing zero PV productions. It is crucial to notify that when the full shading is happened, the hourly results related to the MPPT-On and onsite are set as 0.1515 as stated for no productions in the SAM files (except with the negative sign). It is for separating no production results caused by night times, system failures, and full shadings. Full shadings should be included in the data.

III. The ratios SAM/onsite and MPPT-On/onsite are produced.

IV. For the shading hours of the six months of January, February, March, April, October, and December, the three sets of data are gathered.

V. The t-test is performed for each month representing samples of hourly results when shadings are occurred. The one tail t-test formula in Excel is used for calculating the results of the table, considering P= 0.05. We define that if null hypothesis is rejected, it is interpreted as significant differences between the forecast accuracy of SAM and MPPT-On.

As depicted in the t-test table (6-12), the p-value results for the month of February are significant due to the full shading predicted for high snowfalls. January and April also present a great amount of confidence for the MPPT-On results matching power measured onsite. Two months of October and December show p-values about 0.002 which can be considerably great results comparing to the p-value considered for the test (P=0.05). The month of March depicts the p-value about 0.0514 providing 94.85% possibility of similar results to the actual data when MPPT-On applied. This means that the application of MPPT-On adjusts the power estimations reported by the SAM model for the affected months considerably. Therefore, the proposed ontology improves the power estimations reported by SAM model by including power degradations due to snow coverings. In this manner, using the ontology model aids the user of the SAM software to obtain much accurate power estimations.

Table 6-12 T-test results for hourly productions affected by shading (NREL's visitor parking)

Month	Onsite	SAM	MPPT-On	Shading Hours	SAM/Onsite		MPPT-On/Onsite		P-Value	T-Stat.	T-Crit.
					Mean	ST. Dev.	Mean	ST. Dev.			
Jan	1723.96	9379.71	3170.1	62	749.039	739.846	219.765	398.229	0.0000	123.5354	2.0003
Feb	5280.98	48984.1	1646.24	279	1076.687	825.581	20.137	166.901	0.0000	560.1838	1.9686
Mar	3559.23	7188.54	2552.59	43	608.191	794.719	350.407	647.961	0.0516	44.5047	2.0195
Apr	136.82	8974.09	2347.8	44	0.99982	891.039	352.06	501.721	0.0000	138.4102	2.0195
Oct	740.63	3019.47	1072.11	19	382.029	538.092	5.635	13.604	0.0035	69.8505	2.1098
Dec	13253.1	13035.9	1012.84	94	358.603	563.295	70.542	257.996	0.0004	97.4540	1.9861

6.5.5 Providing Technical Information about the MPPT

The MPPT database, included as individuals in MPPT-On, provides technical information needed for the designed system. Applying one of the SWRL queries to extract information of an AI-based method (method22 in the database) introduces data related to the ANFIS MPPT method including the MPPT characteristics and definitions required for its implementation. Figure 6-23 depicts the SWRL rule of its result of presenting information related to ANFIS method. The MPPT-On ontology including the SWRL rules are available in: https://github.com/khof01/ontology.

It is a query to extract the technical information of Adaptive neuro-fuzzy inference System (ANFIS) MPPT method which is available in the proposed MPPT database. Figure 6-23 portrayed the rule S5 in MPPT-On_v6.1 about ANFIS technique:

- **Rule S5 (MPPT Method) – Characteristics of the ANFIS method**

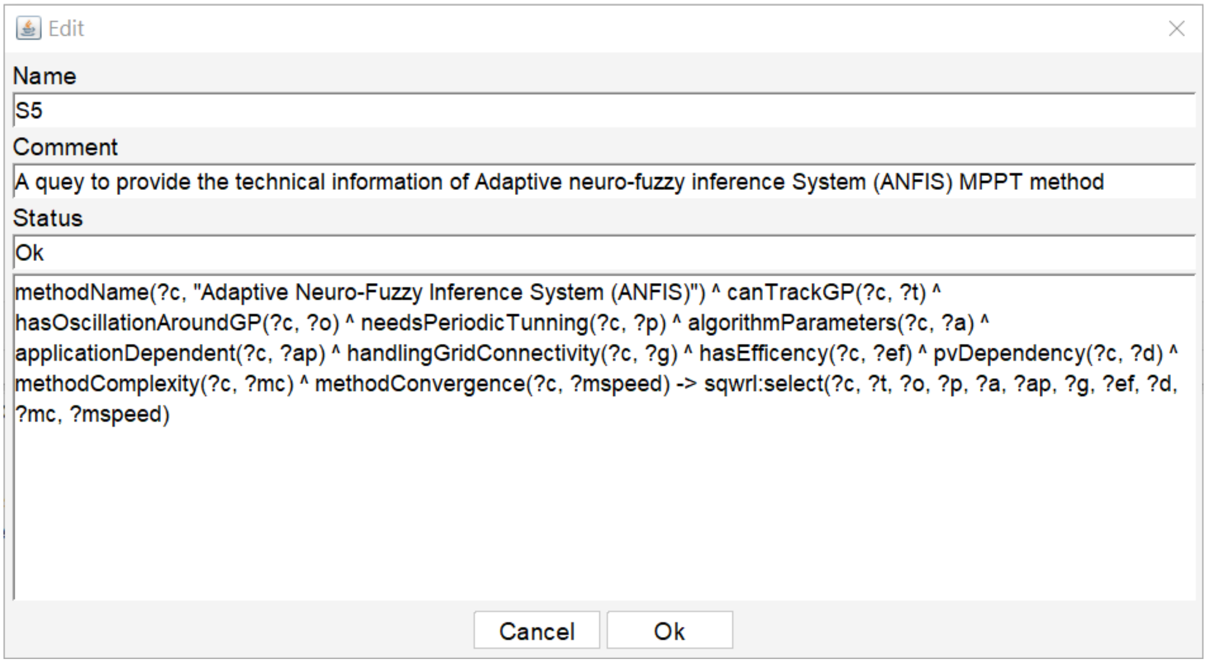


Figure 6-23 SWRL query and its result: information about the ANFIS method

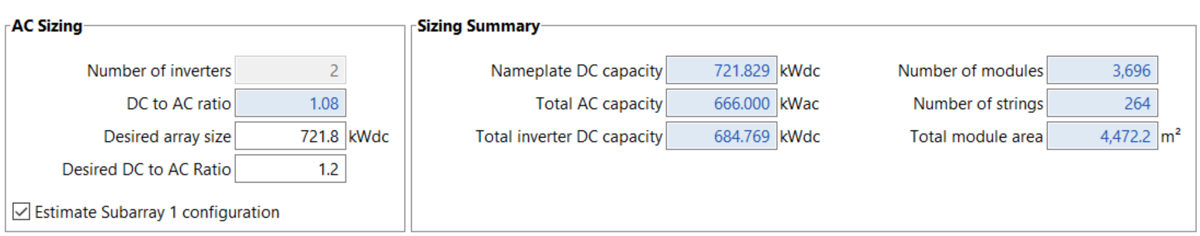
6.6 More Case Studies

To apply the proposed ontology for more case studies and assess its functionality, we use MPPT-On for 4 solar power projects for which NREL obtained their real data measured at the sites. These four case studies are in Golden, Colorado located at a latitude of 39.74° (N), a longitude of 105.18° (W), and an elevation of 1,829 m [165]. Onsite measured irradiance and meteorological data were used as inputs to SAM. In the following sections, the applications of two models including SAM model and MPPT-On are compared to the measured power production for each system. Finally, we show that MPPT-On corrects the power estimation reports provided by SAM model for each case study. Table 6-13 introduces these case studies and their total capacity. We use SAM model to simulate these projects and then analyze the snow data, the year that power outputs are measured onsite, for all projects for 2012. The analysis of the days of PV shading caused by snow are the same as what presented in the previous sections. However, we excluded two scenarios and only considered PV shadings for the days of snow. Weather data and solar irradiance inputs needed for locations of the PV projects (all cases located at Golden, CO) are downloaded from NSRDB. The complete simulations of the case studies can be found in ANNEX XII.

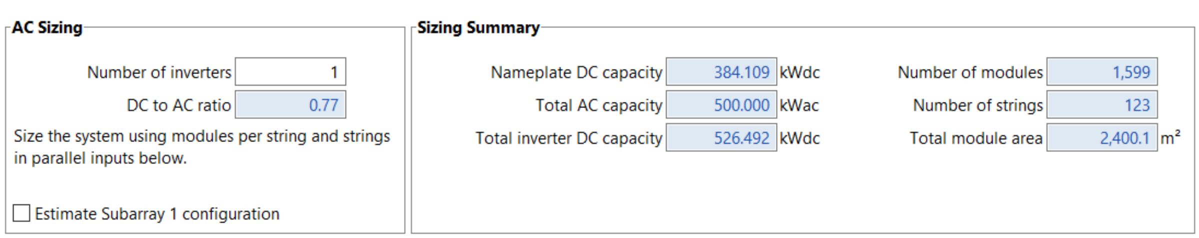
Table 6-13 More case studies and their specifications

Case Study	PV System
Mesa Top	The Mesa Top PV system is a 658-kW AC system installed on top of South Table Mountain nearby to the northwest of NREL's main campus. It produces about 7.2% of NREL's electricity needs with an annual energy production of about 1.2 GWh.
RSF1	The Research Support facility (RSF) 1 is a 385-kW AC system that sits on top of one of NREL's buildings, the RSF. The PV system includes two roof tops of the B and C wings.
RSF2	This is an expansion of the RSF1 building, a 408-kW solar array on the roof of the new A-wing building.
S&TF	The Science & technology Facility System (S&TF) PV system is a 75-kW AC fixed system installed on top of one of the NREL's research building.

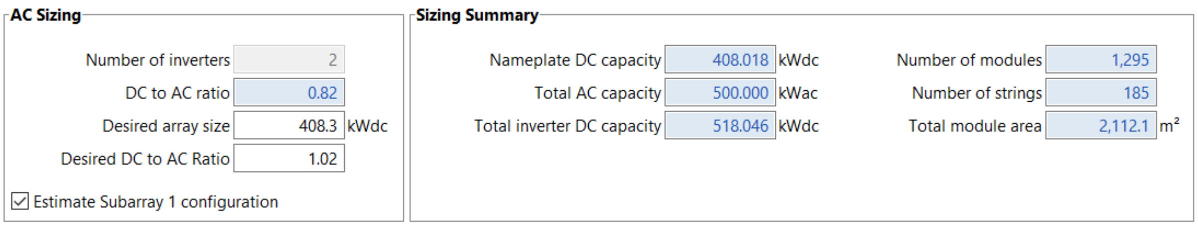
Using SAM model, we simulate these projects based on their specifications (Table 6-14). Figures 6-24 (a) – (d) present technical characteristics of the PV systems designed for Mesa Top, RSF1, RSF2, and S&FT.



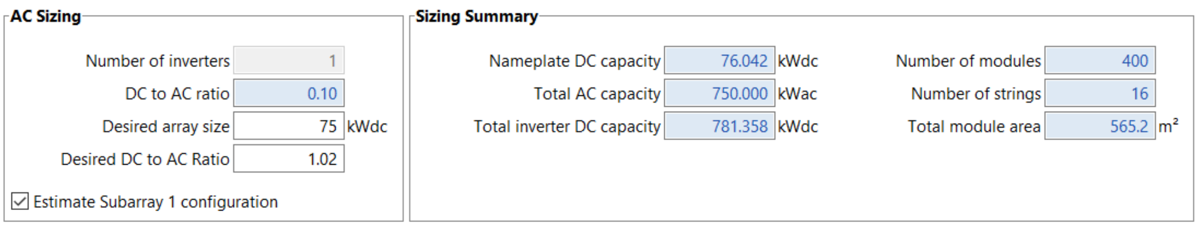
(a): Mesa Top



(b): RSF1



(c): RSF 2



(d): S&TF

Figure 6-24 SAM results: system design summaries for the PV projects

Power estimations and output reports of the simulations are downloaded in Excel files. Power generations estimated by SAM present productions for every single day of the year. However, each one of PV system might experience system shutdown or outage. We need to review the PV system operations to detect any system failure occurred during the year. This attempt eliminates unexpected errors comparing SAM results with measured data obtained onsite, and consequently the application of MPPT-On. Therefore, we take the followings steps for using MPPT-On for adjusting power estimations reported by SAM:

I. Reviewing ambient conditions at the PV sites (Golden, CO)
II. Identifying shading source(s) and the relationships with other environmental factors
III. Identifying the days that the PV system are affected by the shading in the Excel file report
IV. Eliminating power generation data from the Excel file in the days that no power is produced due to the system shutdown or inverter outage
V. Finding the related rules in the MPPT-On that offer information about power corrections

VI. Applying the correction factor(s) to the days that PVs operate under shading in the Excel file

The produced Excel file provides power generations representing more accurate results. In this way, PV operations under shading are taken into account. The application of MPPT-On for each project requires implementing the steps outlined in the previous section. Rules 28 and 29 of the ontology are applied, defining correction factors for snow depths more than and less than one inch (section 6.4.2.1, P129). The level of accuracy desired from the ontology determines how precise we review environmental factors and assess shading conditions of the PV site. Mesa Top, RSF1, RSF2, and S&FT are in the same location of NREL's visitor parking which has been used for the validation of MPPT-On. Therefore, the effect of snow coverings is assessed as the only source causing shadings.

Table 6-14 Days of snowfalls (PV shading) in Golden, CO, in 2012

Month	Snowy Days and the Snow Depth
Jan	[(7-10) & (11-12)] > 1" - (17-18) < 1"
Feb	[(3-22) & (23-25)] > 1"
Mar	N/A
Apr	[(2-3) & 13] > 1"
Oct	(23-24) > 1"
Nov	(10-11) < 1"
Dec	[(18-21) & (23-30) > 1"] – 10< 1"

In table 6-15, the results of the SAM models and the application of MPPT-On for the four case studies can be compared. These PV systems are Mesa Top, RSF 1, RSF 2, and S&FT 1. As shown in the table, the applications of MPPT-On for the case studies improve the SAM results.

Table 6-15 Actual and forecasted production, with forecast accuracy and improvement for the case studies

Project	Onsite	SAM	MPPT-On	SAM/Onsite	MPPT-On/Onsite	Improvement
Mesa	418668.000	576848.810	428213.560	1.378	1.023	35.5%
RSF 1	161507.930	200368.524	146141.337	1.241	0.905	33.6%
RSF 2	202617.840	298873.773	210406.636	1.475	0.704	77.1%

S&FT 1	46074.000	54918.146	47569.808	1.192	1.032	15.9%

6.6.1 Replication of Validation by Third Party Participant

In this section, we asked a third-party participant to test the application of the proposed model, MPPT-On, to check whether the ontology validation performed by us. The third party was a third-year electrical engineering student. In our discussion for choosing a case study, we decided to employ MPPT-On for a case study with real data that provide hourly power productions in a year. NREL provides 9 PV case studies for which measured performance data are available for the community to be used [165]. The systems consist of three utility-scale (greater than 10 MW) systems and six commercial-scale systems (75-700 KW). Onsite measured snow data for the year 2012 can be used as inputs for these projects. One important advantage of using these PV systems is that if there is any system failure or an outage, it is reported in the project description provided by SAM [165]. The NREL's visitor parking PV system has been already used for the ontology validation. Therefore, we focus on the projects listed in table 6-13. Among the case studies, that have been already used in this paper and validated by others [131, 165], we selected RSF 1 as the case study to be tested by the participant. The items below introduce other projects that could be validated. Each PV project is described.

- **Mesa Top**

The Mesa Top PV system is described as a 658 (kW) AC one-axis tracking system with backtracking which was installed in 2008 on top of South Table Mountain, northwest of NREL's main campus. The commercial-scale PV system and was selected at first as the case study for testing. However, after reviewing project characteristics and specifications [165] reveals that there were significant errors at the hourly time scale. Further investigation of this error indicated an issue with SAM bracketing/shading algorithm for one-axis trackers. " The error in SM's bracketing/shading algorithm caused results to be identical to those for a system that did not have any row-to-row shading (due to the rows being sufficiently spaced to reduce this shading to zero)" [165]. Thus, we decided to review other case studies including RSF 1 & 2 or S&TF.

- **S&TF 1**

The Science & Technology Facility system is a 75 (kW) AC fixed PV system that was installed on top of NREL's research buildings. This is a small system barely can be considered as commercial-scale PV system. SAM model may significantly under-estimate energy productions for warmer months and over-estimate if various values of a small-scale project. There is another problem in our case attempting to test the same PV system. SAM model needs almost identical values for various parameters for non-commercial PV systems. This issue affects our two separate attempts for planning the same case study. In this case, choosing unlike PV modules or inverters and their parameters can provide different power output reports.

- **RSF 1**

The Research Support Facility 1 solar array system is a 385 (kW) AC fixed system installed on the roof top of two buildings known as the B and C wings of the NREL research buildings. The full system includes two separate systems sitting on the two buildings. The measured data is based on these two systems. Planning a system consisting of two separate PV systems potentially create problems for defining different values needed during the SAM models.

- **RSF 2 (selected for testing)**

NREL installed a 408 (kW) PV system on the roof of the A-wing building, as part of the building's Leadership in Energy and Environmental Design (LEED) platinum certification. This characteristic and its commercial-scale power generation make this project as a perfect choice for our testing. It can be simulated by SAM model, and its specifications including the system shutdown and inverter outage are presented in [165]. Therefore, Research Support Facility 2 (RSF 2) was selected as the case study. Based on the climate conditions and environmental factors stated for the location of Golden, Co, where the RSF 2 is installed (refer to section 6.4), we consider 7 months for our evaluation. From January to April, October, and

December, it is expected that the PV system of the RSF 2 power plant experience shading conditions due to snow coverings.
It is important to notify again that the full shading due to heavy snowfalls results in no power production. Therefore, the concerning SWRL rules recognized from the ontology are rules 28 and 29 (the full descriptions of the rules were presented in the previous sections.):

- Rule P28 (Shading Condition 26) - snow depth > 1” (Figure 6-22, section 6.4.2.1, P129)
- Rule P29 (Shading Condition 29) - snow depth < 1” (Figure 6-23, section 6.4.2.1, P129)

6.6.1.1 The SAM Simulation and Results Obtained by the Participant

The RSF 2 case study has been modelled by us previously in section 6.5.4. Figure 6-25 portrays the system designed for the project using SAM model. PV module and inverter selected for the system are presented in ANNEX XII. Although technical characteristics of the designed system performed by us is unlike the one simulated by the participant, power generated by both systems are alike, 408 (kW).

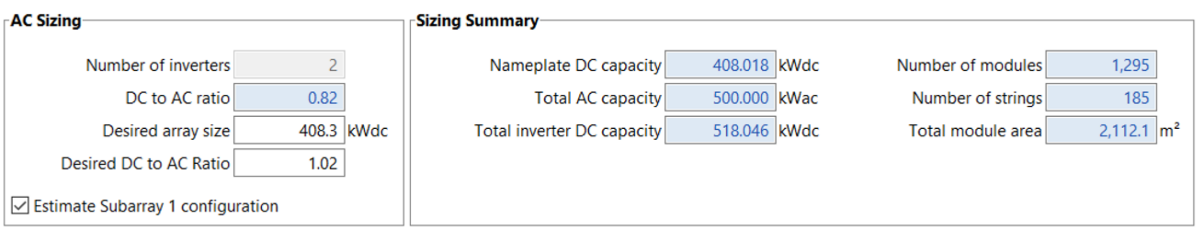


Figure 6-25 Technical characteristics of the RSF 2 designed in SAM (performed by us)

The RSF 2 PV system has been simulated by the participant using the SAM model. Technical characteristics of the PV system designed is depicted in the following figure (6-26). PV module and inverter selected in the simulation are provided in ANNEX XIII.

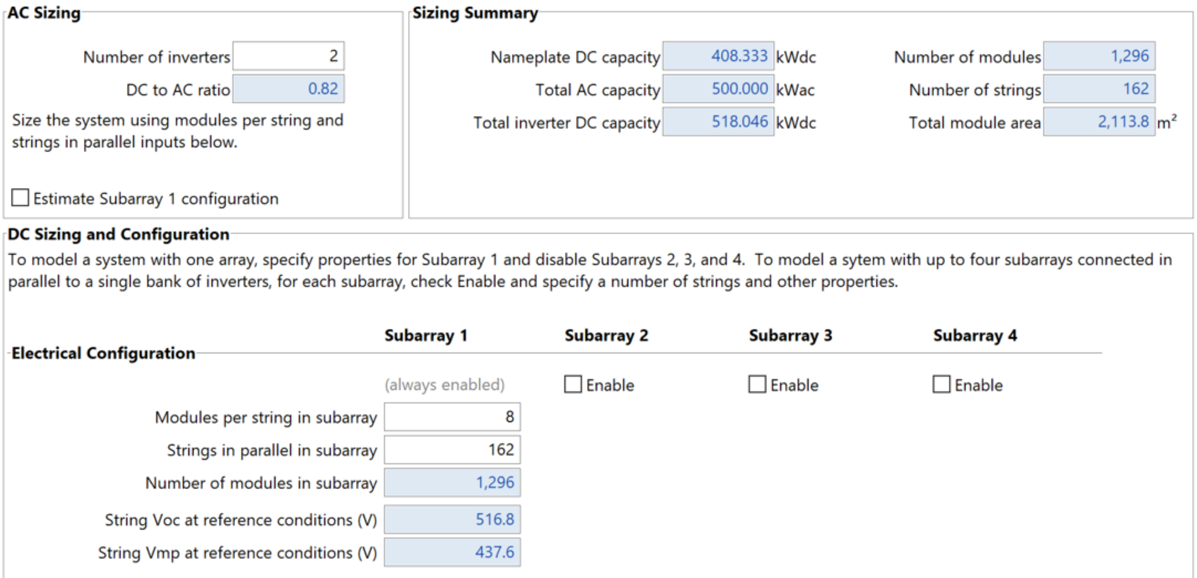
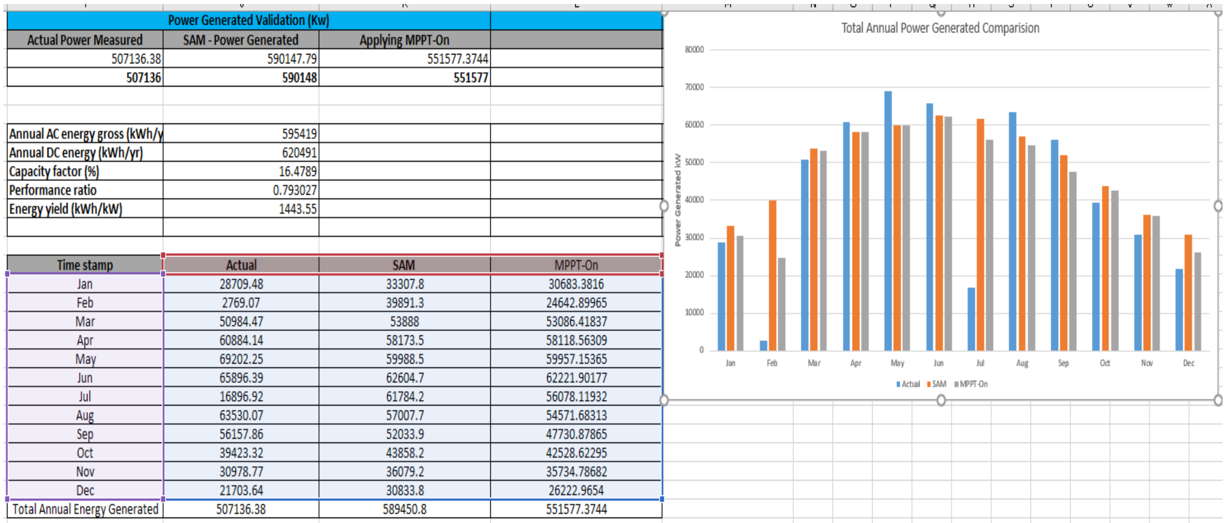


Figure 6-26 Technical characteristics of the RSF 2 designed in SAM (performed by participant)

Hourly data results of three approaches performed by the third-party user are presented in ANNEX XIII. The monthly power outputs reported by the three approaches are used for the statistical analysis later in the next section. Herein, we examine the six months of cold climate as the same as NREL's visitor parking. Table 6-16 presents the monthly power productions reported by the three systems for the six months that PV modules operate under shading conditions caused by snowfalls. As observed, there are substantial improvements for power estimations provided by SAM especially for snowy months of December and February. A snapshot of the Excel file containing power generations reported by the three approaches is depicted in figure 6-27.

Table 6-16 Third-party participant results for the RSF 2 case study for 7 months of PV shadings

Month	Onsite	SAM	MPPT-On	SAM Report	MPPT-On Improvement
Jan	28709.48	33307.8	30683.38	116% overestimation	9.14%
Feb	2769.07	39891.3	24642.9	1440% overestimation	550%
Mar	50984.47	53888	53086.42	105% overestimation	1.6%
Apr	60884.14	58173.5	58118.56	4.46% underestimation	0.09%
Oct	39423.32	43858.2	42528.62	111% overestimation	3.37%
Dec	21703.64	30833.8	26222.97	142% overestimation	21.2%



Power Generated Validation (Kw)			
Actual Power Measured	SAM - Power Generated	Applying MPPT-On	
507136.38	590147.79	551577.3744	
507136	**590148**	**551577**	

Annual AC energy gross (kWh/y	595419		
Annual DC energy (kWh/yr)	620491		
Capacity factor (%)	16.4789		
Performance ratio	0.793027		
Energy yield (kWh/kW)	1443.55		

Time stamp	Actual	SAM	MPPT-On
Jan	28709.48	33307.8	30683.3816
Feb	2769.07	39891.3	24642.89965
Mar	50984.47	53888	53086.41837
Apr	60884.14	58173.5	58118.56309
May	69202.25	59988.5	59957.15365
Jun	65896.39	62604.7	62221.90177
Jul	16896.92	61784.2	56078.11932
Aug	63530.07	57007.7	54571.68313
Sep	56157.86	52033.9	47730.87865
Oct	39423.32	43858.2	42528.62295
Nov	30978.77	36079.2	35734.78682
Dec	21703.64	30833.8	26222.9654
Total Annual Energy Generated	507136.38	589450.8	551577.3744

Figure 6-27 Screenshot of the Excel file representing results for the three system (performed by the participant)

6.6.1.2 Comparison of Results

The participant used the SAM model for simulating the case study, and similar to the research approach of validating NREL's visitor parking, MPPT-On was employed on the results of SAM. The following steps were taken by the user to testify the ontology model:

I. Three sets of data, presenting hourly power productions for the 366 days of the leap year 2012, are made.

II. Hourly data with no power generations are removed from the data sets. We eliminate the data for nighttime hours, system shutdowns, and any type of system interruptions causing zero PV productions. It is crucial to notify that when the full shading is happened, the hourly results related to the MPPT-On and onsite are set as 0.1515 as stated for no productions in the SAM files (except with the negative sign). It is for separating no production results caused by night times, system failures, and full shadings. Full shadings should be included in the data.

III. The ratios SAM/onsite and MPPT-On/onsite are produced for the shading hours of the six months of January, February, March, April, October, and December, the three sets of data are gathered.

IV. The t-test is performed for each month representing samples of hourly results when shadings are occurred. The one tail t-test formula in Excel is used for calculating the results of the table, considering P= 0.05. We define that if null hypothesis is rejected, it is interpreted as significant differences between onsite the forecast accuracy of SAM and MPPT-On.

Implementing these steps presents the results depicted in table (6-17). As observed, the p-value results for every month with snowy days are significantly lower than P=0.05. In fact, the null hypothesis of significant differences between two ratio results are rejected for the six months affected by snow. The p-value results for the months of February and December demonstrate that MPPT-On corrected the power estimations almost alike the actual power measured onsite. This is because of the full shadings predicted for many days in these two months. March also presents a great amount of confidence for the MPPT-On results matching power measured onsite. The three months of January and October show p-values about 0.0005 and lower which can be considerably great results comparing to the p-value considered for the test (P=0.05). The bigger value in the table belongs to the month of April presenting the p-value about 0.0078. Although this value is not as significant as the other months, it still represents a confident estimation provided by MPPT-On.

Table 6-17 T-test for simulation results performed by the participant

Month	Onsite	SAM	MPPT-On	Shading Hours	SAM/Onsite		MPPT-On/Onsite		P-Value	T-Stat.	T-Crit.
					Mean	ST. Dev.	Mean	ST. Dev.			
Jan	2346.99	5288.22	3240.35	47	389.811	563.468	102.209	203.819	0.0009	71.1807	2.0141
Feb	39.54	36731.67	39.54	261	928.94	617.641	1	0	0.0000	603.2145	1.9692
Mar	6.36	7445.67	3209.13	42	1170.151	696.999	504.342	674.913	0.0000	116.4960	2.0211
Apr	813.64	5539.34	2421.99	36	508.18	739.11	164.97	380.36	0.0083	61.5466	2.0322
Oct	2056.65	7800.98	4743.43	70	498.724	614.903	153.51	388.561	0.0006	91.1773	1.9955
Dec	4054.73	11572.01	853.34	105	504.572	530.747	1.501	7.242	0.0000	222.2475	1.9833

Sizing summary of the PV system designed for RSF 2 (Figure 6-26) and additional components of the system (ANNEX XII) clarify that our design is unlike the system designed by the participant. Therefore, the final system produces unlike power generations. Comparing two tables demonstrates a better result for the third-party user when MPPT-On applied, only 4.3% overestimation for the total annual power comparing to our results (6.6%). The reason is that our SAM model designed a PV system with a greater annual power generation. As a result, its deficiencies in the hourly power productions are larger than what the user modelled. In fact, precise simulation for the PV system like the actual system makes the results of applying MPPT-On more accurate. However, the main objective of the test is accomplished, showing that the application of MPPT-On improve the power estimations of SAM model by taking into account snowfalls data.

CHAPTER 7 CONCLUSION

In this work, we have proposed an ontology model (MPPT-On) that connects two interrelated sets of semantics with a logical base of SWRL rules. The ontology reasoning assists end-users to deal with non-trivial processes involved in planning efficient PV systems operating under shading conditions. MPPT-On has been developed and validated using a real-world solar power plant project as a case study (NREL's visitor parking).
The validation of the model depicts the following achievements:

I. The application of MPPT-On significantly improves power estimation reports provided by SAM model, including the impacts of snowfalls.

II. Using SQWRL queries the impacts of several airborne particles and tilt angles on PV performances are defined in the ontology.

III. MPPT-On, as a knowledge-based model, represents information needed for planning an efficient PV system including MPPT methods and shading conditions. Information about the methods contains parameters of the control system, algorithms, characteristics, and related attributes. In the case of shading, the cause of shading and factors affecting it are represented in the ontology. Further, these relationships can be visualized and observed through graphical plug-ins in Protégé.

IV. Valuable planning and designing recommendations in form of SQWRL queries can be extracted from MPPT-On.

The subsequent sections highlight several aspects concerning the research study.

7.1 Advantages of the Ontology Methodology

Moving from data processing to concept processing can be considered as a semantic concept rather than data analysis. Computer science and artificial intelligence research also required a language capable of modeling disparate knowledge with different sources from distinct domains. This fact will fulfill the objective of this research for creating a decision support system interconnecting various sources of information and data. Thus, ontology has been arisen as the most powerful machine processable language for representing domain knowledge. Ontology allows a model to represent data and information with various repository and perform rules to support context-aware systems. Constructing a knowledge base model lead us to utilize ontology engineering and technologies. Using ontology also enables the model to deal with complex data forms, regardless of the sources. We need a model that understand logic of the context and can extract various information from distinctive resources. In our research, this feature helped us to provide potential alternatives and solutions to design a PV system efficiently and plan the project effectively in the model. The followings indicate benefits of using ontologies instead of databases:

I. Ontologies provide a common terminology that is independent to the application of the domain they represent. Besides, the application-independent characteristic of the model allows it to be utilized in different applications. This feature is especially crucial for the purpose of this research where various concepts about the designing and planning of a PV system are involved in the power conversion. In this case, shading conditions require contextual information and weather data about the PV project and the system itself.

II. Ontology models provide inference capabilities for consistency checking. This advantage of ontology-based solutions is especially suitable for a decision support model when trying to categorize the effects of a new environmental factor on shading into an existing class of components. It means that the proposed model can be improved, and new concepts can be added to its classes after building the ontology model.

III. Using Protégé enables us to create a model and collect information. Its application can help to design a system or artifact. Protégé emphasises on a model, whereas in a database, the data is important. Protégé provides richer modeling language that leads to inheritance relationships expressing a web of relationships. In contrast, a database provides a simpler modeling language which is optimized for speed.

7.2 Fulfilment of Research Objectives

As described, the goal of the research is to deliver an ontology model to support the decision-making process in planning PV projects. The model aims to include all essential parameters and factors influencing the design, and consequently the planning. The proposed model offers the access to state-of-the-art domain-specific knowledge needed to deal with power efficiency in solar sector. MPPT-On represents the knowledge base of MPPT methods and includes information required to achieve maximum possible power under shading conditions. Thus, the model describes various characteristics of the shading subject matter. These are presented in the forms of OWL class axioms and their characteristics are defined as objective properties and data properties. Moreover, technical attributes of an MPPT-based controller are specified in the ontology allowing PV planners and practitioners to define various parameters. The rule-based ontology model offers potential solutions to multi-domain nature of planning solar energy projects specially for the design options considering maximum efficiencies. The reasoning framework presents a rule-driven system for collecting information and choosing appropriate parameters needed for the planning.

The application of the proposed ontology was tested with a case study, where power estimations of the designed system were compared with the values of power measured. The power estimations were adjusted using the ontology model. The analysis of the results indicated that MPPT-On could make some levels of corrections (about 15% to more than 200%) depending on the month of the productions. Moreover, SQWRL queries could deliver output reports describing technical characteristics of the MPPT technique used in the control system and several parameters correlated to its algorithm.

7.3 Research Contributions

To manage the research project, we defined several processes throughout the project phases describing the research activities and the fields of studies. The proposed ontology model was developed as the deliverable artifact fulfilling objectives of the research project. The purpose of developing an ontology model was to assist non-technical practitioners employing PV planning tools. The goal has been to create a framework that provides technical information to the users for planning an efficient PV system. We designed an MPPT database that contains important characteristics of dominant MPPT techniques. The database includes attributes of many techniques and can be utilize in any PV planning software. Throughout the research project, we focused on research studies related to MPPT and planning PV systems. The followings are the main findings:

I. MPPT-based control system and the technical specifications

We found that parameters of searching functions in metaheuristic algorithms can be adjusted easily by setting up a few specific features and parameters of the controller implementing the algorithm. Changing input patterns of a simulation could alter the efficiency results of a PV system implementing an MPPT algorithm. In a published paper, we showed that applying three unlike irradiance patterns with different alterations generated three dissimilar efficiencies, even with the application of an identical MPPT method. It was argued that the PV system efficiency can be assessed higher if input patterns modelled with less alterations. This problem addresses uncertainties associated with the simulation and modeling a PV system. Although the direct outcome of this fact is not alongside with the research objectives, it demonstrates the technical difficulties in designing an MPPT-based controller and selecting an appropriate MPPT method. We addressed the important technical features of an MPPT-based control system in the ontology model. These parameters were defined as the data properties in MPPT-On. Moreover, we argued that MPPT control systems as crucial hardware components of any designed PV system need to be added in databases of PV planning tools as the same as PV modules and inverters already included in most applications.

II. Ambient conditions (containing shading, environmental, and climate changes)

When constructing the knowledge base model, we elaborated semantics of ambient conditions in a way that allowed us to categorize important elements. These elements such as dust, pollution particles, and climate conditions assisted us to outline factors affecting power productions in different environmental status. In our perspective, ambient conditions were not limited only to shading conditions.

III. Weather databases and data libraries in PV planning tools

Searching for important concepts informed us that polluted articles and snow databases are not included in data libraries of most planning tools. The main reasons of losing power in a PV system including clouds, pollutions, and snow were overlooked. Although a few planning tools calculated the effect of soiling and the related DC losses. We claimed that the planning applications need to add cloud, pollution, and snow data in the forms of databases to their data library.

IV. PV planning Software

The output reports of a PV planning program contain numerous AC and DC power estimations as well as the system sizing showing that includes components and their technical properties. Depending on the level of expertise provided by the planning tool, the application of MPPT may be comprised in the designed system. However, technical features of the control system are not specified in the output reports. In fact, it is known as a part of the inverter. In our approach, we proposed a decision system presenting an output report that included MPPT controller and its technical features. In this manner, the designed system was provided in a complete setup.

7.3.1 Significance

We claim that the research methodology and the technology used offer valid solutions for planning windfarm projects, in both research and practice. MPPT methods are implemented in the control systems of wind turbines. Also, SAM software provide system design for planning windfarms. Thus, the use of MATLAB for MPPT simulations, the semantic platform proposed in Protégé, SWRL rules, and SQWRL for rule-based can be employed for a similar decision support system (DSS) in wind energy sector. Furthermore, the implemented activities in different layers of the proposed (DSS) framework (Fig. 3-6, P62) can be used for many applications dealing with engineering design and project planning software tools.

Planning and designing PV systems are two distinctive fields of research that requires different knowledge areas. A solar power plant project is planned and implemented by project management team applying project management approaches throughout the project phases. Initial and planning phases of the project are when planning software tools are used. The proposed ontology model can be employed as an additional tool for educating the project team with recommendations, suggestions, and corrections offered by MPPT-On. The convenience of using the model enables planners to obtain several planning reports with respect to different system design configurations. Furthermore, graphical representation and visualization of the model that illustrate relationships of various parameters ease the project communication. Respecting the PV system design, the model provides additional information related to the location, geographical databases, and ambient conditions that may aid engineers to adjust the system design and change its configuration.

7.4 Limitations

The proposed model has been evaluated with six case studies. One might argue that the proposed model could be tested for more case studies. The fact is that the functionality of the ontology is based on the defined rules instead of technicality or characteristics of PV projects. The ontology provides accurate recommendations and adjustments based on the rules that has already been acquired and investigated in academic literatures. It means that the application of MPPT-On for any projects located in the same climate, regardless of technical parameters of the designed system, provide valid results. Thus, defining valid rules indicating power reductions will result in correct outputs. The only concern is that the ontology user should pay attention to enter correct information about the weather data and shading conditions that affect the solar panels in a PV system. Therefore, there is no setback or failure when the proposed model is employed. The proposed model has been created according to scientific papers and a few assumptions with regards to weather data. However, there are a few factors that might limit the functionality of MPPT-On. The limitations are related to the temperature, other ambient elements, the availability of snowfall data, and the reliability of weather databases.

The research context concentrates on the MPPT knowledge area, so that shading conditions are the main reason for the MPPT application. We have focused on the shading conditions caused by various objects instead of the element of temperature and its characteristics. It means that the role of the temperature in MPPTs are not investigated. Therefore, alterations in PV productions caused by snowfalls in different temperature are not considered in the study. Nevertheless, this limitation cannot degrade the functionality of the proposed model as the significant factor affecting the PV productions is the irradiance not the temperature.

Another constraint for applying the developed model is the possible lack of accurate information that could be used for more case studies. The roles of other airborne particles defined in the model could not be challenged because the case studies were located in a safe environment with a minimum degree of ambient conditions.

While snow databases are not available for most geographical locations, it would be difficult to use the SWRL rules and the queries. In that case, MPPT-On needs more information regarding weather databases. The user of the model should provide accurate and valid data to the ontology. Also, the characteristics of snowfalls its physical behaviour are not investigated in the model. The defined SWRL rules address the situation where precipitations are significant. However, in some cases where snowfalls are scattered, less than two inches and light, effects of snow coverings may not pose any significant shading conditions. Based on the actual results of the power productions, the latter term cannot affect the model (the power reductions are considerably low when snowfalls are scattered).

The meteorology data used in PV planning tools are assumed to be accurate and reliable. Power output corrections presented by MPPT-On depend on meteorological data that is used by the planning tool. However, other recommendations and suggestions dealing with the control system can still be effective and reliable.

Finally, there is an important technical requirement that can be perceived as a limitation for using the proposed model. The user must be familiar with the environment of Protégé and running a SWRL rule and a query. MPPT-On is not performing any function by its own and requires a user to apply the rules. Moreover, the user needs to manipulate the power production database and the results reported by the PV planning tool.

7.5 Future Research

The results of this study present that accumulations of environmental particles due to pollutions and its related impacts on PV performances have been overlooked in most research studies concerning MPPT. However, nowadays many PV installations are in the urban environments where polluted particles generate lots of shadings for solar modules. There is a need for integrating pollution databases to PV planning software tools. As proposed in the paper, an MPPT database containing technical attributes of the control system can assist PV system designers and planners to analyze the entire system effectively. Adding such a database and determining its characteristics is an area of research in the context of PV planning.

Another future research area can be pursued in the field of ontology design. A reference framework for building a knowledge base model can help engineers to create more semantic models. Collaborations between these knowledge base models, and AI also improve functionality of AI models. It helps to include linguistic data and knowledge management in ontology models. Hence, using ontology engineering to improve AI techniques can be defined as a valuable research work.

In addition to previous domains, PV planning/designing software is perceived as a research worthy subject. The quality assurance of a PV planning tool guarantees the accuracy of the energy calculated by the software. Defining key performance factors and properties associated with planning tools aid researchers to measure quality of the software products. The metrics qualifying the system performance can be measured by using series of standards. These metrics are considered to construct a framework for the product quality evaluation. Different methods are used to analyze qualitative data that describes the functionality of a PV planning software. Further, validating different quality characteristics requires to define quality benchmarking and quality models. Therefore, identifying quality measures and metrics needed for evaluating the quality of PV planning software can be a valuable area of research.

ANNEX I. The List of Investigated PV Planning Tools

1. https://sam.nrel.gov/
2. http://pvwatts.nrel.gov/
3. https://github.com/mpaolino/pypvwatts
4. https://github.com/mattetti/Pvwatts
5. http://www.rubydoc.info/gems/pvwatts
6. https://github.com/nrcharles/solpy
7. http://solpy.readthedocs.io/en/latest/
8. https://www.aurorasolar.com/features
9. http://www.pvsyst.com/en/
10. https://www.solardesign.co.uk/
11. http://www.mauisolarsoftware.com/
12. https://www.valentin-software.com/en/products/photovoltaics/57/pvsol-premium
13. http://www.laplacesolar.com/photovoltaic-products/solar-pro-pv-simulation-design/
14. https://sourceforge.net/projects/rapsim/
15. http://ieeexplore.ieee.org/document/6873803/
16. https://www.homerenergy.com/homer-pro.html
17. https://www.nrcan.gc.ca/energy/software-tools/7465
18. https://en.wikipedia.org/wiki/RETScreen
19. http://www.nrcan.gc.ca/energy/software-tools/7417
20. http://www.trace-software.com/archelios/photovoltaic-pv-software/
21. https://www.electrographics.it/en/products/solergo.php
22. http://gascad.at/en
23. http://www.velasolaris.com/english/home.html
24. https://us.sunpower.com/sites/sunpower/files/media-library/white-papers/wp-pvsim-solar-energy-system-performance-modeling.pdf
25. http://www.etu-software.com/M/SOFTWARE/Renewables-Simulation/PV-Simulation/Seite.html,154165,96655

26. https://www.solarschmiede.de/en/pvscout-20-premium
27. http://photovoltaic-software.com/pvgis.php
28. https://sundat.ftcsolar.com/
29. http://freegreenius.dlr.de/
30. http://www.dds-cad.net/products/dds-cad-pv/
31. http://www.fchart.com/pvfchart/

ANNEX II. The Questionnaire

I) Partial Shading Conditions (PSCs)

Shading conditions and various related factors, affecting a PV system efficiency, are the purpose of this question group.

1. Is the effect of partial shading conditions (PSCs) considered in your PV system design?

2. Which external factor(s) is (are) included in the design? [Snow, Ice, Dust, Temporary objects (trees, buildings...), Pollution-related particles, Clouds, Other]

3. Do you consider the physical properties of the particles causing shading conditions? (for instance: size, shape, and weight of particles)

4. Which external factor(s) do you think affect the efficiency of the PV system the most? [Snow, Ice, Dust, Temporary objects (trees, buildings...), Pollution-related particles, Clouds, Other]

5. Do you use the same PV model for PVs under uniform and partial shading conditions?

6. Do you apply specific irradiance patterns to model the PSC?

7. Do you calculate the overall efficiency for the PV system?

8. Does the irradiance input used for the simulation represent real-world shading conditions? *

9. Do you have any recommendation or suggestion concerning PSCs?

II) PV System Modeling and Simulation

As an electrical circuit model enables a PV system designer to predict variations of *I-V* and *P-V* curves to the ambient conditions and environmental factors, this question group focus on PV system modeling and simulation.

10. Which simulation or modeling tools do you use? Please briefly explain why.

For instance, MATLAB, PSpice, …

11. Does the configuration of PV arrays affect your PV system model?

12. Which PV cell model is used in the simulation? [Ideal diode model, Single diode model, Single diode-Rs model, Single diode-Rp model, Two diode model]

13. Do you involve weather databases for modeling the system?

14. Do you apply the same shape, pattern, and variation for the input variables of your model (temperature and irradiance) regardless of environmental conditions?

It is being asked to determine whether your model simulates the input variables based on the weather data related to the location of the PV system or you apply a pre-simulated pattern for all applications.

15. What ambient condition(s) is(are) considered in the model? [Cloud, Wind speed, Wind direction, Humidity, Shading conditions, Other]

16. Do you determine the technology type of the PV used in the model?

17. What type(s) of technology is(are) defined in your design? [Mono-crystalline, Poly-crystalline, Amorphous, Thermal, Smooth surface, Sticky surface, Other]

18. Do you apply site locations in your design?

19. Do you have any recommendation or suggestion about PV system modeling and simulation when selecting an appropriate MPPT?

III) MPPT Approaches

Maximum Power Point Tracking (MPPT) methods are developed to overcome impacts of PSCs on PV system performances.

20. Is an MPPT method used in the design?

21. Which MPPT classification is chosen? [Perturbation and Observation (P&O), Fuzzy Logic (FL), Artificial Neural Networks (ANN), Hybrid methods, Meta-heuristic algorithms, Other]

22. Do you consider PV system architecture when chosing an MPPT method?

23. Which PV characteristic(s) is(are) involved in your design when selecting an MPPT method? [PV tilt, PV type (mono-crystalline, poly-crystalline, amorphous), PV surface material, PV surface glazing, PV angle, Other]

24. In your opinion, which parameter could be considered as the most important factor when choosing an appropriate MPPT method? [Efficiency, Periodic tuning, Detecting PSCs, Convenience, Fast convergence, Application-independent, Cost-effective, Less oscillation around maximum power point, Other]

25. What is(are) the control parameter(s) in your design? **[**Duty cycle, Voltage, Current]

26. What is(are) the reference factor(s) in your design? [Voltage, Current, Duty cycle, Other]
27. What is(are) the sensed parameter(s) in the PV control system? [Voltage, Current, Other]
28. Do you determine the type of microcontroller used in the simulation?
29. Do you have any recommendation or suggestion about MPPT approaches, algorithms, etc.?

ANNEX III. Consent Form & Déclaration éthique acceptee

1. **Invitation:** The purpose of this form is to solicit your participation in the abovementioned research, which aims to develop an ontology model used for the decision-making process of MPPT when dealing with power management in PV systems.
2. **Objectives:** In this work, an MPPT ontology-based model, named MPPT-On, is presented offering access to the state-of-the-art information needed to design an efficient PV system. This system aids non-technical end-users to cope with non-trivial processes associated with PV system design. The proposed ontology involves: 1) ambient conditions and environmental factors, 2) important factors associated with PSCs in modeling a PV system, and 3) requirements of an appropriate MPPT method.
3. **Survey:** Your participation in this research project consists of completing a 2-question survey in three groups.
4. **Confidentiality:**

4.1. The list of participants and all data collected during this study are entirely confidential, and it will not be possible to identify participants from research results.

4.3. We may mention in our future publications some information concerning the sector and/or role in which you operate.

4.4. If we want to report nominative information, we will make this request to you by email, and will invite you to revise and approve which information we have the right to publish or not. You shall have the privilege to retract information at any time before publication.

5. **Publication of Results:** Our research results will be published as part of a doctoral thesis, in academic journals in the form of articles addressing one or more components of success factors, in a book integrating all our results, on our eventual web site as synopses of our articles and books, and as academic and professional conferences, where we will report briefly on our ongoing research.
6. **Data Protection:** The data collected will be kept in our personal computers under pass-word protection. The only persons with access to this data are the doctoral student and his thesis director. No other person will have access to this data.

7. Voluntary Participation: Your participation in this study is completely voluntary, it will be on an anonymous basis and all information shared will remain confidential at all time. You are free to participate, and you can withdraw from it at any time without prejudice. Duration of the survey is between 10-15 minutes.

8. Risks and Benefits: There are no risks associated with your participation, all information and discussions are anonymous and remain confidential at all time. The contribution to the advancement of knowledge in the application of emerging technologies for cost reduction is the direct benefit anticipated. No monetary compensation will be provided.

9. Contact information of the researcher: If you have any questions about this research or further data to provide, you may contact the researcher:

Farhad Khosrojerdi, Ph.D. Candidate in Computer Science, Department of Engineering and Computer Science, Université du Québec en Outaouais, khof01@uqo.ca

10. Contact Information of the Supervisor: If you have any questions about this research project, you may also contact the thesis director:

Mr. Stéphane Gagnon, Ph.D., Associate Professor in IT Management, Department of Administrative Sciences, Université du Québec en Outaouais, stephane.gagnon@uqo.ca

11. Contact Information of the Research Ethics Committee: If you have any questions or concerns regarding the ethics of this study, please contact the Research Ethics Committee at Université du Québec en Outaouais:

Mr. André Durivage, Ph.D., Chair, Research Ethics Committee, Office of the General SecretaryUniversité du Québec en Outaouais, Pavillon Alexandre-Taché 283, Alexandre-Taché, E2100 C.P. 1250, succursale Hull, Gatineau, QC, Canada, J8X 3X7

Tel.: 819-595-3900, Ext. 3970

Fax: 819-595-3924

Email: comite.ethique@uqo.ca

Web: http://uqo.ca/ethique

12. Permission for Secondary Data: With your permission, we would like to be able to store the data collected at the end of the project for other research activities in the same field. In order to preserve your personal information and identity, the data will be de-identified, that is, it will no longer be possible for anyone to link the data to your identity. We are committed to complying with the same rules of ethics as for the current project.

There is no need to consent to this part in order to participate in the current research. If you do not agree to it, your data will be destroyed at the end of this project. If you agree, your data will be kept for a period of 15 years after completion of the current project and subsequently destroyed.

13. Agreement: Your signature certifies that you understand clearly the instructions on your participation in the research project and indicates your consent to participate. It does not mean that you agree to alienate your rights or to release the researchers and others responsible for the project of their legal and professional responsibilities. You are free to withdraw from the study at any time without prejudice. Since your participation must be as informed as your initial decision to participate in the project, you need to be aware of the ins and outs of the project as the research is being conducted. Therefore, do not hesitate to ask for clarification or new information at any time during the project.

Upon reading the information regarding my participation in the research project, I am signing in this form to indicate that I have willingly agreed to participate. I am retaining one copy of this consent form, which has been signed in duplicate.

UQO
COMITÉ D'ÉTHIQUE
DE LA RECHERCHE DE L'UQO

Déclaration éthique

NUMÉRO DE DOSSIER : 2914
Cet espace est réservé au CÉR

1- TITRE

1.1 – Titre du projet de recherche ou de l'infrastructure financée
Veuillez définir tout sigle ou acronyme.

Projet (remplir les sections 2, 3, 4, 6, 7 et 8) :
Modeling Power Efficiency for Renewable Energy Project Planning: A Software Quality Evaluation Methodology

Infrastructure financée (remplir les sections 2, 5, 6 et 8) :

2- PERSONNE RESPONSABLE DU PROJET OU DE L'INFRASTRUCTURE DE RECHERCHE

2.1 – Identification

☐ Madame	Prénom: Farhad
☑ Monsieur	Nom: Khosrojerdi

2.2 – Statut

☐ Professeur
☐ Autre
Précisez:

☑ Étudiant
Code permanent: KHOF20126904
☐ Stagiaire postdoctoral
Code permanent:

2.3 – Coordonnées

Adresse de correspondance: 2092 Helene-Campbell Rd., Nepean, ON K2J6A5	Département: DII, local LB-B2011
Adresse électronique: khof01@uqo.ca	Programme (ex.: Maîtrise en ...): PhD STI (3081)
Téléphone: Jour: (613) 316-7808 Soir: (613) 316-7808	Directeur/directrice de recherche: Stéphane Gagnon N° de poste: 1942

3- CO-CHERCHEURS

Nom	**Statut** (P) Professeur (E) Étudiant (R) Personnel de recherche	**Établissement**
Stéphane Gagnon	P	DSA, UQO

4- RENSEIGNEMENTS RELATIFS À UN PROJET DE RECHERCHE
(Veuillez remplir toutes les sections)

4.1 – Ce projet est-il financé? Veuillez définir tout sigle ou acronyme.	
☐ Oui. Par qui? : ☑ Non	
4.2 – Unité budgétaire (si disponible)	
4.3 – Numéro d'octroi fourni par l'organisme subventionnaire	
4.4 – Ce projet est-il sous la responsabilité d'un autre établissement? Veuillez définir tout sigle ou acronyme.	
☐ Oui. Lequel? : ☑ Non	
4.5 – Les projets soumis au CÉR doivent avoir fait l'objet d'une évaluation scientifique. Ce projet a fait l'objet d'une évaluation par :	
☐ un comité d'organisme subventionnaire	Lequel:
☐ un comité de recherche départemental	Lequel:
☐ le comité de la recherche et de la création de l'UQO	
☐ un pair	Lequel:
☐ un directeur de recherche	Lequel:
☑ autre	Lequel: Comité des programmes de 3ième cycle en STI
Si votre projet n'a pas fait l'objet d'une évaluation scientifique, veuillez en expliquer les raisons:	

5- RENSEIGNEMENTS RELATIFS AU FINANCEMENT D'INFRASTRUCTURE DE RECHERCHE NE NÉCESSITANT PAS UN CERTIFICAT D'ÉTHIQUE.

5.1 – Nom de l'organisme subventionnaire Veuillez définir tout sigle ou acronyme.
5.2 – Numéro de l'unité budgétaire (si disponible)

6- DÉCLARATION DE CONFLIT D'INTÉRÊTS

☐ **OUI**, je déclare qu'il existe un risque de conflit d'intérêts personnel ou institutionnel réel, potentiel ou apparent, et que j'ai complété le formulaire ***Déclaration de conflit d'intérêts*** qui se trouve à l'annexe B de la ***Politique d'intégrité dans les activités de recherche et de création*** et l'aie transmise aux personnes concernées.

☑ **NON**, je déclare qu'il n'existe aucun risque de conflit d'intérêts personnel ou institutionnel réel, potentiel ou apparent tel que défini dans ***Politique d'intégrité dans les activités de recherche et de création***.

7- PROJET DE RECHERCHE
(Cochez la case qui décrit le mieux votre situation)

SECTION A - ACTIVITÉS DE RECHERCHE NÉCESSITANT UN CERTIFICAT D'ÉTHIQUE
JE DÉCLARE QUE MON PROJET DE RECHERCHE EST: ☐ Une recherche menée avec des êtres humains par le biais d'une intervention, d'une interaction, d'une observation en milieu naturel ou la collecte de données confidentielles et personnelles sur des individus qui ne sont pas disponibles publiquement;
☐ Une utilisation secondaire de données (c'est-à-dire pour des fins autres que celles pour lesquelles elles ont été recueillies) qui contiennent de l'information qui peut permettre d'identifier un être humain ou un groupe et qui ne sont pas accessibles ni disponibles publiquement;
☐ Une recherche qui se situe à l'intérieur d'un programme ou d'un projet déjà approuvé par le Comité d'éthique de la recherche, mais pour lequel le chercheur (professeur ou étudiant) effectue un recrutement non prévu au projet initial;
☐ Une recherche qui comporte l'utilisation de renseignements nominatifs issus d'un projet préalablement approuvé ou d'une banque de données, mais dont l'information sera utilisée à des fins non prévues initialement, ou qui débordent des paramètres du consentement donné à l'origine;
☐ Autre – vous devez fournir le détail de vos activités de recherche:

SECTION B – ACTIVITÉS DE RECHERCHE NE NÉCESSITANT PAS UN CERTIFICAT D'ÉTHIQUE

JE DÉCLARE QUE MON PROJET DE RECHERCHE EST :

- ☐ Une recherche qui a trait à une personnalité publique ou à un artiste vivant et qui repose sur des documents accessibles au public, sans que la personne concernée ne soit approchée directement;
- ☐ Un projet de recherche fondé exclusivement sur l'utilisation secondaire de renseignements anonymes ou de matériel biologique humain anonyme, à condition que les procédures de couplage, d'enregistrement ou de diffusion ne créent pas de renseignements identificatoires (EPTC2, article 2.4);
- ☐ Des activités artistiques qui intègrent essentiellement une pratique créative et qui ne font pas appel à une pratique créative en vue de recueillir auprès de participants des réponses qui seront ensuite analysées dans le cadre des questions liées au projet de recherche (EPTC2, article 2.6);
- ☐ Un sondage et/ou une étude de marché, réalisés sans recueillir des renseignements personnels et/ou confidentiels;
- ☐ Une étude d'assurance-qualité pour une entreprise ou une organisation, une étude comparative de performance ou étude de coûts d'utilisation;
- ☐ Une évaluation de rendement ou administration de tests effectués dans le contexte d'un cours ou d'un processus pédagogique régulier qui ne comporte aucun élément de recherche;
- ☐ Une analyse de politiques publiques, enquête journalistique, critique littéraire;
- ☐ Une étude strictement limitée à l'évaluation du rendement d'un organisme ou de son personnel;
- ☑ Autre – vous devez fournir le détail de vos activités de recherche :

Renewable Energy Project Planning requires the use of advanced modeling software to plan the appropriate system parameters and optimize its efficiency prior to development. In the case of Photovoltaic (PV) systems, a key method for power efficiency is Maximum Power Point Tracking (MPPT) methods. While standard equipment is available to implement this feature, there is no standard model used by all modeling software.

We propose to apply a Software Quality Evaluation Methodology to perform a formal comparison of 5 leading Renewable Energy Project Planning software (i.e., NREL's SAM and PVWatts, PVsyst, etc.). We focus on the way they model MPPT, develop a metamodel that will help represent the PV model in generic terms, which can then help translate models across software. Our findings can help Renewable Energy Project Planning by providing a generic method to select the right software tool and ensure conformity of the different PV models to the master, evidence-based model.

Our analysis is illustrated using 9 datasets from various PV model scenarios developed by the NREL. These datasets are publicly available under an open source license: https://sam.nrel.gov/libraries, https://developer.nrel.gov/, https://developer.nrel.gov/docs/solar/, https://developer.nrel.gov/terms/

Si vous avez coché l'une des cases apparaissant à la **Section A**, vous devez remplir une ***Demande de certificat d'éthique pour une recherche avec des êtres humains ou avec des données secondaires***, selon le cas. Les formulaires sont disponibles à l'adresse www.uqo.ca/ethique

Si vous avez coché l'une des cases apparaissant à la **Section B**, vous n'avez pas à remplir une demande de certificat d'éthique. Si au cours de votre projet vous deviez modifier votre recherche par l'ajout de participants humains ou faire une utilisation secondaire de données qui permet d'identifier des sujets, vous devrez remplir une demande de certificat éthique et l'acheminer au secrétariat du comité d'éthique de la recherche avant de commencer et/ou de poursuivre vos activités.

8- SIGNATURES

Je déclare que toutes les informations fournies dans la présente Déclaration éthique sont exactes et complètes. Je m'engage à respecter les principes de protection des renseignements personnels, à informer les membres de mon équipe de recherche des règles de respect de ces principes et à leur faire signer un engagement à la confidentialité, le cas échéant.

SIGNÉ à (lieu) Gatineau , le (date) 2018-03-14

____

Signature de la personne responsable de l'activité de recherche

☑ Authentification électronique si transmission par MOODLE

Pour les projets des étudiants/étudiantes et des stagiaires postdoctoraux, la signature de la personne qui supervise l'activité de recherche est également requise.

SIGNÉ à (lieu) Gatineau , le (date) 2018-03-14

____

Signature du directeur ou de la directrice de recherche

☑ Authentification électronique si transmission par MOODLE

SECTION RÉSERVÉE AU COMITÉ D'ÉTHIQUE DE LA RECHERCHE

Numéro de dossier : 2914

Date : 15/03/2018 [redacted]

Signature [redacted]

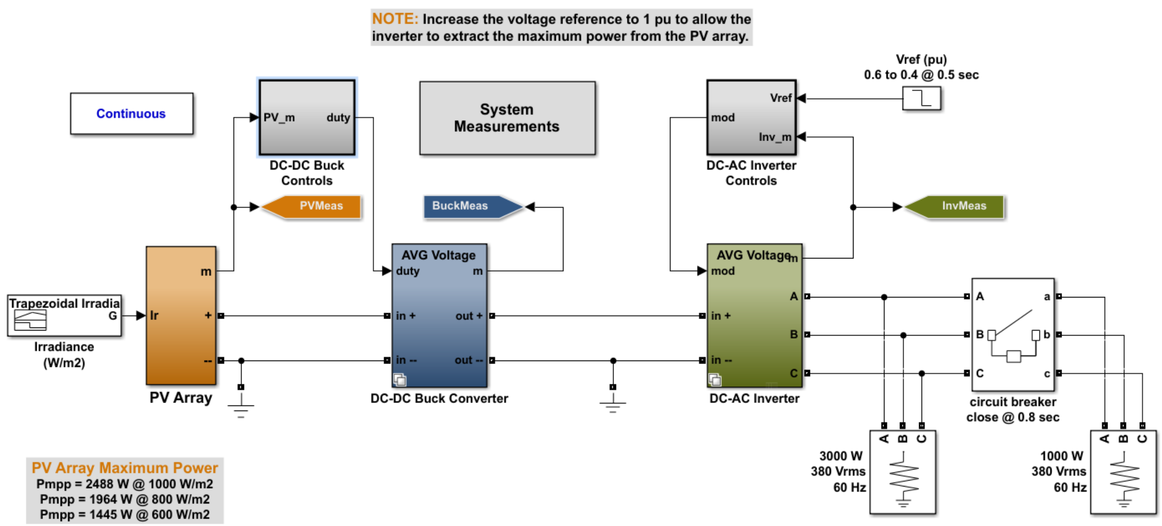
SECTION RÉSERVÉE À L'ADMINISTRATION POUR L'OUVERTURE DU COMPTE

Unité budgétaire confirmée :

Date :

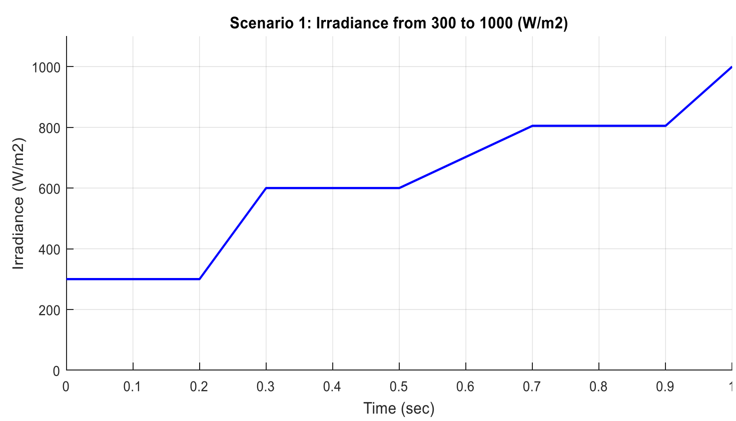
Signature :

ANNEX IV. MATLAB Simulation: Applications of Input Patterns

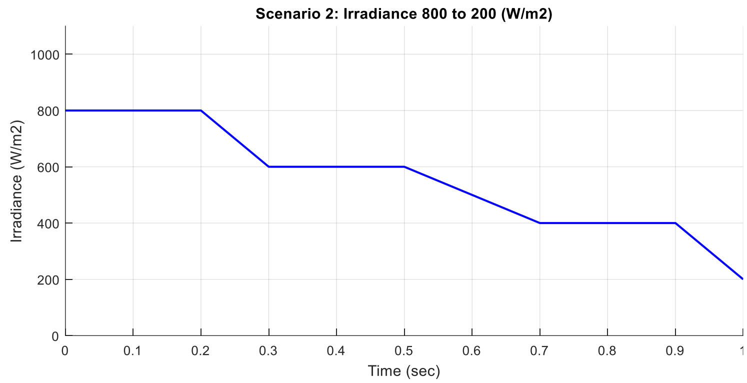


The simulation model is designed by [173].

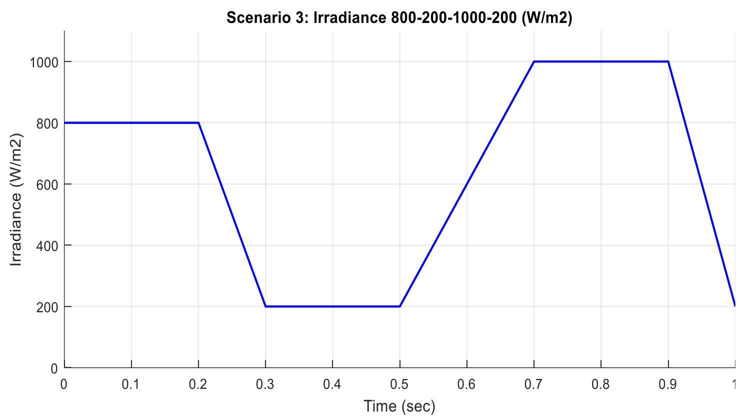
- Diagrams of Three Different Input Patterns Applied to the Simulation



Scenario 1: irradiance from 300 (W/m^2) to 1000 (W/m^2)

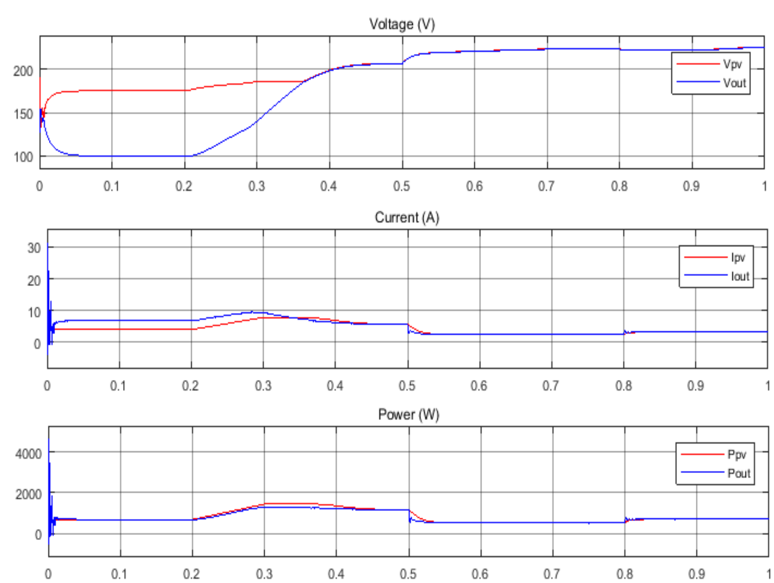


Scenario 2: irradiance from 800 (W/m^2) to 200 (W/m^2) gradually

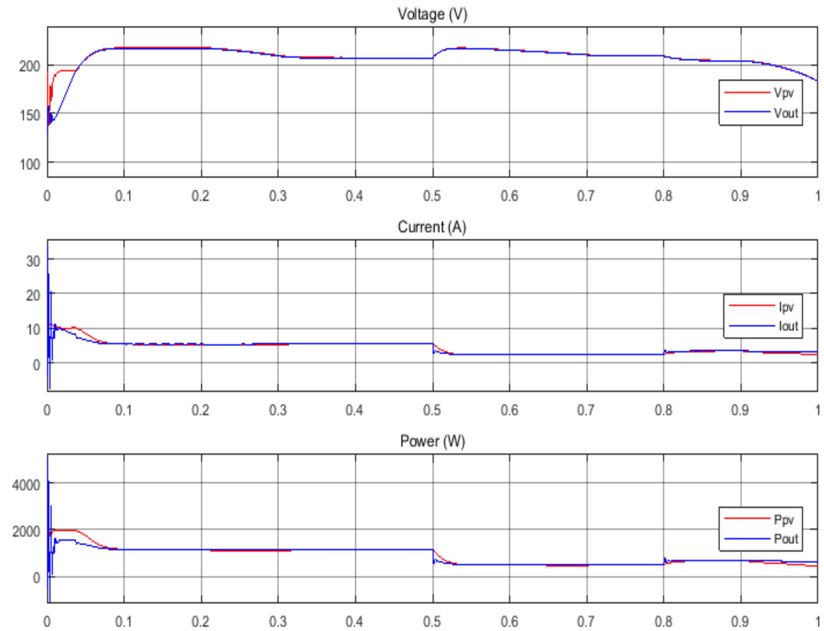


Scenario 3: irradiance from 800 (W/m^2) to 200 (W/m^2)

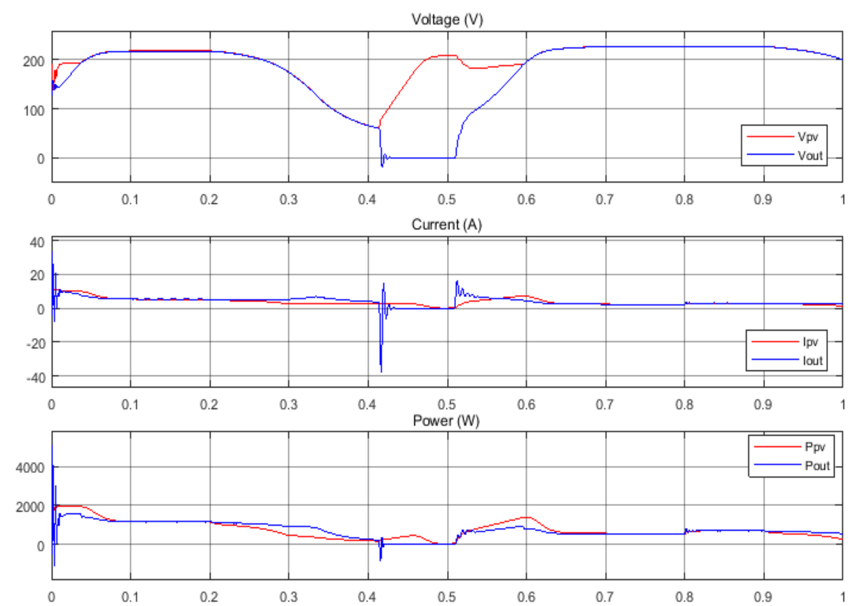
- **Output Results of applying Three Different Input Patterns: Same MPPT**



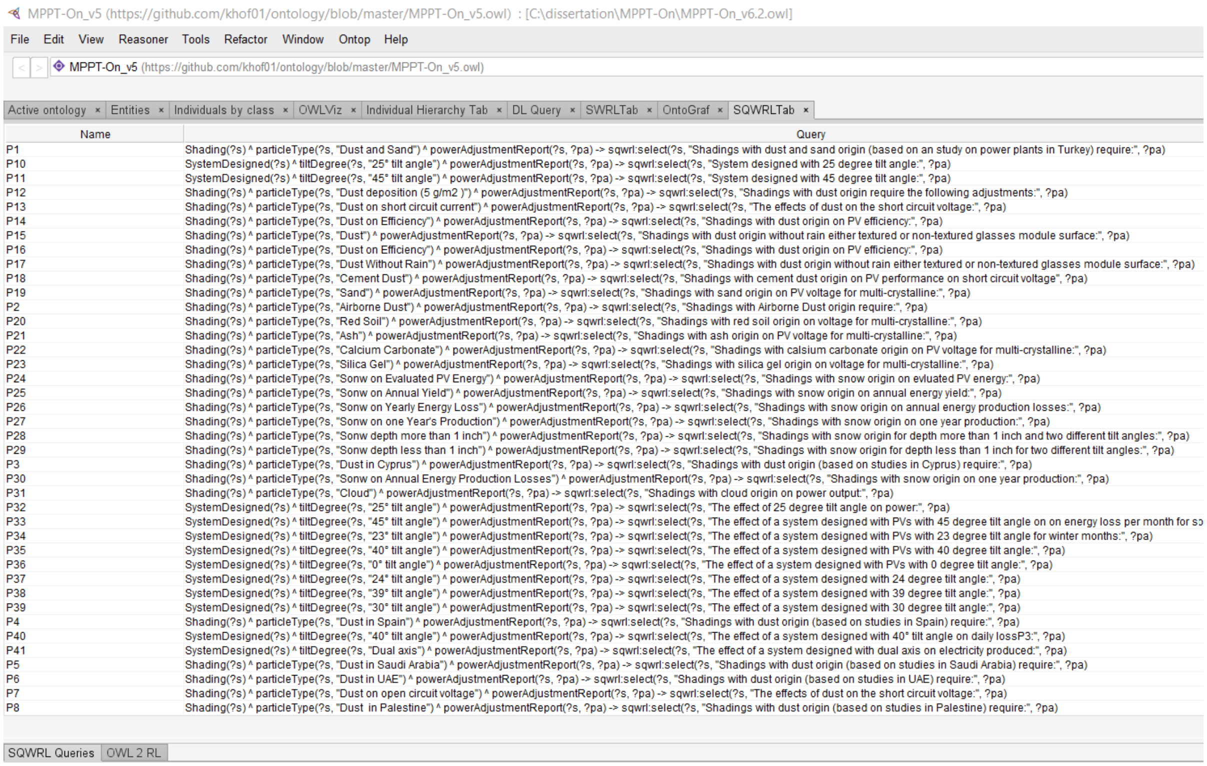
Outputs for Scenario 2



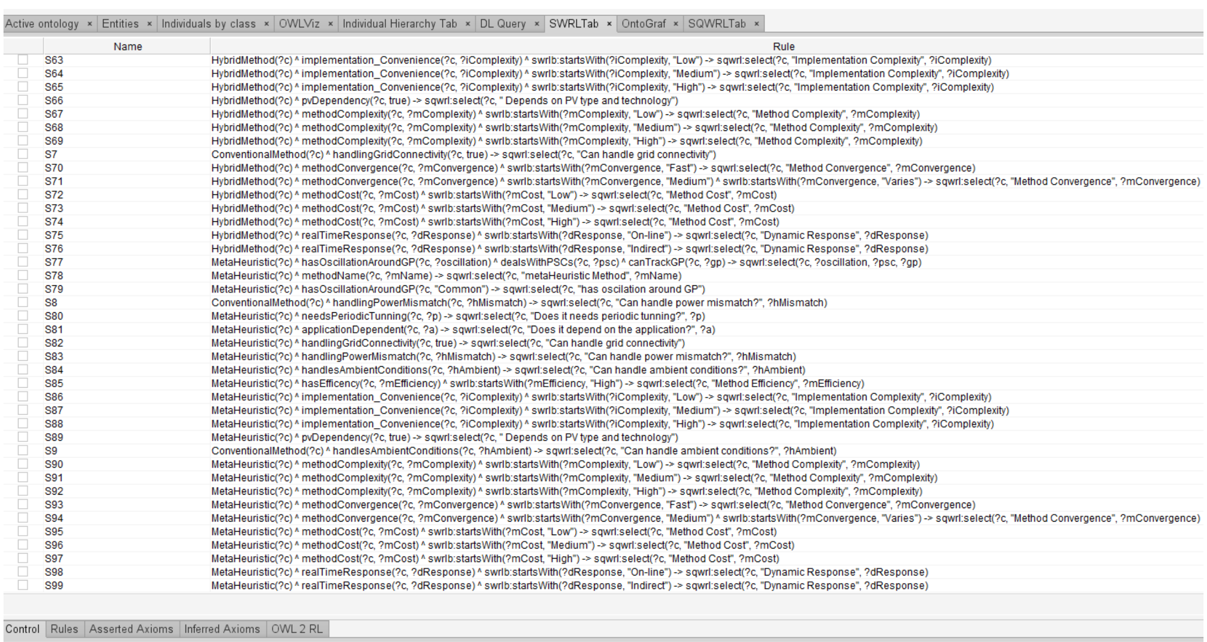
Outputs for Scenario 3



ANNEX V. Screenshots of SWRL Rules and SQWRL Queries



Name	Query
P1	Shading(?s) ^ particleType(?s, "Dust and Sand") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust and sand origin (based on an study on power plants in Turkey) require:", ?pa)
P10	SystemDesigned(?s) ^ tiltDegree(?s, "25° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "System designed with 25 degree tilt angle:", ?pa)
P11	SystemDesigned(?s) ^ tiltDegree(?s, "45° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "System designed with 45 degree tilt angle:", ?pa)
P12	Shading(?s) ^ particleType(?s, "Dust deposition (5 g/m2)") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin require the following adjustments:", ?pa)
P13	Shading(?s) ^ particleType(?s, "Dust on short circuit current") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effects of dust on the short circuit voltage:", ?pa)
P14	Shading(?s) ^ particleType(?s, "Dust on Efficiency") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin on PV efficiency:", ?pa)
P15	Shading(?s) ^ particleType(?s, "Dust") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin without rain either textured or non-textured glasses module surface:", ?pa)
P16	Shading(?s) ^ particleType(?s, "Dust on Efficiency") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin on PV efficiency:", ?pa)
P17	Shading(?s) ^ particleType(?s, "Dust Without Rain") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin without rain either textured or non-textured glasses module surface:", ?pa)
P18	Shading(?s) ^ particleType(?s, "Cement Dust") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with cement dust origin on PV performance on short circuit voltage", ?pa)
P19	Shading(?s) ^ particleType(?s, "Sand") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with sand origin on PV voltage for multi-crystalline:", ?pa)
P2	Shading(?s) ^ particleType(?s, "Airborne Dust") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with Airborne Dust origin require:", ?pa)
P20	Shading(?s) ^ particleType(?s, "Red Soil") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with red soil origin on voltage for multi-crystalline:", ?pa)
P21	Shading(?s) ^ particleType(?s, "Ash") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with ash origin on PV voltage for multi-crystalline:", ?pa)
P22	Shading(?s) ^ particleType(?s, "Calcium Carbonate") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with calsium carbonate origin on PV voltage for multi-crystalline:", ?pa)
P23	Shading(?s) ^ particleType(?s, "Silica Gel") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with silica gel origin on voltage for multi-crystalline:", ?pa)
P24	Shading(?s) ^ particleType(?s, "Sonw on Evaluated PV Energy") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin on evluated PV energy:", ?pa)
P25	Shading(?s) ^ particleType(?s, "Sonw on Annual Yield") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin on annual energy yield:", ?pa)
P26	Shading(?s) ^ particleType(?s, "Sonw on Yearly Energy Loss") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin on annual energy production losses:", ?pa)
P27	Shading(?s) ^ particleType(?s, "Sonw on one Year's Production") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin on one year production:", ?pa)
P28	Shading(?s) ^ particleType(?s, "Sonw depth more than 1 inch") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin for depth more than 1 inch and two different tilt angles:", ?pa)
P29	Shading(?s) ^ particleType(?s, "Sonw depth less than 1 inch") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin for depth less than 1 inch for two different tilt angles:", ?pa)
P3	Shading(?s) ^ particleType(?s, "Dust in Cyprus") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin (based on studies in Cyprus) require:", ?pa)
P30	Shading(?s) ^ particleType(?s, "Sonw on Annual Energy Production Losses") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with snow origin on one year production:", ?pa)
P31	Shading(?s) ^ particleType(?s, "Cloud") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with cloud origin on power output:", ?pa)
P32	SystemDesigned(?s) ^ tiltDegree(?s, "25° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of 25 degree tilt angle on power:", ?pa)
P33	SystemDesigned(?s) ^ tiltDegree(?s, "45° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with PVs with 45 degree tilt angle on on energy loss per month for so
P34	SystemDesigned(?s) ^ tiltDegree(?s, "23° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with PVs with 23 degree tilt angle for winter months:", ?pa)
P35	SystemDesigned(?s) ^ tiltDegree(?s, "40° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with PVs with 40 degree tilt angle:", ?pa)
P36	SystemDesigned(?s) ^ tiltDegree(?s, "0° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with PVs with 0 degree tilt angle:", ?pa)
P37	SystemDesigned(?s) ^ tiltDegree(?s, "24° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with 24 degree tilt angle:", ?pa)
P38	SystemDesigned(?s) ^ tiltDegree(?s, "39° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with 39 degree tilt angle:", ?pa)
P39	SystemDesigned(?s) ^ tiltDegree(?s, "30° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with 30 degree tilt angle:", ?pa)
P4	Shading(?s) ^ particleType(?s, "Dust in Spain") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin (based on studies in Spain) require:", ?pa)
P40	SystemDesigned(?s) ^ tiltDegree(?s, "40° tilt angle") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with 40° tilt angle on daily lossP3:", ?pa)
P41	SystemDesigned(?s) ^ tiltDegree(?s, "Dual axis") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effect of a system designed with dual axis on electricity produced:", ?pa)
P5	Shading(?s) ^ particleType(?s, "Dust in Saudi Arabia") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin (based on studies in Saudi Arabia) require:", ?pa)
P6	Shading(?s) ^ particleType(?s, "Dust in UAE") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin (based on studies in UAE) require:", ?pa)
P7	Shading(?s) ^ particleType(?s, "Dust on open circuit voltage") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "The effects of dust on the short circuit voltage:", ?pa)
P8	Shading(?s) ^ particleType(?s, "Dust in Palestine") ^ powerAdjustmentReport(?s, ?pa) -> sqwrl:select(?s, "Shadings with dust origin (based on studies in Palestine) require:", ?pa)

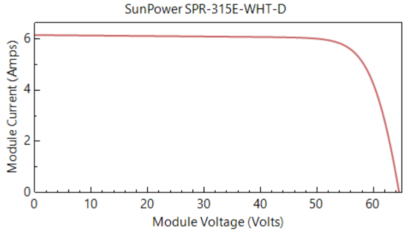


Name	Rule
S63	HybridMethod(?c) ^ implementation_Convenience(?c, ?iComplexity) ^ swrlb:startsWith(?iComplexity, "Low") -> sqwrl:select(?c, "Implementation Complexity", ?iComplexity)
S64	HybridMethod(?c) ^ implementation_Convenience(?c, ?iComplexity) ^ swrlb:startsWith(?iComplexity, "Medium") -> sqwrl:select(?c, "Implementation Complexity", ?iComplexity)
S65	HybridMethod(?c) ^ implementation_Convenience(?c, ?iComplexity) ^ swrlb:startsWith(?iComplexity, "High") -> sqwrl:select(?c, "Implementation Complexity", ?iComplexity)
S66	HybridMethod(?c) ^ pvDependency(?c, true) -> sqwrl:select(?c, " Depends on PV type and technology")
S67	HybridMethod(?c) ^ methodComplexity(?c, ?mComplexity) ^ swrlb:startsWith(?mComplexity, "Low") -> sqwrl:select(?c, "Method Complexity", ?mComplexity)
S68	HybridMethod(?c) ^ methodComplexity(?c, ?mComplexity) ^ swrlb:startsWith(?mComplexity, "Medium") -> sqwrl:select(?c, "Method Complexity", ?mComplexity)
S69	HybridMethod(?c) ^ methodComplexity(?c, ?mComplexity) ^ swrlb:startsWith(?mComplexity, "High") -> sqwrl:select(?c, "Method Complexity", ?mComplexity)
S7	ConventionalMethod(?c) ^ handlingGridConnectivity(?c, true) -> sqwrl:select(?c, "Can handle grid connectivity")
S70	HybridMethod(?c) ^ methodConvergence(?c, ?mConvergence) ^ swrlb:startsWith(?mConvergence, "Fast") -> sqwrl:select(?c, "Method Convergence", ?mConvergence)
S71	HybridMethod(?c) ^ methodConvergence(?c, ?mConvergence) ^ swrlb:startsWith(?mConvergence, "Medium") ^ swrlb:startsWith(?mConvergence, "Varies") -> sqwrl:select(?c, "Method Convergence", ?mConvergence)
S72	HybridMethod(?c) ^ methodCost(?c, ?mCost) ^ swrlb:startsWith(?mCost, "Low") -> sqwrl:select(?c, "Method Cost", ?mCost)
S73	HybridMethod(?c) ^ methodCost(?c, ?mCost) ^ swrlb:startsWith(?mCost, "Medium") -> sqwrl:select(?c, "Method Cost", ?mCost)
S74	HybridMethod(?c) ^ methodCost(?c, ?mCost) ^ swrlb:startsWith(?mCost, "High") -> sqwrl:select(?c, "Method Cost", ?mCost)
S75	HybridMethod(?c) ^ realTimeResponse(?c, ?dResponse) ^ swrlb:startsWith(?dResponse, "On-line") -> sqwrl:select(?c, "Dynamic Response", ?dResponse)
S76	HybridMethod(?c) ^ realTimeResponse(?c, ?dResponse) ^ swrlb:startsWith(?dResponse, "Indirect") -> sqwrl:select(?c, "Dynamic Response", ?dResponse)
S77	MetaHeuristic(?c) ^ hasOscillationAroundGP(?c, ?oscillation) ^ dealsWithPSCs(?c, ?psc) ^ canTrackGP(?c, ?gp) -> sqwrl:select(?c, ?oscillation, ?psc, ?gp)
S78	MetaHeuristic(?c) ^ methodName(?c, ?mName) -> sqwrl:select(?c, "metaHeuristic Method", ?mName)
S79	MetaHeuristic(?c) ^ hasOscillationAroundGP(?c, "Common") -> sqwrl:select(?c, "has oscilation around GP")
S8	ConventionalMethod(?c) ^ handlingPowerMismatch(?c, ?hMismatch) -> sqwrl:select(?c, "Can handle power mismatch?", ?hMismatch)
S80	MetaHeuristic(?c) ^ needsPeriodicTunning(?c, ?p) -> sqwrl:select(?c, "Does it needs periodic tunning?", ?p)
S81	MetaHeuristic(?c) ^ applicationDependent(?c, ?a) -> sqwrl:select(?c, "Does it depend on the application?", ?a)
S82	MetaHeuristic(?c) ^ handlingGridConnectivity(?c, true) -> sqwrl:select(?c, "Can handle grid connectivity")
S83	MetaHeuristic(?c) ^ handlingPowerMismatch(?c, ?hMismatch) -> sqwrl:select(?c, "Can handle power mismatch?", ?hMismatch)
S84	MetaHeuristic(?c) ^ handlesAmbientConditions(?c, ?hAmbient) -> sqwrl:select(?c, "Can handle ambient conditions?", ?hAmbient)
S85	MetaHeuristic(?c) ^ hasEfficency(?c, ?mEfficiency) ^ swrlb:startsWith(?mEfficiency, "High") -> sqwrl:select(?c, "Method Efficiency", ?mEfficiency)
S86	MetaHeuristic(?c) ^ implementation_Convenience(?c, ?iComplexity) ^ swrlb:startsWith(?iComplexity, "Low") -> sqwrl:select(?c, "Implementation Complexity", ?iComplexity)
S87	MetaHeuristic(?c) ^ implementation_Convenience(?c, ?iComplexity) ^ swrlb:startsWith(?iComplexity, "Medium") -> sqwrl:select(?c, "Implementation Complexity", ?iComplexity)
S88	MetaHeuristic(?c) ^ implementation_Convenience(?c, ?iComplexity) ^ swrlb:startsWith(?iComplexity, "High") -> sqwrl:select(?c, "Implementation Complexity", ?iComplexity)
S89	MetaHeuristic(?c) ^ pvDependency(?c, true) -> sqwrl:select(?c, " Depends on PV type and technology")
S9	ConventionalMethod(?c) ^ handlesAmbientConditions(?c, ?hAmbient) -> sqwrl:select(?c, "Can handle ambient conditions?", ?hAmbient)
S90	MetaHeuristic(?c) ^ methodComplexity(?c, ?mComplexity) ^ swrlb:startsWith(?mComplexity, "Low") -> sqwrl:select(?c, "Method Complexity", ?mComplexity)
S91	MetaHeuristic(?c) ^ methodComplexity(?c, ?mComplexity) ^ swrlb:startsWith(?mComplexity, "Medium") -> sqwrl:select(?c, "Method Complexity", ?mComplexity)
S92	MetaHeuristic(?c) ^ methodComplexity(?c, ?mComplexity) ^ swrlb:startsWith(?mComplexity, "High") -> sqwrl:select(?c, "Method Complexity", ?mComplexity)
S93	MetaHeuristic(?c) ^ methodConvergence(?c, ?mConvergence) ^ swrlb:startsWith(?mConvergence, "Fast") -> sqwrl:select(?c, "Method Convergence", ?mConvergence)
S94	MetaHeuristic(?c) ^ methodConvergence(?c, ?mConvergence) ^ swrlb:startsWith(?mConvergence, "Medium") ^ swrlb:startsWith(?mConvergence, "Varies") -> sqwrl:select(?c, "Method Convergence", ?mConvergence)
S95	MetaHeuristic(?c) ^ methodCost(?c, ?mCost) ^ swrlb:startsWith(?mCost, "Low") -> sqwrl:select(?c, "Method Cost", ?mCost)
S96	MetaHeuristic(?c) ^ methodCost(?c, ?mCost) ^ swrlb:startsWith(?mCost, "Medium") -> sqwrl:select(?c, "Method Cost", ?mCost)
S97	MetaHeuristic(?c) ^ methodCost(?c, ?mCost) ^ swrlb:startsWith(?mCost, "High") -> sqwrl:select(?c, "Method Cost", ?mCost)
S98	MetaHeuristic(?c) ^ realTimeResponse(?c, ?dResponse) ^ swrlb:startsWith(?dResponse, "On-line") -> sqwrl:select(?c, "Dynamic Response", ?dResponse)
S99	MetaHeuristic(?c) ^ realTimeResponse(?c, ?dResponse) ^ swrlb:startsWith(?dResponse, "Indirect") -> sqwrl:select(?c, "Dynamic Response", ?dResponse)

ANNEX VI. SAM Results for the Case Study: NREL's Visitor Parking

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C



			Temperature coefficients			
Nominal efficiency	19.3177	%				
Maximum power (Pmp)	315.072	Wdc	-0.386	%/°C	-1.216	W/°C
Max power voltage (Vmp)	54.7	Vdc				
Max power current (Imp)	5.8	Adc				
Open circuit voltage (Voc)	64.6	Vdc	-0.273		-0.176	V/°C
Short circuit current (Isc)	6.1	Adc	0.062	%/°C	0.004	A/°C

Bifacial Specifications

☐ Module is bifacial

Transmission fraction 0.013 0-1

Bifaciality 0.65 0-1

Ground clearance height 1 m

Temperature Correction

◉ Nominal operating cell temperature (NOCT) method

○ Heat transfer method

See Help for more information about CEC cell temperature models.

NOCT Method Parameters

Mounting standoff: Ground or rack mounted

Array height: One story building height or lower

Heat Transfer Method Parameters

Mounting configuration: Rack

Heat transfer dimensions: Module Dimensions

Mounting structure orientation: Structures do not impede flow underneath module

Module width: 1 m

Module length: 1.63 m

Rows of modules in array: 1

Columns of modules in array: 10

Temperature behind the module: 20 °C

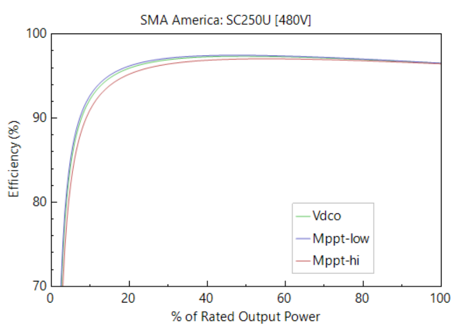
Space between module back and roof surface: 0.05 m

Inverter CEC Database

Filter: Name

Name	Paco	Pdco	Pso	Pnt	Vac	Vdcmax	Vdco	Mppt_high	Mppt_low	C0	C1	C2	C3
SMA America: SC-1850-US [385V]	166...	1710379.875	6102.88...	498.3	385	950	665	950	570	-1.03E-08	0.000016	0.002163	0.000456
SMA America: SC-2200-US [385V]	207...	2152704	7223.27...	623.7	385	950	665	950	570	-1.23E-08	0.000014	0.001452	0.000057
SMA America: SC125U [208V]	125...	134204.0781	674.989...	37.5	208	480	330	480	275	-2.28E-07	0.000027	0.005298	0.001335
SMA America: SC125U [480V]	125...	133516.7188	662.484...	37.5	480	480	330	480	275	-1.84E-07	0.000037	0.003548	0.001526
SMA America: SC250U [480V]	250...	259022.8594	2064.52...	75	480	480	370	480	330	-1.27E-07	5.29E-06	0.001166	-0.00089:

Efficiency Curve and Characteristics



Number of MPPT inputs: 1

CEC weighted efficiency: 96.841 %

European weighted efficiency: 96.271 %

Datasheet Parameters

Maximum AC power	250000	Wac
Maximum DC power	259023	Wdc
Power use during operation	2064.53	Wdc
Power use at night	75	Wac
Nominal AC voltage	480	Vac
Maximum DC voltage	480	Vdc
Maximum DC current	700.062	Adc
Minimum MPPT DC voltage	330	Vdc
Nominal DC voltage	370	Vdc
Maximum MPPT DC voltage	480	Vdc

Sandia Coefficients

C0	-1.27e-07	1/Wac
C1	5.29e-06	1/Vdc
C2	0.001166	1/Vdc
C3	-0.000893	1/Vdc

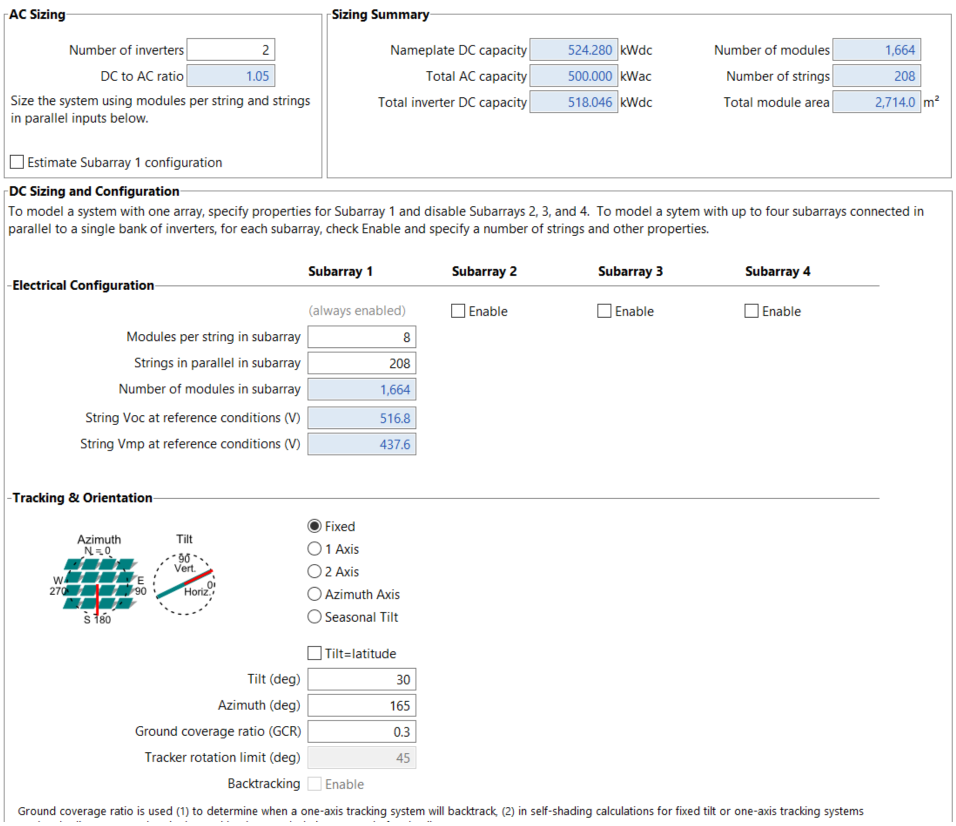
Note: If you are modeling a system with microinverters or DC power optimizers, see the Losses page to adjust the system losses accordingly.

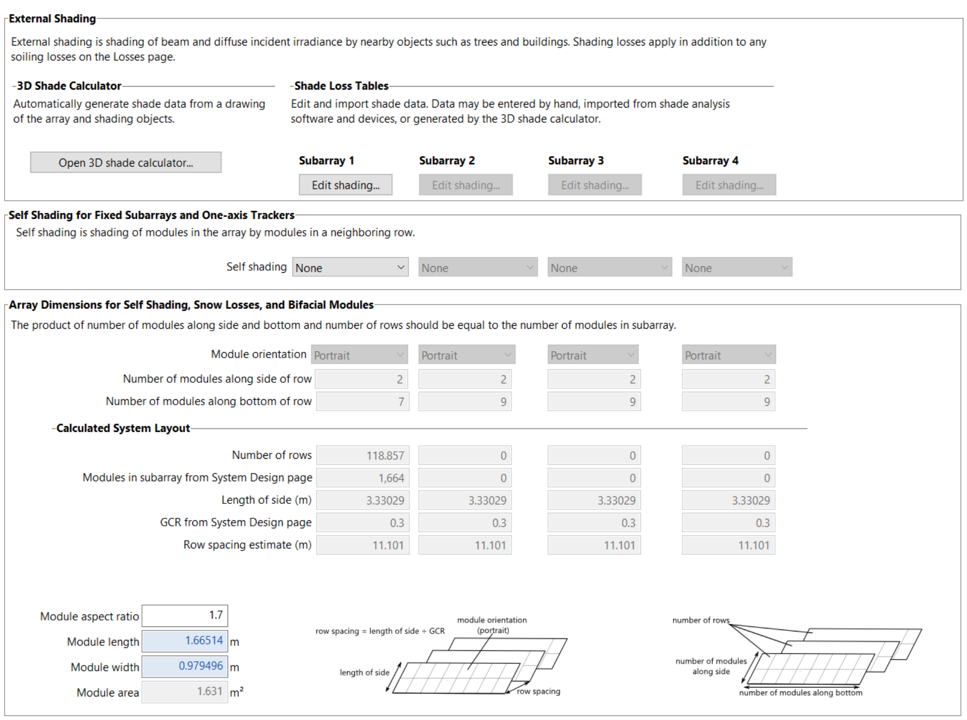
CEC Information

CEC name: SMA America: SC250U [480V]

CEC type: Utility Interactive

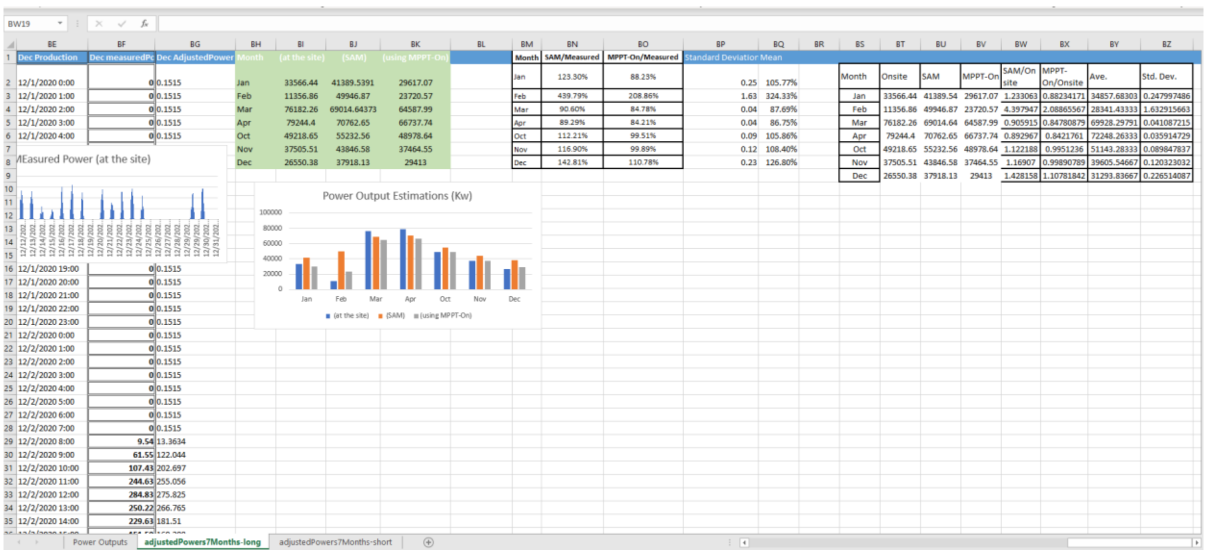
CEC date: 4/16/2018


AC Sizing
Number of inverters 2
DC to AC ratio 1.05
Size the system using modules per string and strings in parallel inputs below.
Estimate Subarray 1 configuration
Sizing Summary
Nameplate DC capacity 524.280 kWdc
Total AC capacity 500.000 kWac
Total inverter DC capacity 518.046 kWdc
Number of modules 1,664
Number of strings 208
Total module area 2,714.0 m²
DC Sizing and Configuration
To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a sytem with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.
Subarray 1
Subarray 2
Subarray 3
Subarray 4
Electrical Configuration
(always enabled)
Enable
Enable
Enable
Modules per string in subarray 8
Strings in parallel in subarray 208
Number of modules in subarray 1,664
String Voc at reference conditions (V) 516.8
String Vmp at reference conditions (V) 437.6
Tracking & Orientation
Azimuth
N 0
W 270
E 90
S 180
Tilt
90 Vert.
Horiz.
Fixed
1 Axis
2 Axis
Azimuth Axis
Seasonal Tilt
Tilt=latitude
Tilt (deg) 30
Azimuth (deg) 165
Ground coverage ratio (GCR) 0.3
Tracker rotation limit (deg) 45
Backtracking Enable
Ground coverage ratio is used (1) to determine when a one-axis tracking system will backtrack, (2) in self-shading calculations for fixed tilt or one-axis tracking systems

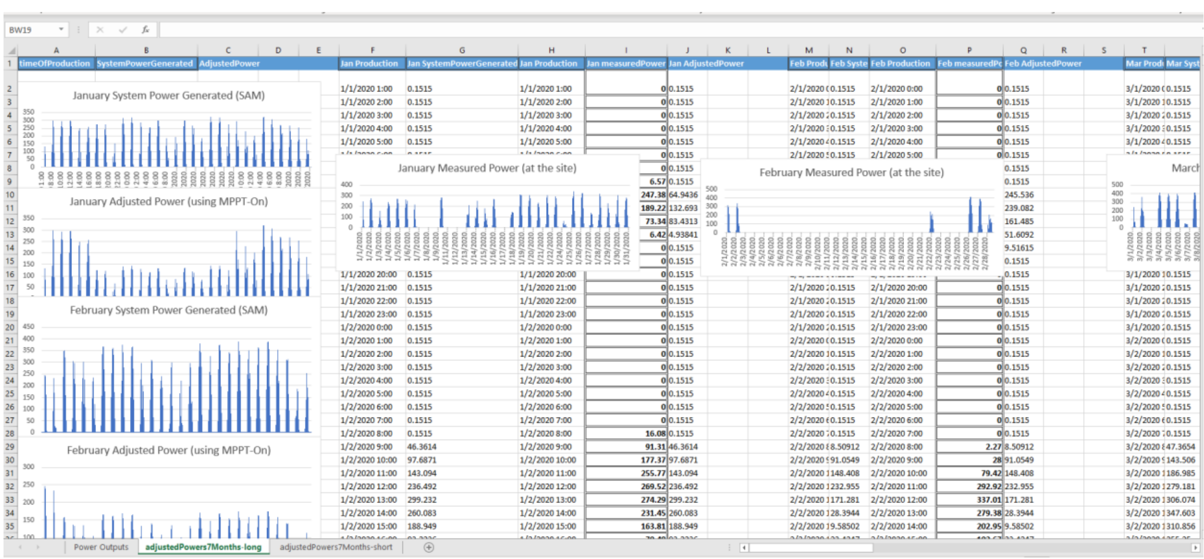

External Shading
External shading is shading of beam and diffuse incident irradiance by nearby objects such as trees and buildings. Shading losses apply in addition to any soiling losses on the Losses page.
3D Shade Calculator
Automatically generate shade data from a drawing of the array and shading objects.
Open 3D shade calculator...
Shade Loss Tables
Edit and import shade data. Data may be entered by hand, imported from shade analysis software and devices, or generated by the 3D shade calculator.
Subarray 1
Subarray 2
Subarray 3
Subarray 4
Edit shading...
Edit shading...
Edit shading...
Edit shading...
Self Shading for Fixed Subarrays and One-axis Trackers
Self shading is shading of modules in the array by modules in a neighboring row.
Self shading None None None None
Array Dimensions for Self Shading, Snow Losses, and Bifacial Modules
The product of number of modules along side and bottom and number of rows should be equal to the number of modules in subarray.
Module orientation Portrait Portrait Portrait Portrait
Number of modules along side of row 2 2 2 2
Number of modules along bottom of row 7 9 9 9
Calculated System Layout
Number of rows 118.857 0 0 0
Modules in subarray from System Design page 1,664 0 0 0
Length of side (m) 3.33029 3.33029 3.33029 3.33029
GCR from System Design page 0.3 0.3 0.3 0.3
Row spacing estimate (m) 11.101 11.101 11.101 11.101
Module aspect ratio 1.7
Module length 1.66514 m
Module width 0.979496 m
Module area 1.631 m²
row spacing = length of side ÷ GCR
module orientation (portrait)
length of side
row spacing
number of rows
number of modules along side
number of modules along bottom

ANNEX VII. The Excel File: Adjusted Powers for: Longer Shadings

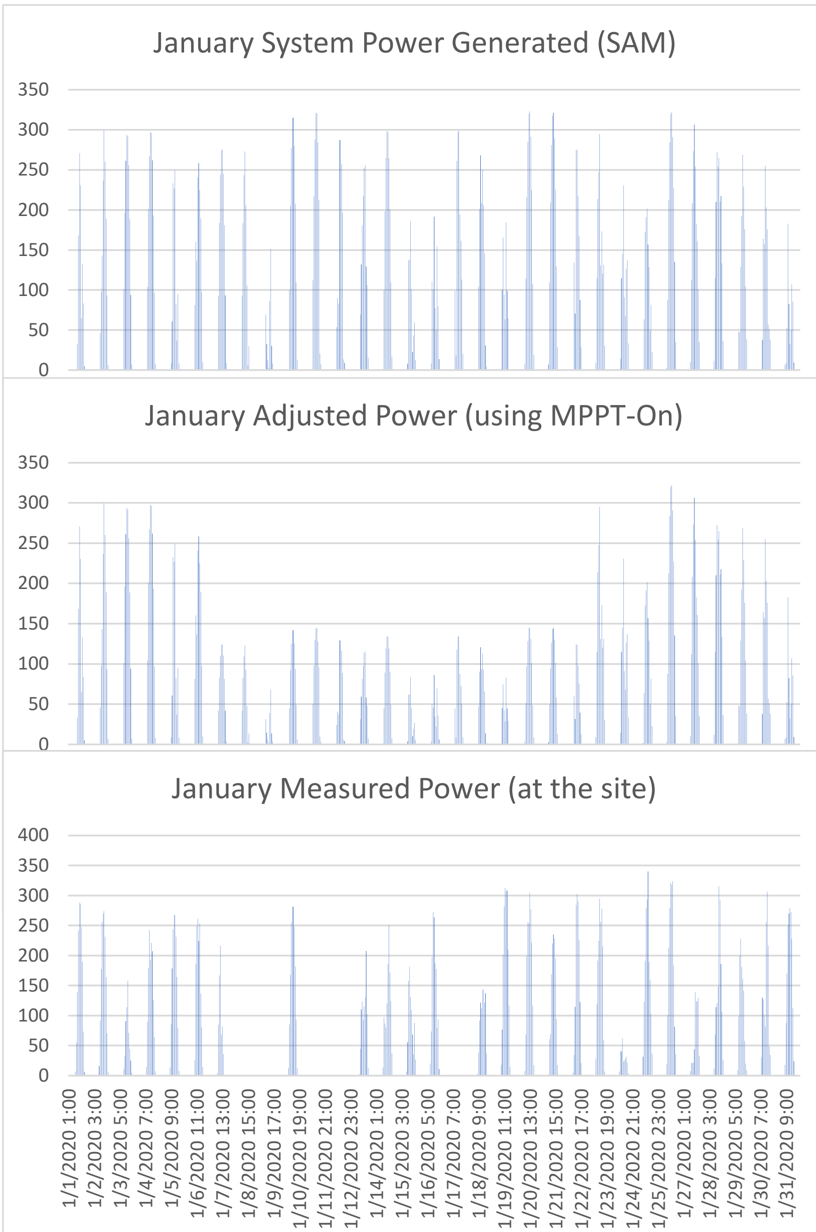
Hourly power generations: I) the SAM model, II) the application of MPPT-On, and III) measured power onsite



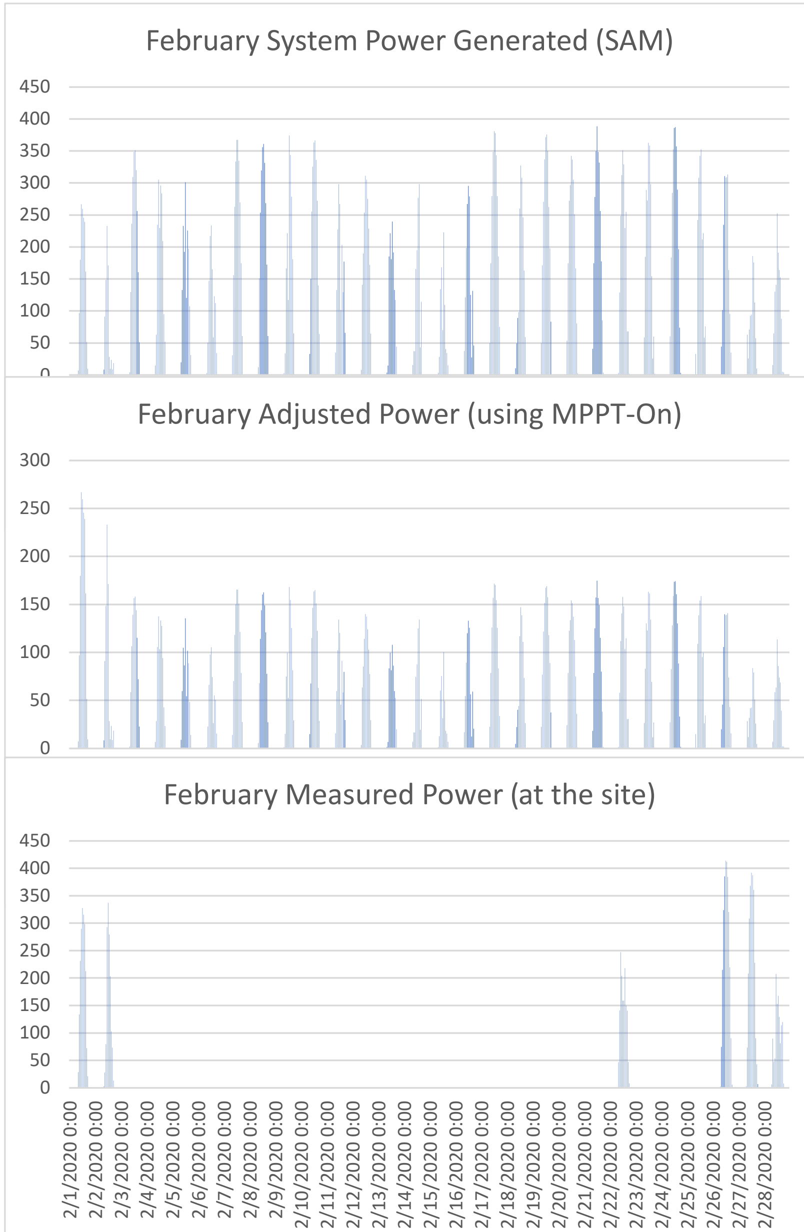
System power generations for months of (Jan-Apr) and (Oct-Dec) simulated by SAM



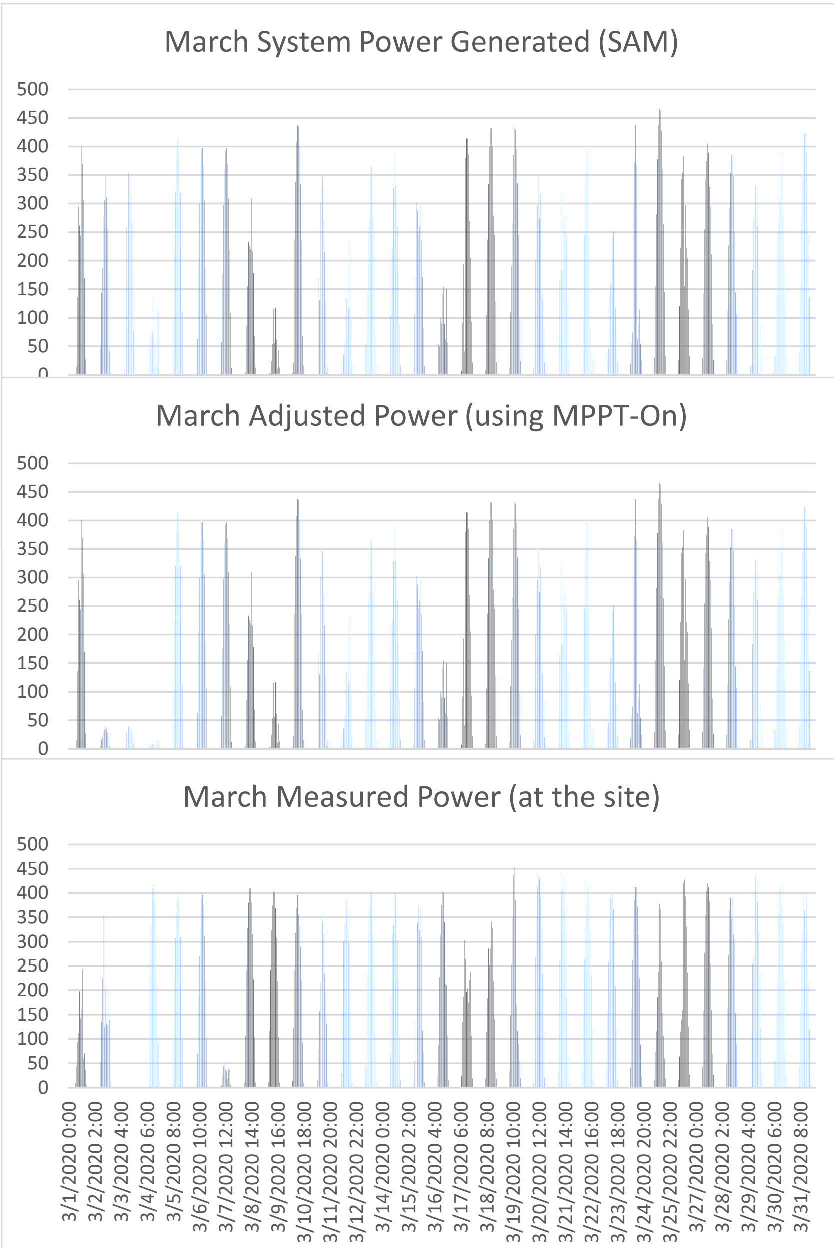
ANNEX VIII. Daily Power Outputs: Expecting Extended Durations for Shading



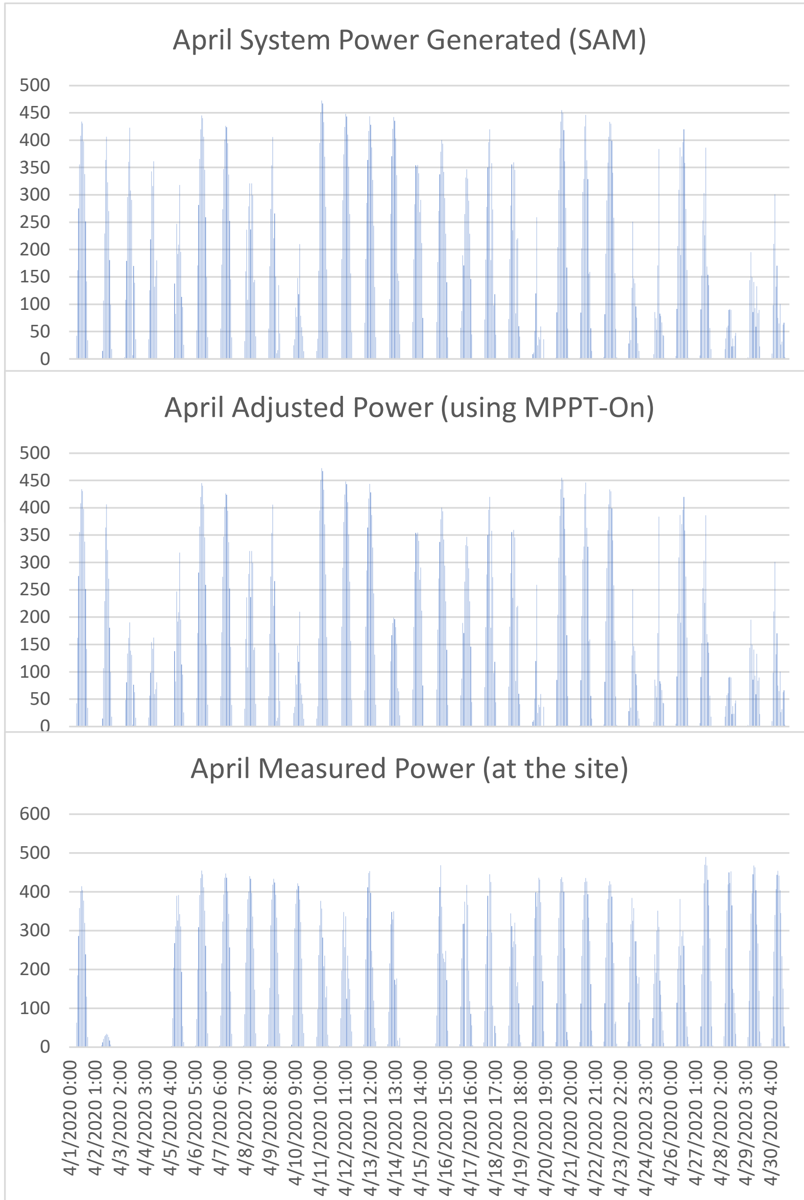
Comparing daily power outputs in January: SAM simulation, using the ontology, and measured at the site



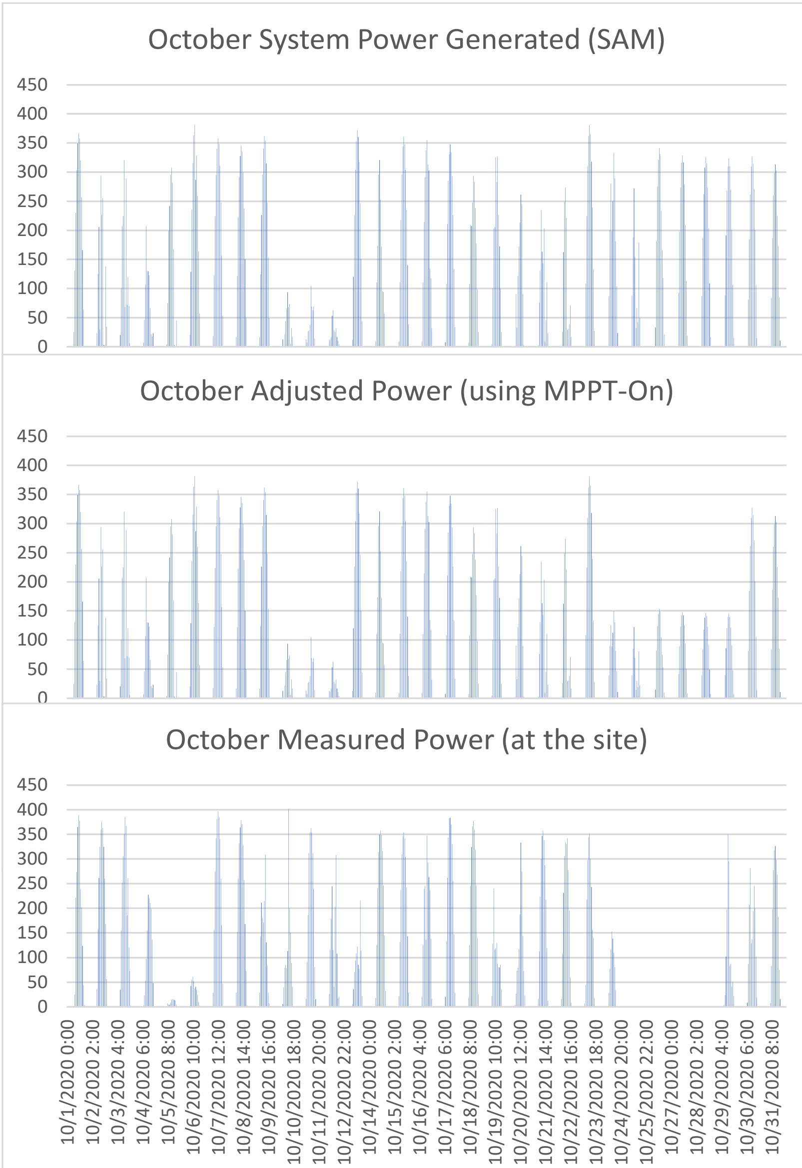
Comparing daily power outputs in February: SAM simulation, using the ontology, and measured at the site



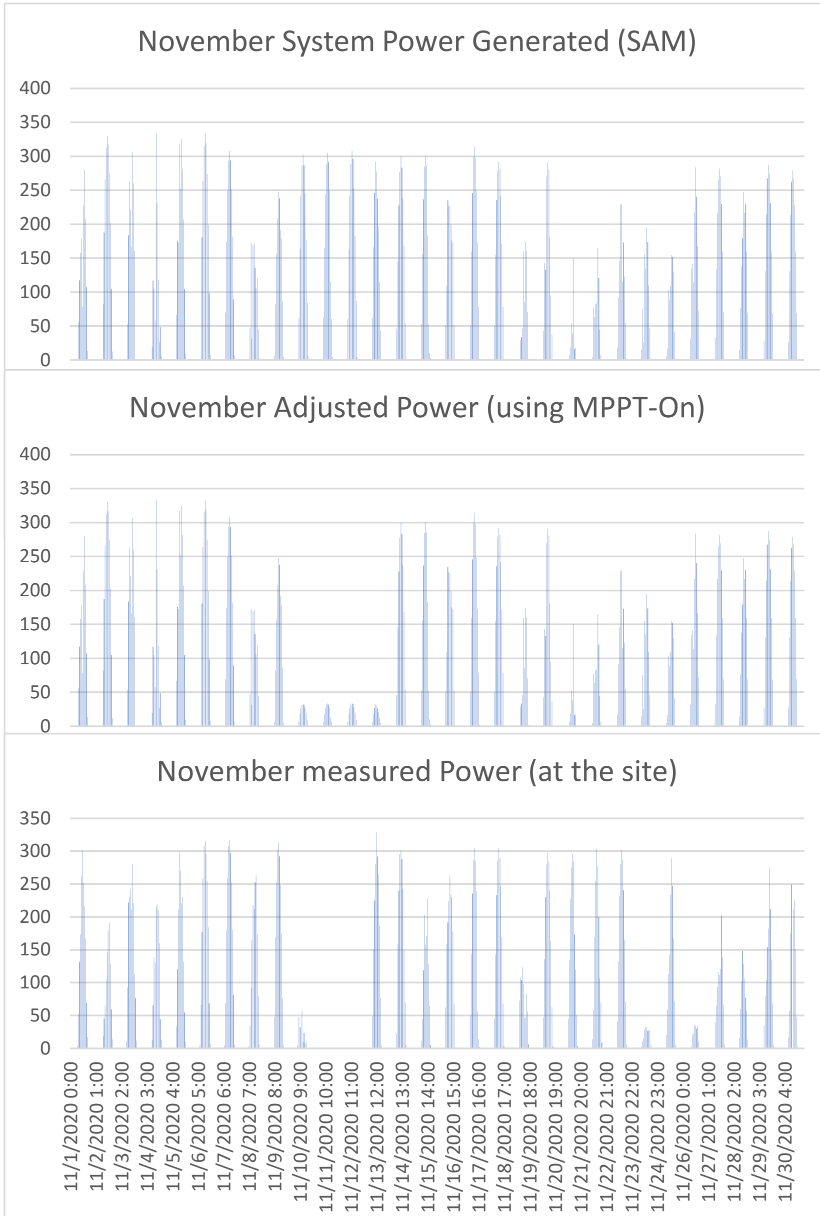
Comparing daily power outputs in March: SAM simulation, using the ontology, and measured at the site



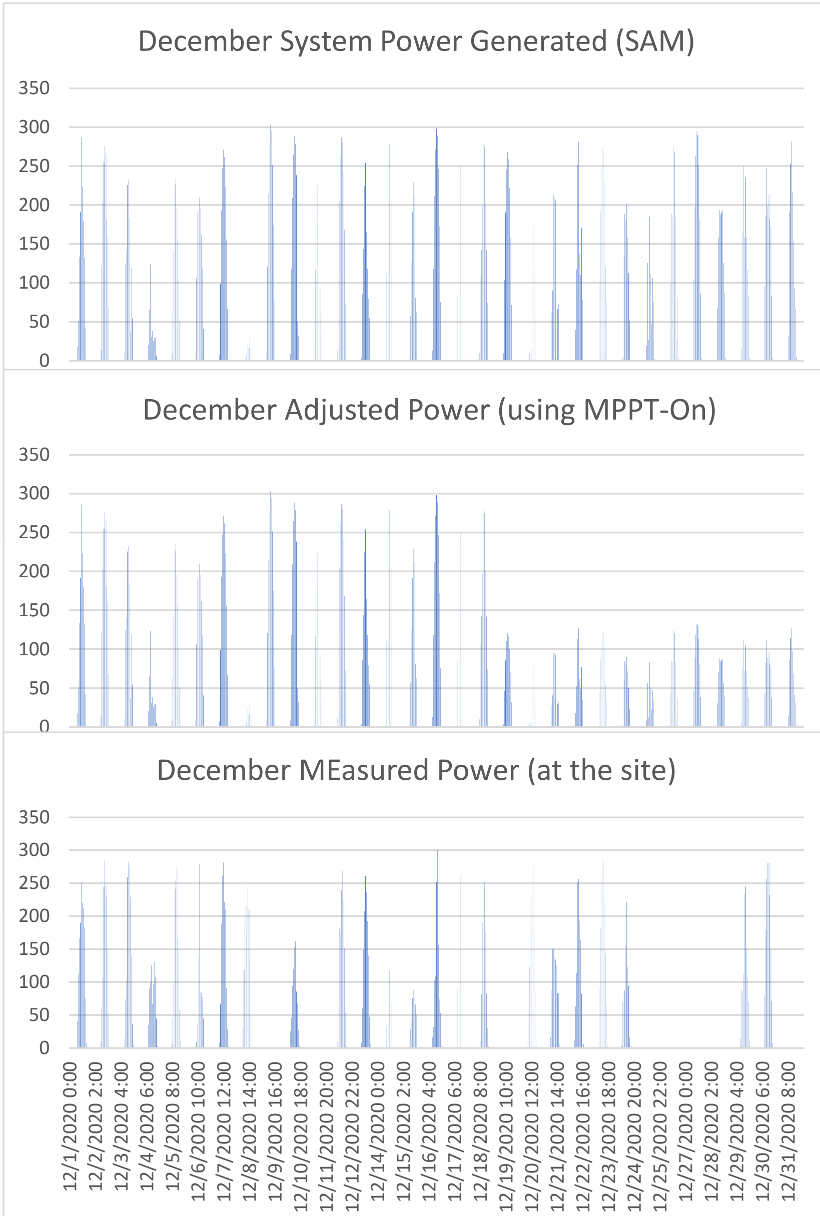
Comparing daily power outputs in April: SAM simulation, using the ontology, and measured at the site



Comparing daily power outputs in October: SAM simulation, using the ontology, and measured at the site



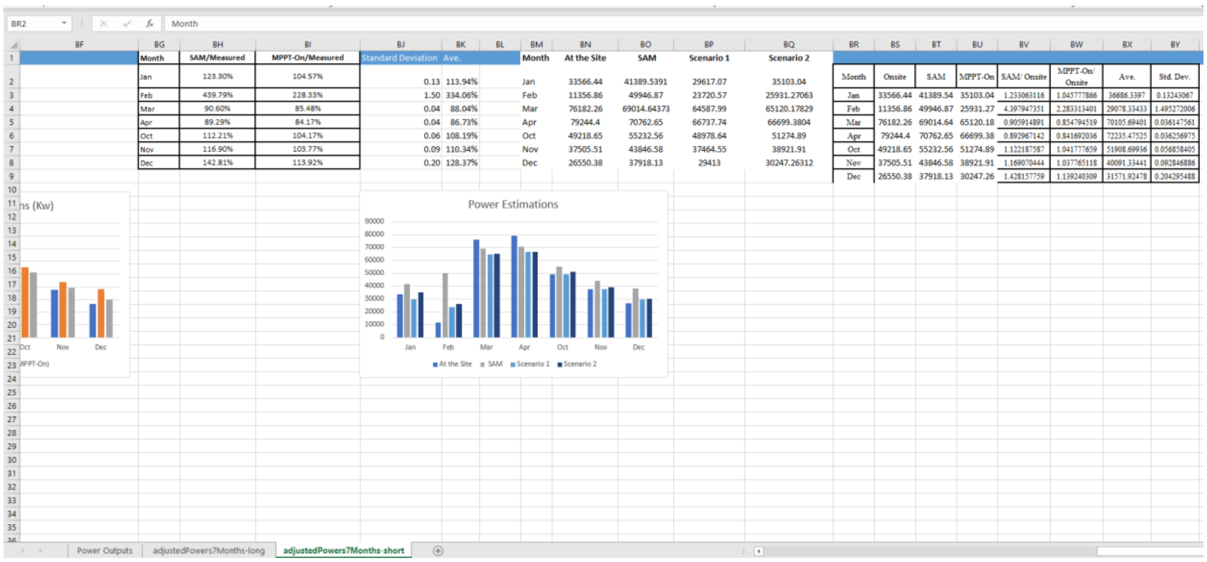
Comparing daily power outputs in November: SAM simulation, using the ontology, and measured at the site



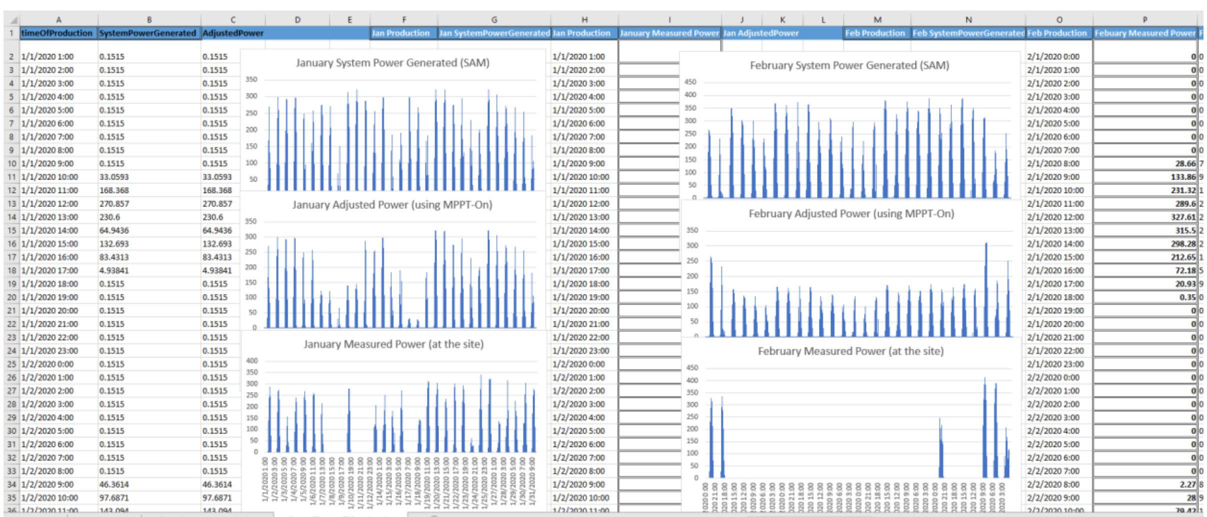
Comparing daily power outputs in December: SAM simulation, using the ontology, and measured at the site

ANNEX IX. The Excel File: Adjusted Powers for: Longer Shadings

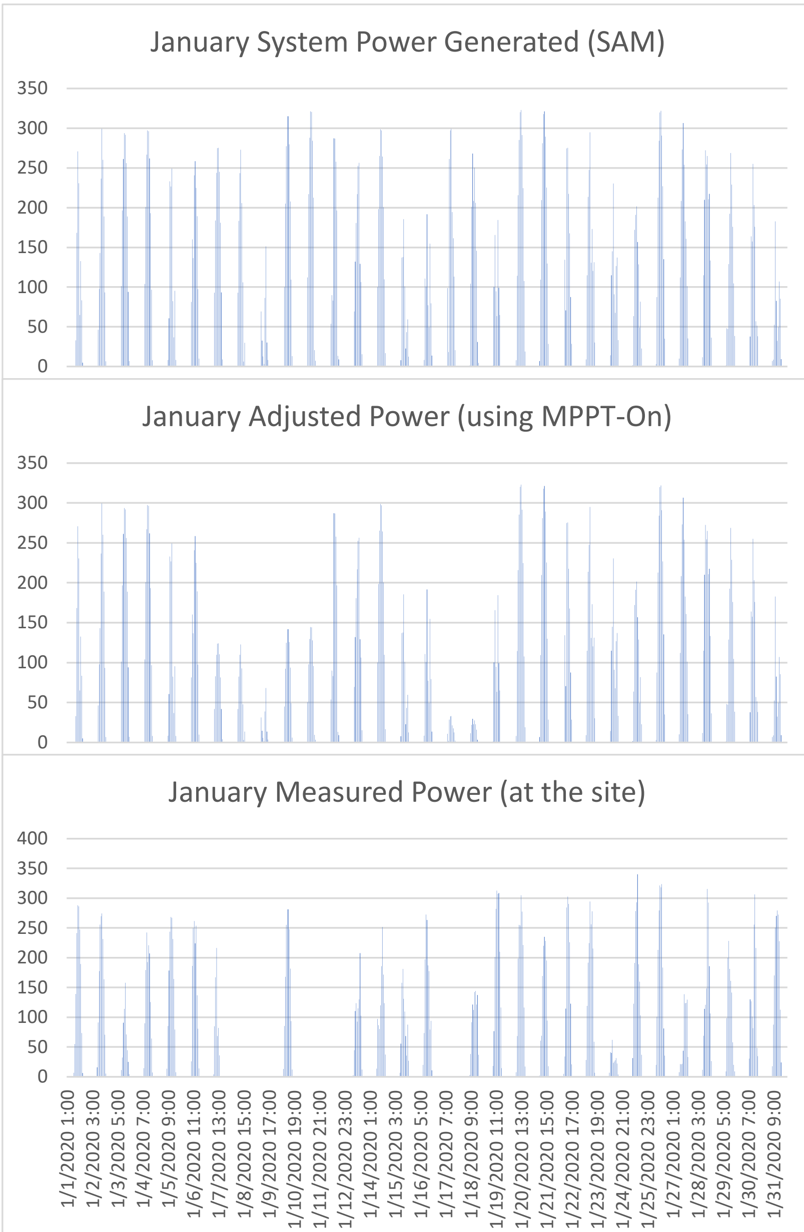
Hourly power generations: I) the SAM model, II) the application of MPPT-On, and III) measured power onsite



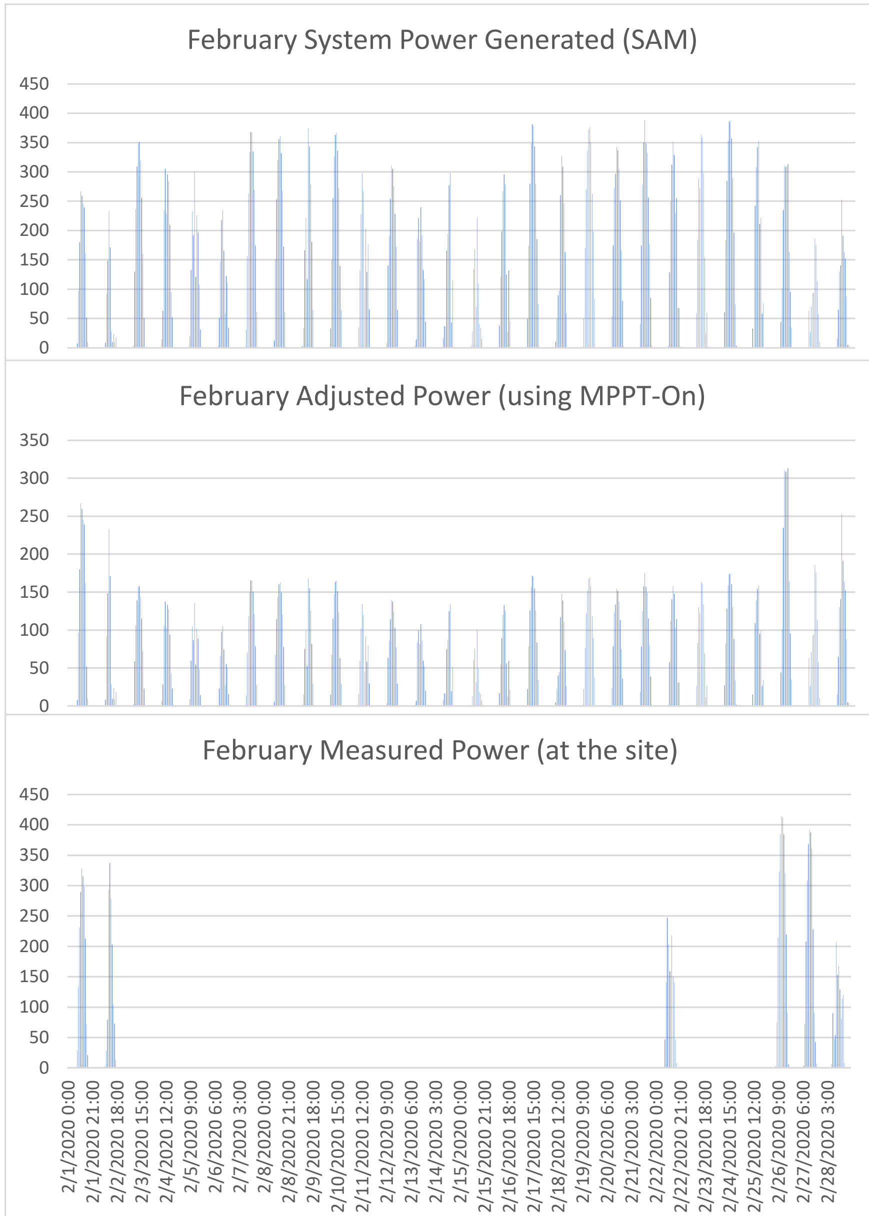
System power generations for months of (Jan-Apr) and (Oct-Dec) simulated by SAM



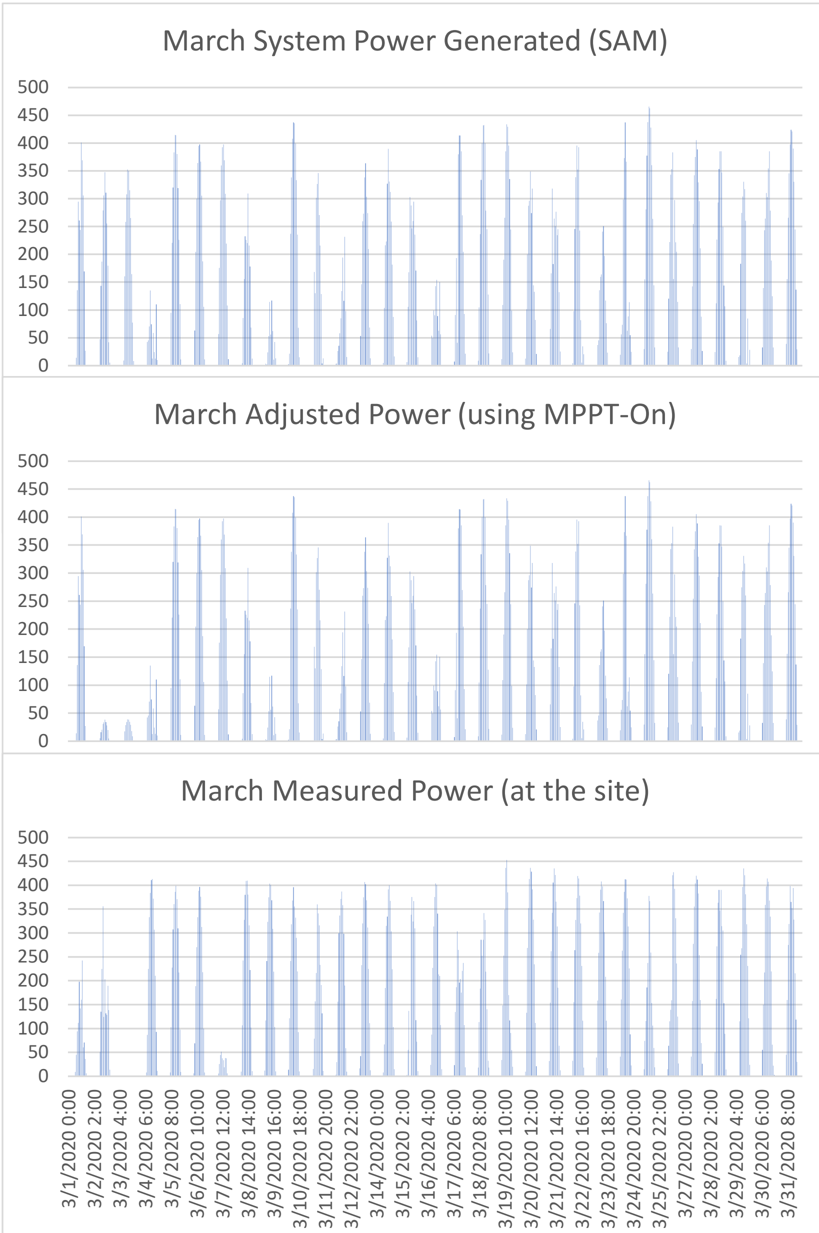
ANNEX X. Daily Power Outputs: Expecting Shorter Durations of Shading



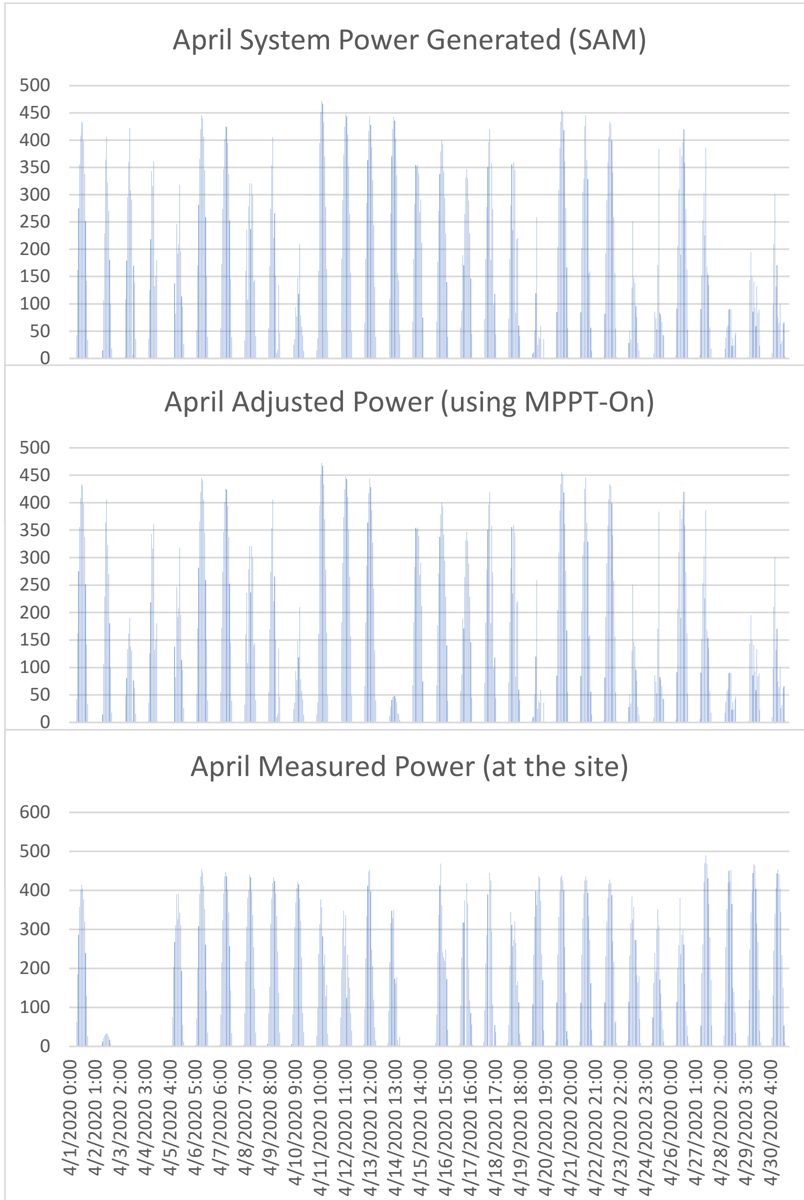
Comparing daily power outputs in January: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



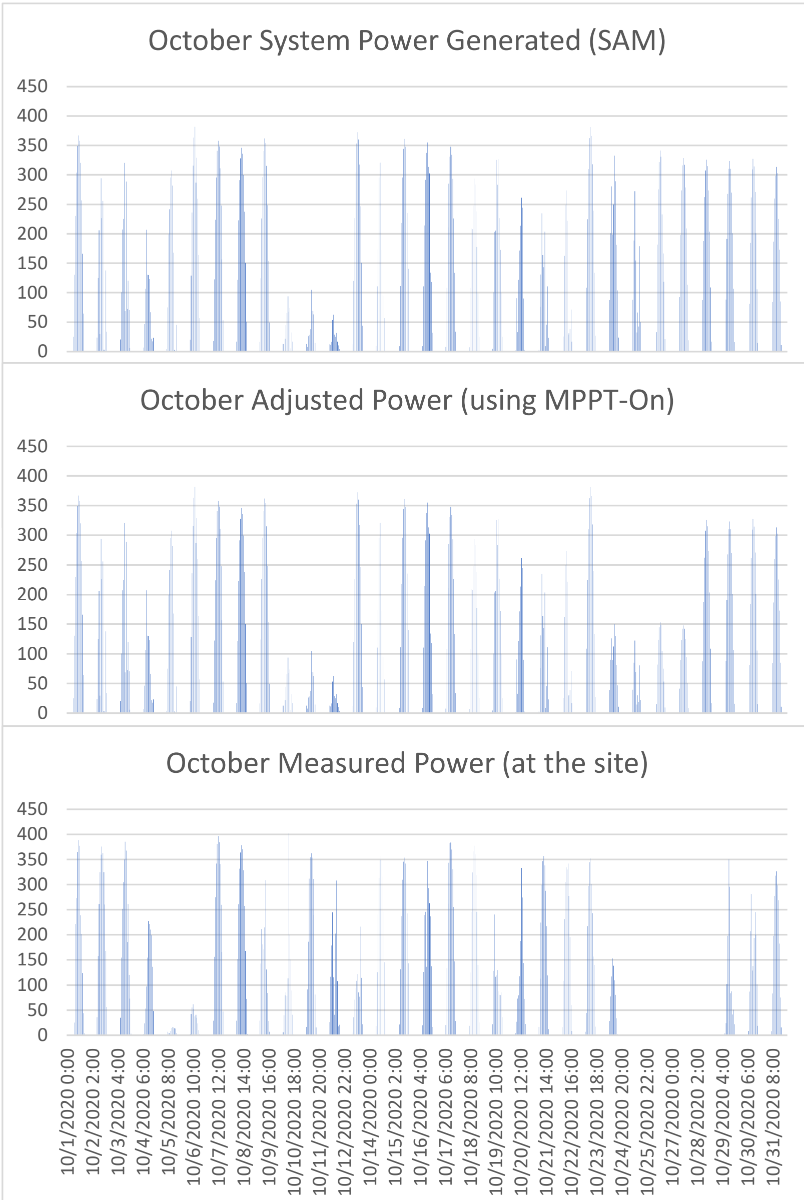
Comparing daily power outputs in February: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



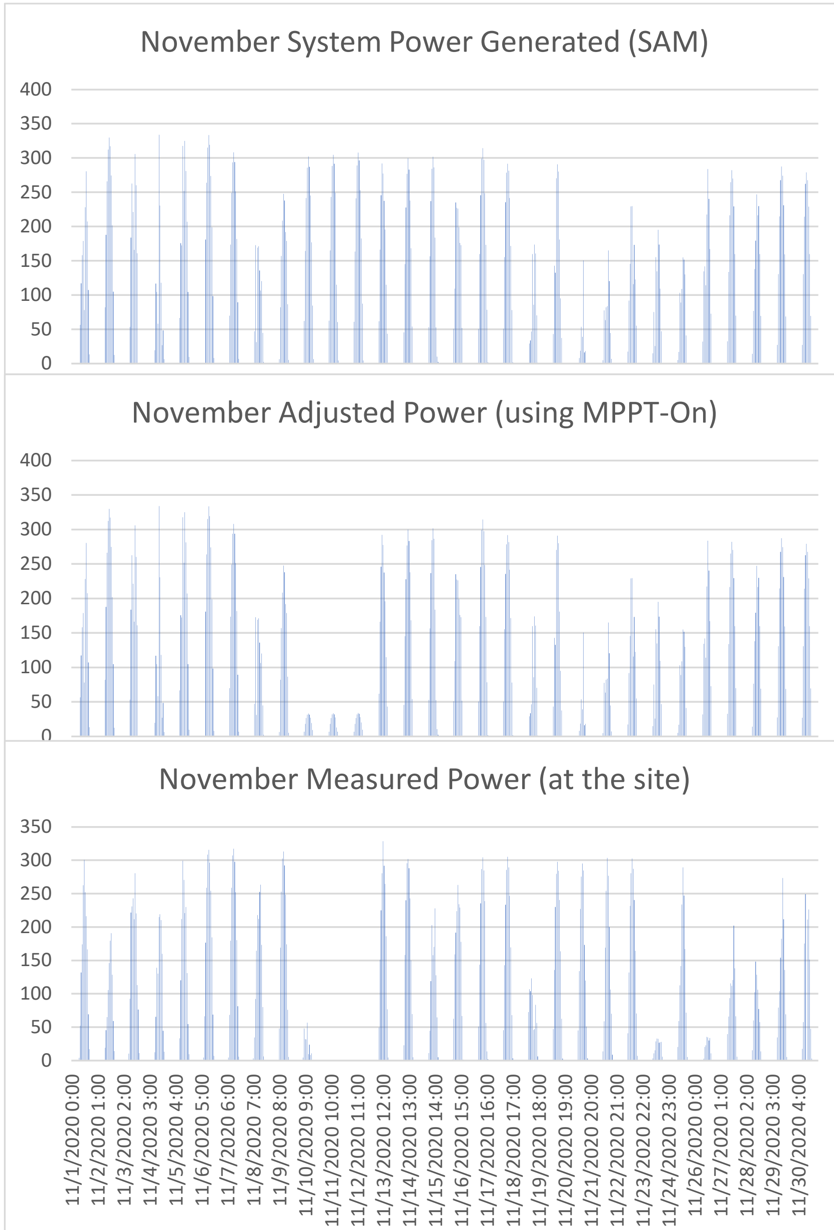
Comparing daily power outputs in March: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



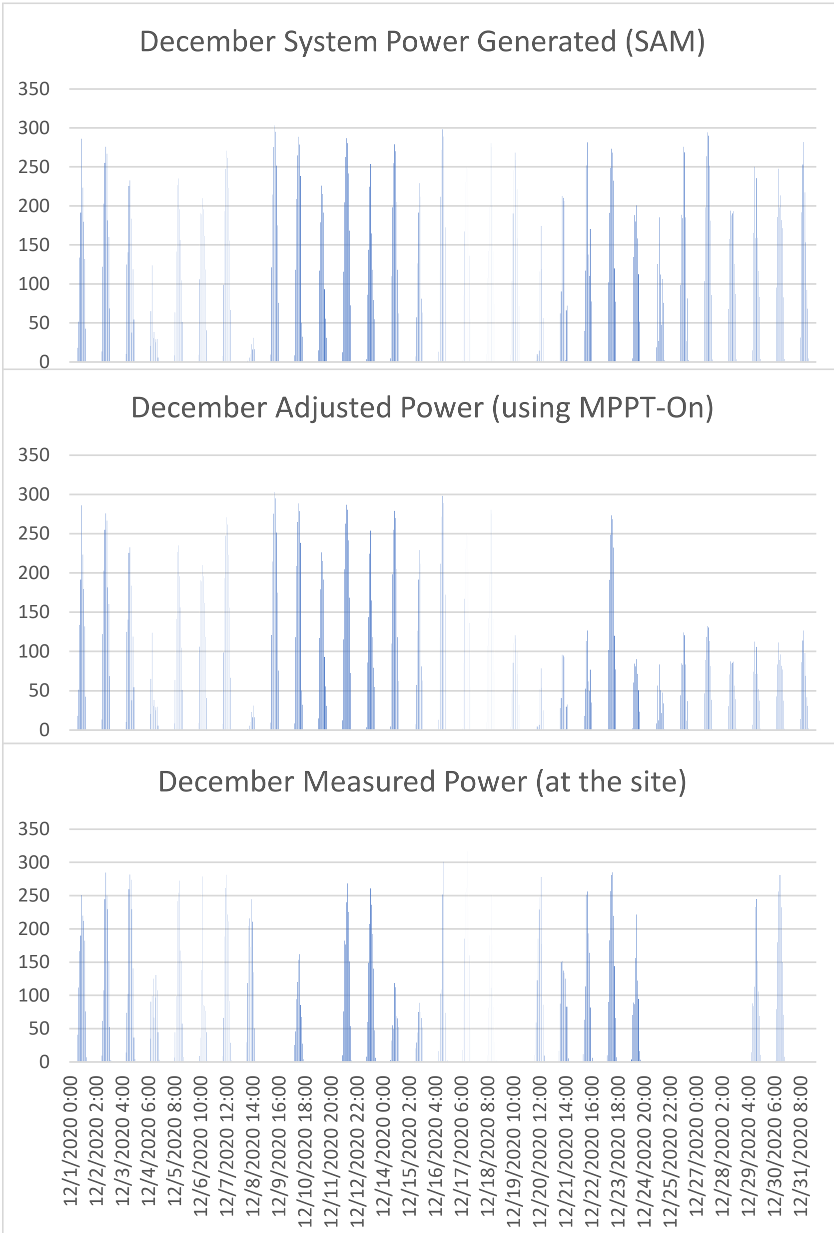
Comparing daily power outputs in April: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



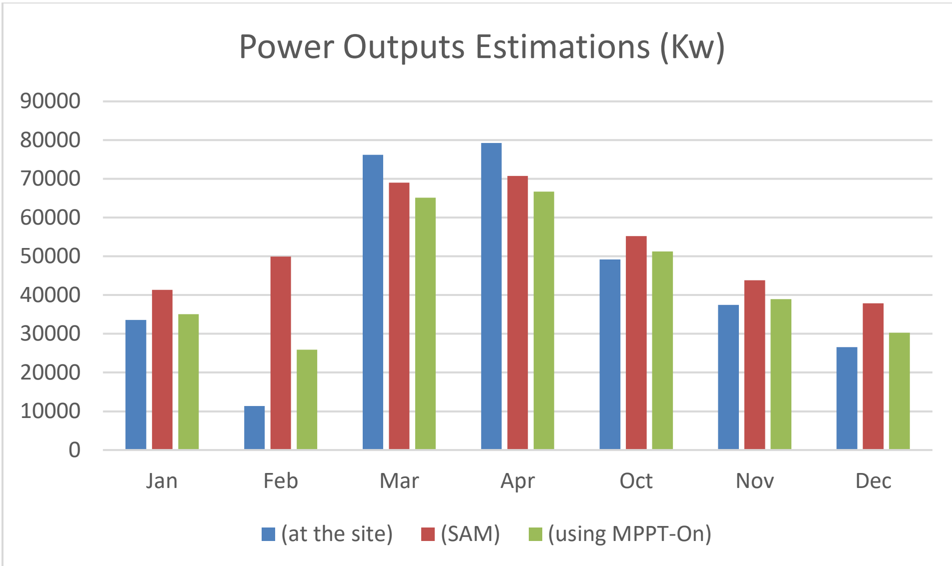
Comparing daily power outputs in October: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



Comparing daily power outputs in November: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



Comparing daily power outputs in December: SAM simulation, using the ontology, and measured at the site (shorter durations for snow coverings)



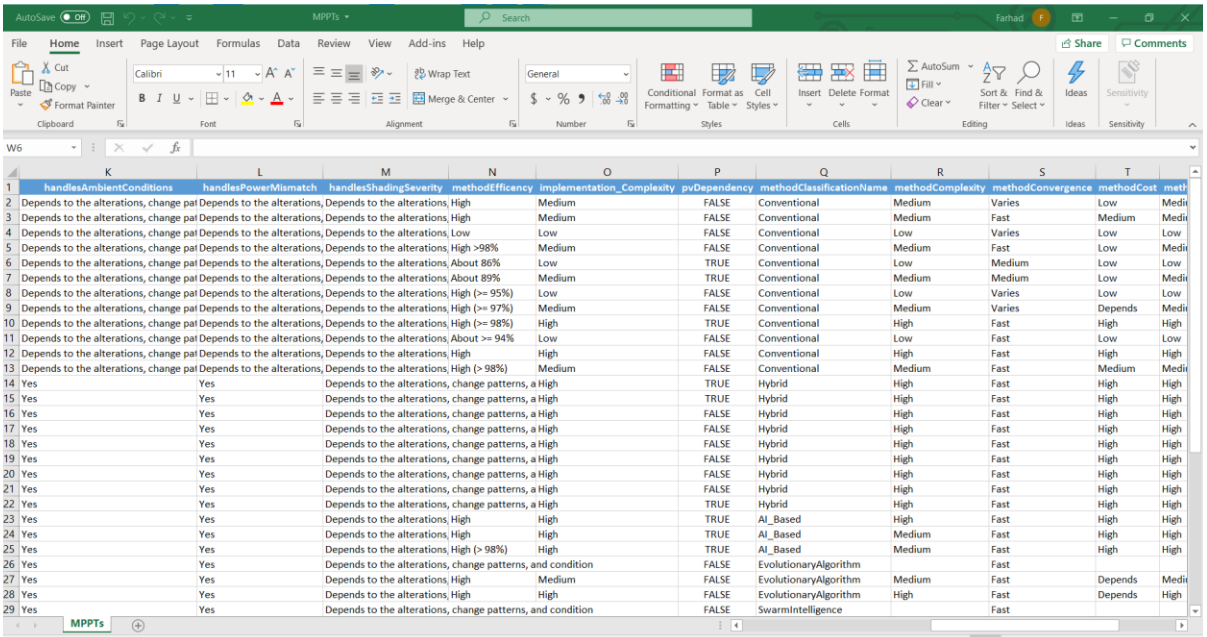
Monthly power outputs calculated by the three systems (expecting longer shading times)

Monthly power (Kw) output reports (expecting shorter durations for shading)

Month	Onsite	SAM	MPPT-On	SAM/ Onsite	MPPT-On/ Onsite
Jan	33,566.4	41,389.5	35,103	1.233	1.045
Feb	11,356.9	49,946.9	25,931.3	4.397	2.283
Mar	76,182.3	69,014.6	65,120.2	0.905	0.854
Apr	79,244.4	70,762.6	66,699.4	0.892	0.841
Oct	49,218.6	55,232.6	51,275	1.122	1.041
Nov	37,505.5	43,846.6	38,922	1.169	1.037
Dec	26,550.4	37,918.1	30,247.3	1.428	1.139

ANNEX XI. MPPT Methods (The Database): the Excel File

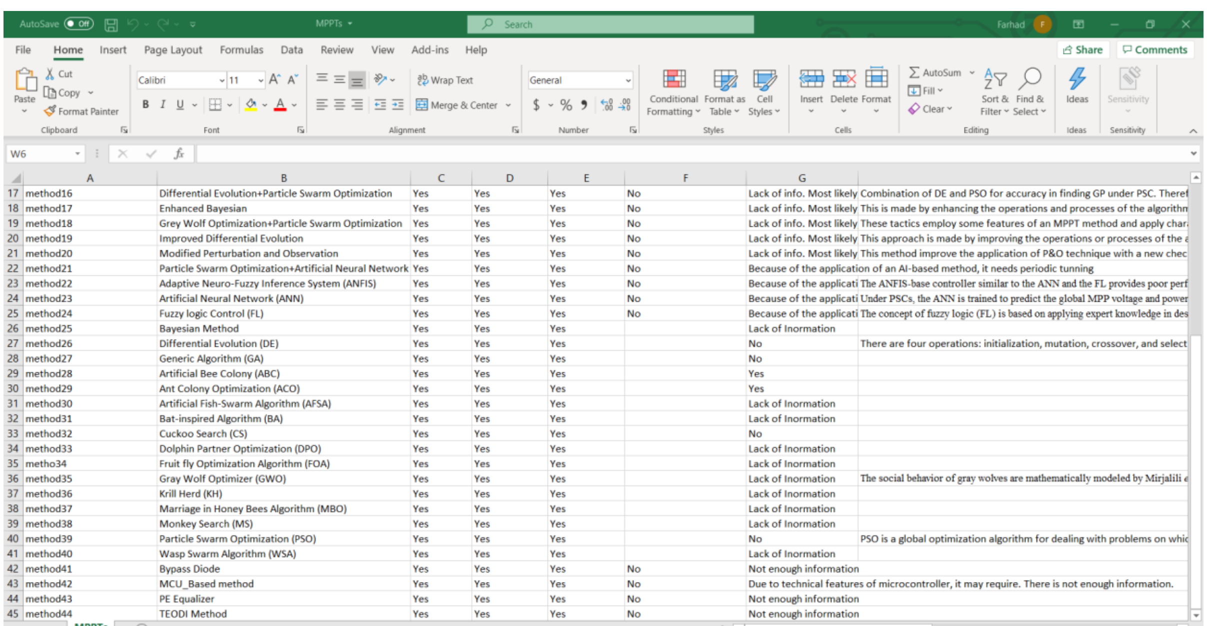
Data about characteristics of MPPT methods and their functionality dealing with shading conditions



	K	L	M	N	O	P	Q	R	S	T	
1	handlesAmbientConditions	handlesPowerMismatch	handlesShadingSeverity	methodEfficency	implementation_Complexity	pvDependency	methodClassificationName	methodComplexity	methodConvergence	methodCost	meth
2	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High	Medium	FALSE	Conventional	Medium	Varies	Low	Medi
3	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High	Medium	FALSE	Conventional	Medium	Fast	Medium	Medi
4	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	Low	Low	FALSE	Conventional	Low	Varies	Low	Low
5	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High >98%	Medium	FALSE	Conventional	Medium	Fast	Low	Medi
6	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	About 86%	Low	TRUE	Conventional	Low	Medium	Low	Low
7	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	About 89%	Medium	TRUE	Conventional	Medium	Medium	Low	Medi
8	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High (>= 95%)	Low	FALSE	Conventional	Low	Varies	Low	Low
9	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High (>= 97%)	Medium	FALSE	Conventional	Medium	Varies	Depends	Medi
10	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High (>= 98%)	High	TRUE	Conventional	High	Fast	High	High
11	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	About >= 94%	Low	FALSE	Conventional	Low	Fast	Low	Low
12	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High	High	FALSE	Conventional	High	Fast	High	High
13	Depends to the alterations, change pat	Depends to the alterations,	Depends to the alterations,	High (> 98%)	Medium	FALSE	Conventional	Medium	Fast	Medium	Medi
14	Yes	Yes	Depends to the alterations, change patterns, a		High	TRUE	Hybrid	High	Fast	High	High
15	Yes	Yes	Depends to the alterations, change patterns, a		High	TRUE	Hybrid	High	Fast	High	High
16	Yes	Yes	Depends to the alterations, change patterns, a		High	FALSE	Hybrid	High	Fast	High	High
17	Yes	Yes	Depends to the alterations, change patterns, a		High	FALSE	Hybrid	High	Fast	High	High
18	Yes	Yes	Depends to the alterations, change patterns, a		High	FALSE	Hybrid	High	Fast	High	High
19	Yes	Yes	Depends to the alterations, change patterns, a		High	FALSE	Hybrid	High	Fast	High	High
20	Yes	Yes	Depends to the alterations, change patterns, a		High	FALSE	Hybrid	High	Fast	High	High
21	Yes	Yes	Depends to the alterations, change patterns, a		High	FALSE	Hybrid	High	Fast	High	High
22	Yes	Yes	Depends to the alterations, change patterns, a		High	TRUE	Hybrid	High	Fast	High	High
23	Yes	Yes	Depends to the alterations,	High	High	TRUE	AI_Based	High	Fast	High	High
24	Yes	Yes	Depends to the alterations,	High	High	TRUE	AI_Based	Medium	Fast	High	High
25	Yes	Yes	Depends to the alterations,	High (> 98%)	High	TRUE	AI_Based	Medium	Fast	High	High
26	Yes	Yes	Depends to the alterations, change patterns, and condition			FALSE	EvolutionaryAlgorithm		Fast		
27	Yes	Yes	Depends to the alterations,	High	Medium	FALSE	EvolutionaryAlgorithm	Medium	Fast	Depends	Medi
28	Yes	Yes	Depends to the alterations,	High	High	FALSE	EvolutionaryAlgorithm	High	Fast	Depends	High
29	Yes	Yes	Depends to the alterations, change patterns, and condition			FALSE	SwarmIntelligence		Fast		

MPPTs

MPPT methods added to the MPPT-On as individuals included in a database



	A	B	C	D	E	F	G	
17	method16	Differential Evolution+Particle Swarm Optimization	Yes	Yes	Yes	No	Lack of info. Most likely	Combination of DE and PSO for accuracy in finding GP under PSC. Theref
18	method17	Enhanced Bayesian	Yes	Yes	Yes	No	Lack of info. Most likely	This is made by enhancing the operations and processes of the algorithm
19	method18	Grey Wolf Optimization+Particle Swarm Optimization	Yes	Yes	Yes	No	Lack of info. Most likely	These tactics employ some features of an MPPT method and apply char
20	method19	Improved Differential Evolution	Yes	Yes	Yes	No	Lack of info. Most likely	This approach is made by improving the operations or processes of the a
21	method20	Modified Perturbation and Observation	Yes	Yes	Yes	No	Lack of info. Most likely	This method improve the application of P&O technique with a new chec
22	method21	Particle Swarm Optimization+Artificial Neural Network	Yes	Yes	Yes	No	Because of the application of an AI-based method, it needs periodic tunning	
23	method22	Adaptive Neuro-Fuzzy Inference System (ANFIS)	Yes	Yes	Yes	No	Because of the applicati	The ANFIS-base controller similar to the ANN and the FL provides poor perf
24	method23	Artificial Neural Network (ANN)	Yes	Yes	Yes	No	Because of the applicati	Under PSCs, the ANN is trained to predict the global MPP voltage and power
25	method24	Fuzzy logic Control (FL)	Yes	Yes	Yes	No	Because of the applicati	The concept of fuzzy logic (FL) is based on applying expert knowledge in des
26	method25	Bayesian Method	Yes	Yes	Yes		Lack of Inormation	
27	method26	Differential Evolution (DE)	Yes	Yes	Yes		No	There are four operations: initialization, mutation, crossover, and select
28	method27	Generic Algorithm (GA)	Yes	Yes	Yes		No	
29	method28	Artificial Bee Colony (ABC)	Yes	Yes	Yes		Yes	
30	method29	Ant Colony Optimization (ACO)	Yes	Yes	Yes		Yes	
31	method30	Artificial Fish-Swarm Algorithm (AFSA)	Yes	Yes	Yes		Lack of Inormation	
32	method31	Bat-inspired Algorithm (BA)	Yes	Yes	Yes		Lack of Inormation	
33	method32	Cuckoo Search (CS)	Yes	Yes	Yes		No	
34	method33	Dolphin Partner Optimization (DPO)	Yes	Yes	Yes		Lack of Inormation	
35	metho34	Fruit fly Optimization Algorithm (FOA)	Yes	Yes	Yes		Lack of Inormation	
36	method35	Gray Wolf Optimizer (GWO)	Yes	Yes	Yes		Lack of Inormation	The social behavior of gray wolves are mathematically modeled by Mirjalili e
37	method36	Krill Herd (KH)	Yes	Yes	Yes		Lack of Inormation	
38	method37	Marriage in Honey Bees Algorithm (MBO)	Yes	Yes	Yes		Lack of Inormation	
39	method38	Monkey Search (MS)	Yes	Yes	Yes		Lack of Inormation	
40	method39	Particle Swarm Optimization (PSO)	Yes	Yes	Yes		No	PSO is a global optimization algorithm for dealing with problems on whic
41	method40	Wasp Swarm Algorithm (WSA)	Yes	Yes	Yes		Lack of Inormation	
42	method41	Bypass Diode	Yes	Yes	Yes	No	Not enough information	
43	method42	MCU_Based method	Yes	Yes	Yes	No	Due to technical features of microcontroller, it may require. There is not enough information.	
44	method43	PE Equalizer	Yes	Yes	Yes	No	Not enough information	
45	method44	TEODI Method	Yes	Yes	Yes	No	Not enough information	

MPPTs

ANNEX XII. SAM Results for Mesa Top, RSF 1, RSF 2, S&TF

Name	Latitude	Longitude	Time zone	Elevation	Station ID	Source
fargo_nd_46.9_-96.8_mts1_60_tmy	46.9	-96.8	-6	274	14914	TMY2
imperial_ca_32.835205_-115.572398_psmv3_60_tmy	32.85	-115.58	-8	-20	72911	NSRDB
phoenix_az_33.450495_-111.983688_psmv3_60_tmy	33.45	-111.98	-7	358	78208	NSRDB
tucson_az_32.116521_-110.933042_psmv3_60_tmy	32.13	-110.94	-7	773	67345	NSRDB
golden_39.749672_-105.216019_psm3_60_tmy	39.73	-105.22	-7	1934	145808	NSRDB
India_IND_Agartala (SUNY)	23.85	91.25	5.5	0	80048	SUNY

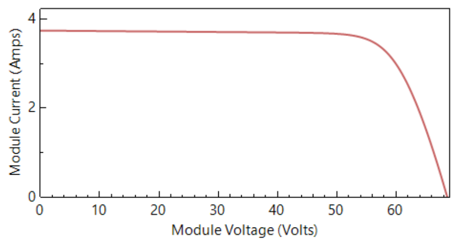
SAM scans the following folders on your computer for valid weather files and adds them to your Solar Resource library. To use weather files stored on your computer, click Add/remove Weather File Folders and add folders containing valid weather files.

Mesa:

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C

SANYO ELECTRIC CO LTD OF PANASONIC GROUP HIP-195DA3



			Temperature coefficients			
Nominal efficiency	16.1405	%				
Maximum power (Pmp)	195.300	Wdc	-0.340	%/°C	-0.664	W/°C
Max power voltage (Vmp)	55.8	Vdc				
Max power current (Imp)	3.5	Adc				
Open circuit voltage (Voc)	68.7	Vdc	-0.280		-0.192	V/°C
Short circuit current (Isc)	3.7	Adc	0.046	%/°C	0.002	A/°C

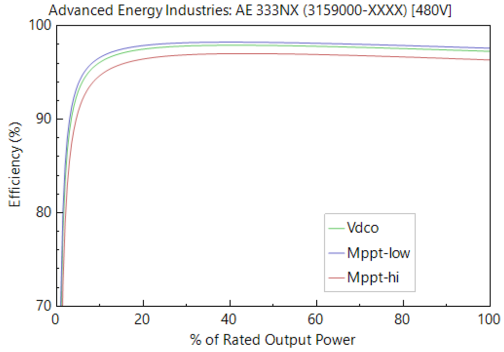
Bifacial Specifications

☐ Module is bifacial

Transmission fraction	0.013	0-1
Bifaciality	0.65	0-1
Ground clearance height	1	m

Efficiency Curve and Characteristics

Advanced Energy Industries: AE 333NX (3159000-XXXX) [480V]



Number of MPPT inputs: 1

CEC weighted efficiency: 97.619 %

European weighted efficiency: 97.449 %

Datasheet Parameters

Maximum AC power	333000	Wac
Maximum DC power	342385	Wdc
Power use during operation	1101.4	Wdc
Power use at night	99.9	Wac
Nominal AC voltage	480	Vac
Maximum DC voltage	960	Vdc
Maximum DC current	462.682	Adc
Minimum MPPT DC voltage	660	Vdc
Nominal DC voltage	740	Vdc
Maximum MPPT DC voltage	960	Vdc

Sandia Coefficients

C0	-5.53e-08	1/Wac
C1	4.4e-05	1/Vdc
C2	0.001128	1/Vdc
C3	0.000516	1/Vdc

Note: If you are modeling a system with microinverters or DC power optimizers, see the Losses page to adjust the system losses accordingly.

CEC Information

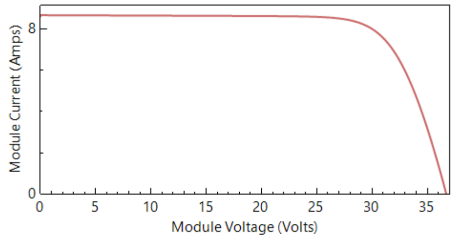
CEC name: Advanced Energy Industries: AE 333NX (3159000-XXXX) [480V] — CEC type: Utility Interactive — CEC date: n/a

RSF 1:

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C

Solon Solon Black 230/15 240



	Value	Unit	Temperature coefficients	Unit		Unit
Nominal efficiency	16.0039	%				
Maximum power (Pmp)	240.218	Wdc	-0.495	%/°C	-1.189	W/°C
Max power voltage (Vmp)	29.6	Vdc				
Max power current (Imp)	8.1	Adc				
Open circuit voltage (Voc)	36.8	Vdc	-0.376		-0.138	V/°C
Short circuit current (Isc)	8.6	Adc	0.046	%/°C	0.004	A/°C

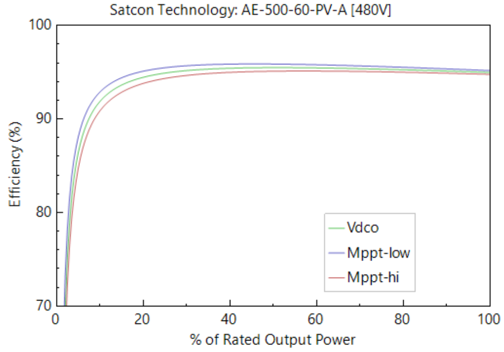
Bifacial Specifications

☐ Module is bifacial

Transmission fraction	0.013	0-1
Bifaciality	0.65	0-1
Ground clearance height	1	m

Efficiency Curve and Characteristics

Satcon Technology: AE-500-60-PV-A [480V]



Number of MPPT inputs: 1

CEC weighted efficiency: 95.138 %

European weighted efficiency: 94.725 %

Datasheet Parameters

Maximum AC power	500000	Wac
Maximum DC power	526492	Wdc
Power use during operation	3024.81	Wdc
Power use at night	150	Wac
Nominal AC voltage	480	Vac
Maximum DC voltage	480	Vdc
Maximum DC current	1299.98	Adc
Minimum MPPT DC voltage	330	Vdc
Nominal DC voltage	405	Vdc
Maximum MPPT DC voltage	480	Vdc

Sandia Coefficients

C0	-4.1e-08	1/Wac
C1	2.9e-05	1/Vdc
C2	0.001625	1/Vdc
C3	-0.001414	1/Vdc

Note: If you are modeling a system with microinverters or DC power optimizers, see the Losses page to adjust the system losses accordingly.

CEC Information

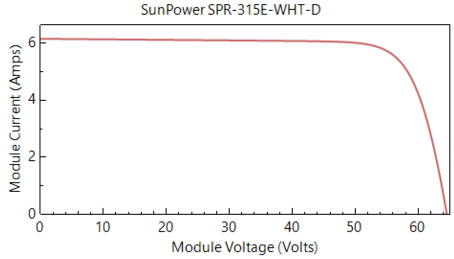
CEC name: Satcon Technology: AE-500-60-PV-A [480V] CEC type: Utility Interactive CEC date: n/a

RSF 2:

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C

SunPower SPR-315E-WHT-D

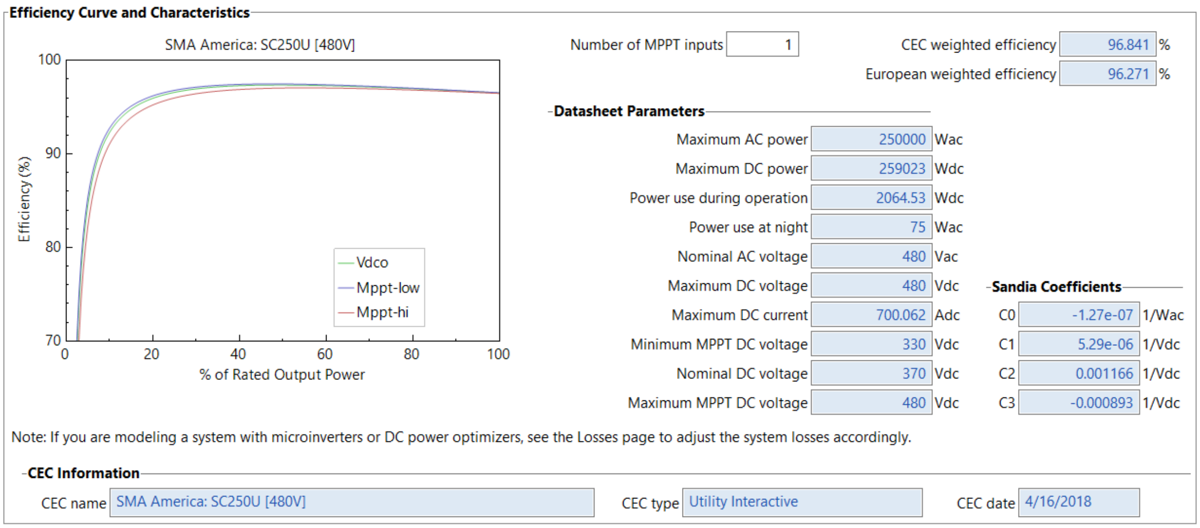


	Value	Unit	Temperature coefficients	Unit		Unit
Nominal efficiency	19.3177	%				
Maximum power (Pmp)	315.072	Wdc	-0.386	%/°C	-1.216	W/°C
Max power voltage (Vmp)	54.7	Vdc				
Max power current (Imp)	5.8	Adc				
Open circuit voltage (Voc)	64.6	Vdc	-0.273		-0.176	V/°C
Short circuit current (Isc)	6.1	Adc	0.062	%/°C	0.004	A/°C

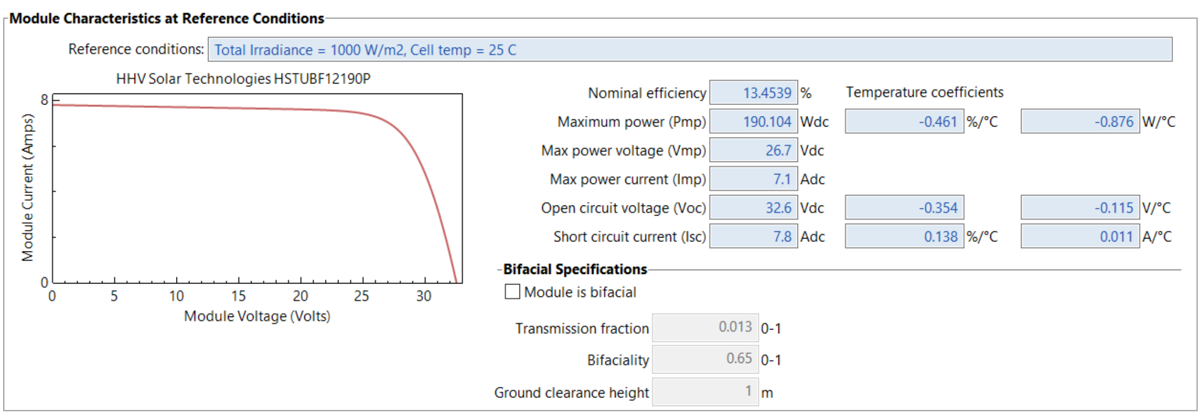
Bifacial Specifications

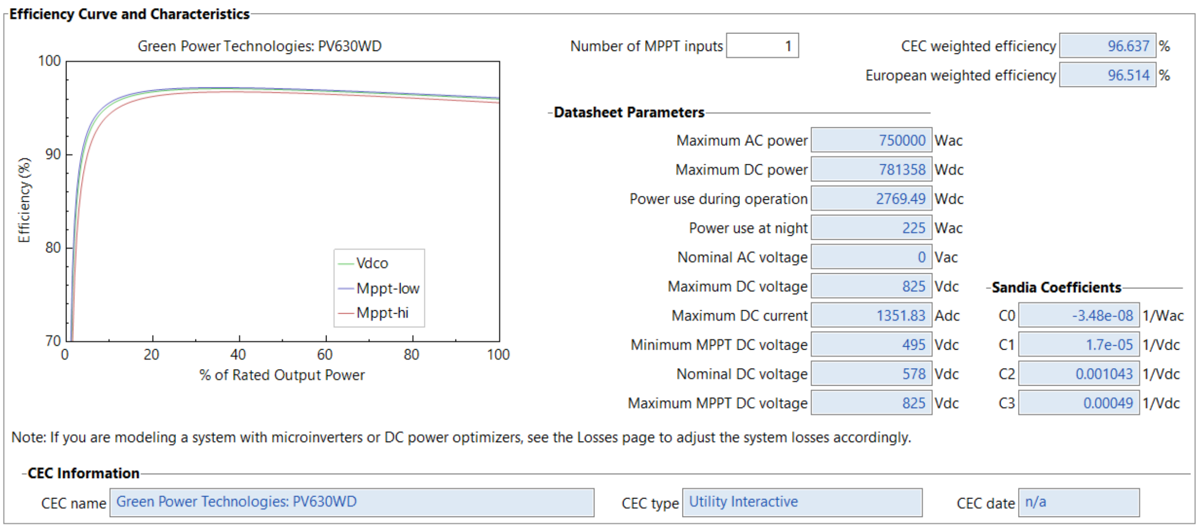
☐ Module is bifacial

Transmission fraction	0.013	0-1
Bifaciality	0.65	0-1
Ground clearance height	1	m


Efficiency Curve and Characteristics
SMA America: SC250U [480V]
Efficiency (%)
% of Rated Output Power
Vdco
Mppt-low
Mppt-hi
Number of MPPT inputs 1
CEC weighted efficiency 96.841 %
European weighted efficiency 96.271 %
Datasheet Parameters
Maximum AC power 250000 Wac
Maximum DC power 259023 Wdc
Power use during operation 2064.53 Wdc
Power use at night 75 Wac
Nominal AC voltage 480 Vac
Maximum DC voltage 480 Vdc
Maximum DC current 700.062 Adc
Minimum MPPT DC voltage 330 Vdc
Nominal DC voltage 370 Vdc
Maximum MPPT DC voltage 480 Vdc
Sandia Coefficients
C0 -1.27e-07 1/Wac
C1 5.29e-06 1/Vdc
C2 0.001166 1/Vdc
C3 -0.000893 1/Vdc
Note: If you are modeling a system with microinverters or DC power optimizers, see the Losses page to adjust the system losses accordingly.
CEC Information
CEC name SMA America: SC250U [480V]
CEC type Utility Interactive
CEC date 4/16/2018

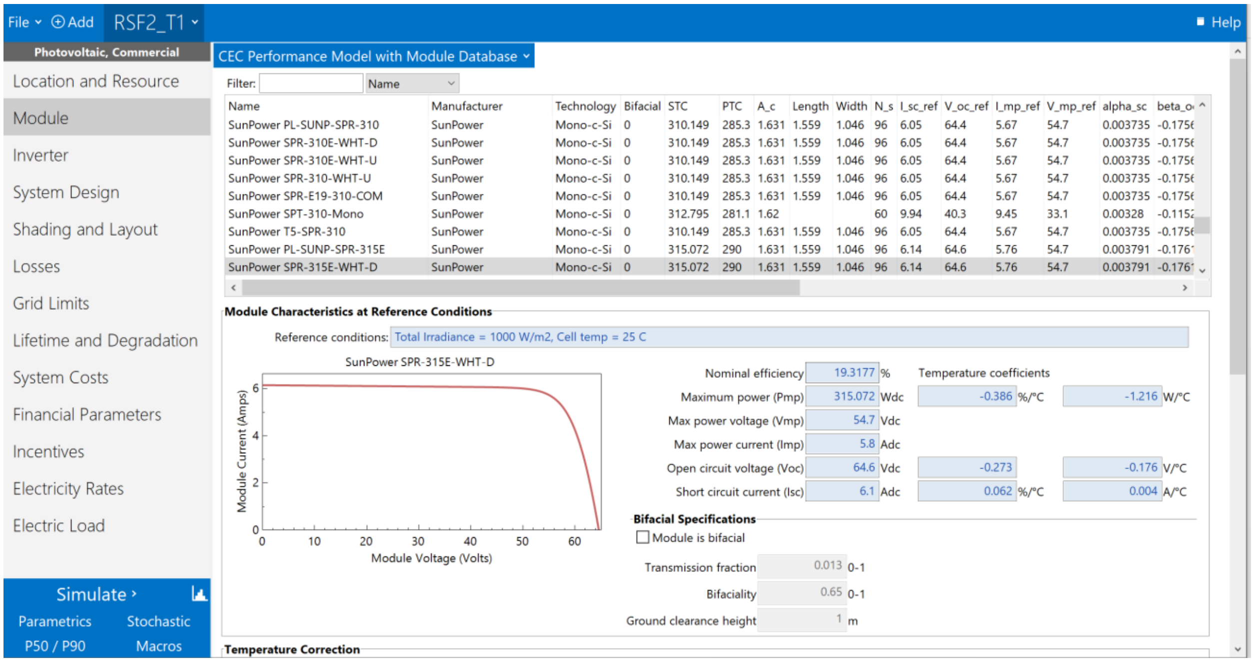
S & TF:


Module Characteristics at Reference Conditions
Reference conditions: Total Irradiance = 1000 W/m2, Cell temp = 25 C
HHV Solar Technologies HSTUBF12190P
Module Current (Amps)
Module Voltage (Volts)
Nominal efficiency 13.4539 %
Temperature coefficients
Maximum power (Pmp) 190.104 Wdc -0.461 %/°C -0.876 W/°C
Max power voltage (Vmp) 26.7 Vdc
Max power current (Imp) 7.1 Adc
Open circuit voltage (Voc) 32.6 Vdc -0.354 -0.115 V/°C
Short circuit current (Isc) 7.8 Adc 0.138 %/°C 0.011 A/°C
Bifacial Specifications
Module is bifacial
Transmission fraction 0.013 0-1
Bifaciality 0.65 0-1
Ground clearance height 1 m

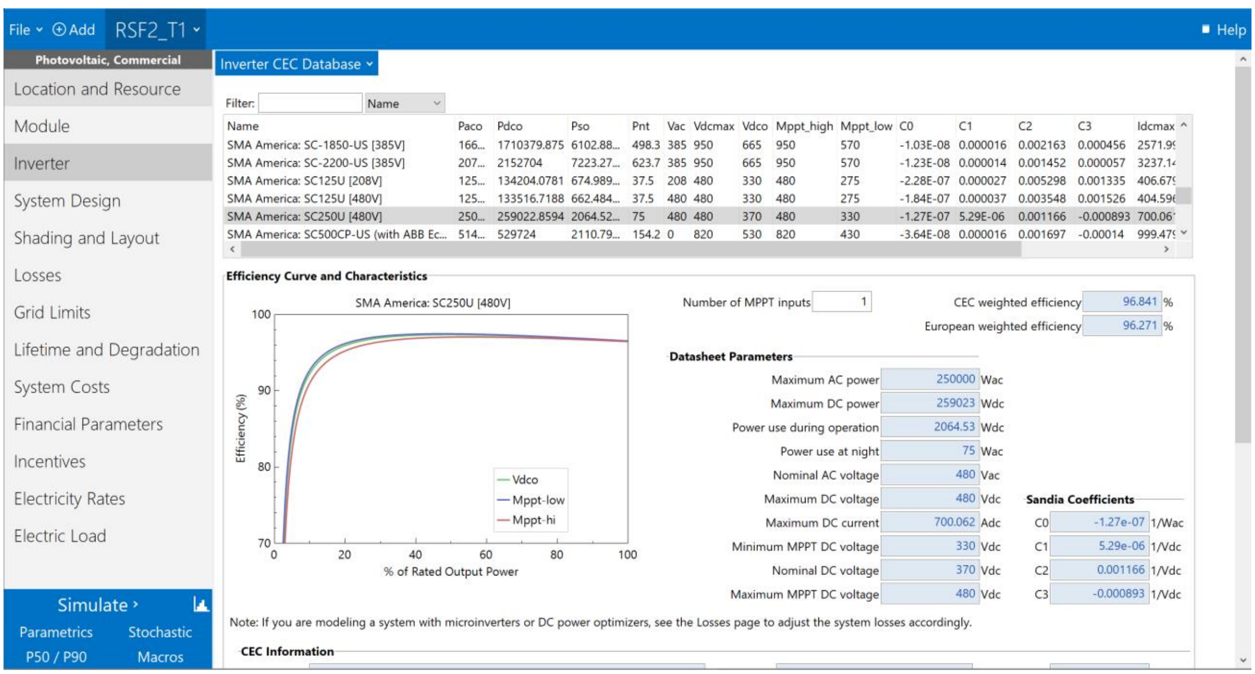

Efficiency Curve and Characteristics
Green Power Technologies: PV630WD
Efficiency (%)
100
90
80
70
0
20
40
60
80
100
% of Rated Output Power
Vdco
Mppt-low
Mppt-hi
Number of MPPT inputs 1
CEC weighted efficiency 96.637 %
European weighted efficiency 96.514 %
Datasheet Parameters
Maximum AC power 750000 Wac
Maximum DC power 781358 Wdc
Power use during operation 2769.49 Wdc
Power use at night 225 Wac
Nominal AC voltage 0 Vac
Maximum DC voltage 825 Vdc
Maximum DC current 1351.83 Adc
Minimum MPPT DC voltage 495 Vdc
Nominal DC voltage 578 Vdc
Maximum MPPT DC voltage 825 Vdc
Sandia Coefficients
C0 -3.48e-08 1/Wac
C1 1.7e-05 1/Vdc
C2 0.001043 1/Vdc
C3 0.00049 1/Vdc
Note: If you are modeling a system with microinverters or DC power optimizers, see the Losses page to adjust the system losses accordingly.
CEC Information
CEC name Green Power Technologies: PV630WD
CEC type Utility Interactive
CEC date n/a

ANNEX XIII. SAM Results: Third Party Participant (screenshots)

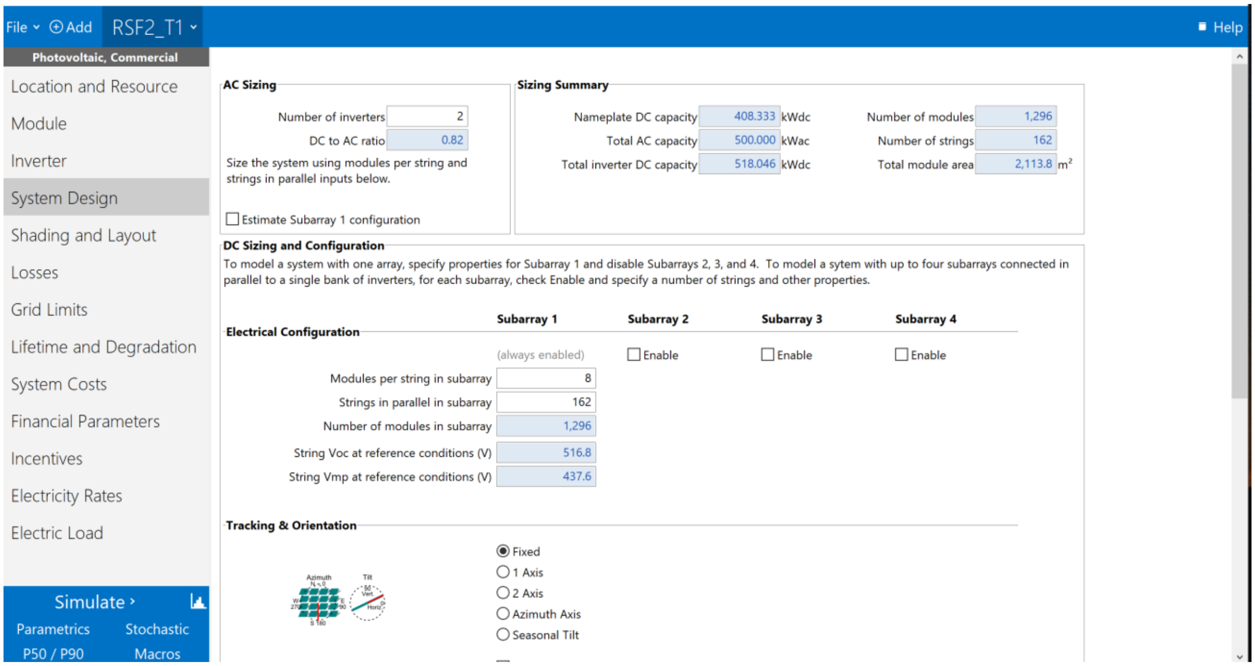
Module selected to match that of the validated pdf



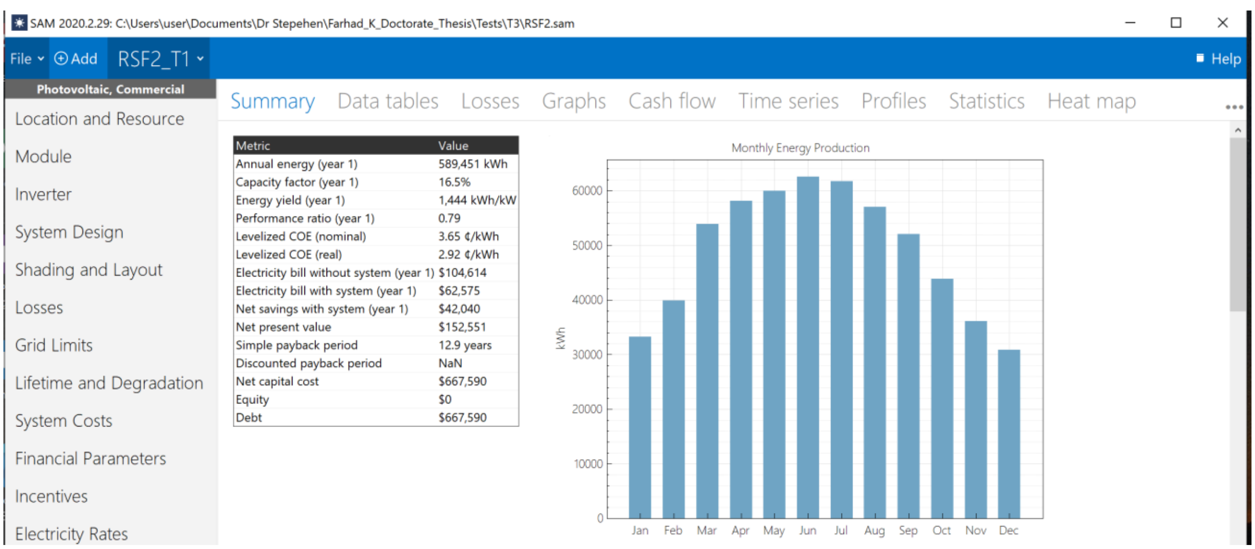
Inverter selected to match that of the validated pdf



Arrays selected to match that of the validated pdf



Simulated output produced by SAM after all the specifications were selected



Metric	Value
Annual energy (year 1)	589,451 kWh
Capacity factor (year 1)	16.5%
Energy yield (year 1)	1,444 kWh/kW
Performance ratio (year 1)	0.79
Levelized COE (nominal)	3.65 ¢/kWh
Levelized COE (real)	2.92 ¢/kWh
Electricity bill without system (year 1)	$104,614
Electricity bill with system (year 1)	$62,575
Net savings with system (year 1)	$42,040
Net present value	$152,551
Simple payback period	12.9 years
Discounted payback period	NaN
Net capital cost	$667,590
Equity	$0
Debt	$667,590

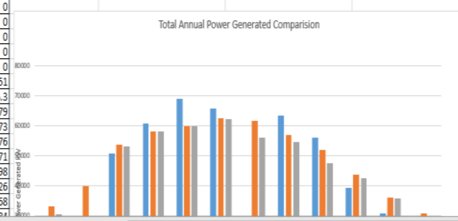
RSF 2: The Excel file of the output results

Time stamp	ystem power generated | (kW	AvgSnowDepth(cm)	SAM - Power Generated	Applying MPPT-On (kW)	Measured	Actual Power Measured (kW)
2020-01-01 0:00	-0.1515	0	0	0	-999	0
2020-01-01 1:00	-0.1515	0.3209	0	0	-999	0
2020-01-01 2:00	-0.1515	0.3833	0	0	-999	0
2020-01-01 3:00	-0.1515	0.3972	0	0	-999	0
2020-01-01 4:00	-0.1515	0.4901	0	0	-999	0
2020-01-01 5:00	-0.1515	0.4534	0	0	-999	0
2020-01-01 6:00	-0.1515	0.5516	0	0	-999	0
2020-01-01 7:00	-0.1515	0.5801	0	0	4.12	4.12
2020-01-01 8:00	-0.1515	0.6022	0	0	44.34	44.34
2020-01-01 9:00	24.6027	0.6223	24.6027	21.896403	122.59	122.59
2020-01-01 10:00	135.296	0.6409	135.296	120.41344	201.83	201.83
2020-01-01 11:00	221.125	0.6734	221.125	196.80125	241.07	241.07
2020-01-01 12:00	186.188	0.643	186.188	165.70732	236.76	236.76
2020-01-01 13:00	48.9215	0.5271	48.9215	43.540135	206.98	206.98
2020-01-01 14:00	106.214	0.2141	106.214	94.53046	160.52	160.52
2020-01-01 15:00	67.9858	0.2798	67.9858	60.507362	68.47	68.47
2020-01-01 16:00	2.76175	0.2315	2.76175	2.4579575	5.64	5.64
2020-01-01 17:00	-0.1515	0.2566	0	0	-999	0
2020-01-01 18:00	-0.1515	0.2859	0	0	-999	0
2020-01-01 19:00	-0.1515	0.3019	0	0	-999	0
2020-01-01 20:00	-0.1515	0.2632	0	0	-999	0
2020-01-01 21:00	-0.1515	0.302	0	0	-999	0
2020-01-01 22:00	-0.1515	0.2604	0	0	-999	0
2020-01-01 23:00	-0.1515	0.2937	0	0	-999	0
2020-01-02 0:00	-0.1515	0.2802	0	0	-999	0
2020-01-02 1:00	-0.1515	0.3219	0	0	-999	0
2020-01-02 2:00	-0.1515	0.4212	0	0	-999	0
2020-01-02 3:00	-0.1515	0.4149	0	0	-999	0
2020-01-02 4:00	-0.1515	0.4558	0	0	-999	0
2020-01-02 5:00	-0.1515	0.4664	0	0	-999	0
2020-01-02 6:00	-0.1515	0.3558	0	0	-999	0
2020-01-02 7:00	-0.1515	0.4386	0	0	11.51	11.51
2020-01-02 8:00	37.5533	0.4062	37.5533	33.422437	86.3	86.3
2020-01-02 9:00	77.8506	0.2454	77.8506	69.287034	166.79	166.79
2020-01-02 10:00	113.901	0.1348	113.901	101.37189	215.73	215.73
2020-01-02 11:00	192.517	0.263	192.517	171.34013	226.76	226.76
2020-01-02 12:00	242.984	0.2494	242.984	216.25576	227.71	227.71
2020-01-02 13:00	211.018	0.132	211.018	187.80602	194.98	194.98
2020-01-02 14:00	153.899	0.0967	153.899	136.97011	141.26	141.26
2020-01-02 15:00	76.4113	-0.0711	76.4113	76.4113	68	68

Power Generated Validation (Kw)			
Actual Power Measured	SAM - Power Generated	Applying MPPT-On	
507136.38	590147.79	551577.3744	
507136	**590148**	**551577**	

Annual AC energy gross (kWh/y	595419		
Annual DC energy (kWh/yr)	620491		
Capacity factor (%)	16.4789		
Performance ratio	0.793027		
Energy yield (kWh/kW)	1443.55		

Time stamp	Actual	SAM	MPPT-On
Jan	28709.48	33307.8	30683.3816
Feb	2769.07	39891.3	24642.89965
Mar	50984.47	53888	53086.41837
Apr	60884.14	58173.5	58118.56309
May	69202.25	59988.5	59957.15365
Jun	65896.39	62604.7	62221.90177
Jul	16896.92	61784.2	56078.11932
Aug	63530.07	57007.7	54571.68313
Sep	56157.86	52033.9	47730.87865
Oct	39423.32	43858.2	42528.62295
Nov	30978.77	36079.2	35734.78682
Dec	21703.64	30833.8	26222.9654
Total Annual Energy Generated	507136.38	589450.8	551577.3744



RSF2 Output Generated

LIST OF BIBLIOGRAPHICAL REFERENCES

References

Uncategorized References

[1] A. M. S. Aldobhani and R. John, "Maximum power point tracking of PV System using ANFIS prediction and fuzzy logic tracking," presented at the The International Multiconference of Engineers and Computer Scientists Hong Kong, 19-21 March, 2008, 2008.

[2] B. Parida, S. Iniyan, and R. Goic, "A review of solar photovoltaic technologies," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 3, pp. 1625-1636, 2011.

[3] A. Bloom *et al.*, "It's Indisputable: Five Facts About Planning and Operating Modern Power Systems," *IEEE Power and Energy Magazine,* vol. 15, no. 6, pp. 22-30, 2017.

[4] M. Seyedmahmoudian *et al.*, "State of the art artificial intelligence-based MPPT techniques for mitigating partial shading effects on PV systems – A review," *Renewable and Sustainable Energy Reviews,* vol. 64, pp. 435-455, 2016.

[5] S. Subiyanto, A. Mohamed, and M. A. Hannan, "Intelligent maximum power point tracking for PV system using Hopfield neural network optimized fuzzy logic controller," *Energy and Buildings*, vol. 51, pp. 29-38, 2012.

[6] F. Khosrojerdi and N. Mazlum, "Effects of Irradiance Patterns on Efficiency of a Photovoltaic System Controlled by the Perturbation and Observation Method," in *9th PEDSTC*, Tehran, Iran, 2018, p. 6: IEEE.

[7] A. M. S. Aldobhani and R. John, "Maximum Power Point Tracking of PV System Using ANFIS Prediction and Fuzzy Logic Tracking," in *International MultiConference of Engineers and Computer Scientists*, Hong Kong, 2008, vol. II, p. 8.

[8] Y. Poissant and A. C. Vikis, "Overview of photovoltaic solar cell R&D capability in Canada ED. 4," in "CanmetENERGY, Varennes Research Centre," Natural Resources Canada2013.

[9] A. G´omez-P´erez, "Evaluation of Ontologies," *International Journal of Intelligent Systems*, vol. 16, pp. 391-409, 2001.

[10] Wikipedia, "File:Semantic web stack.svg," 2015.

[11] P. Joshi and S. Arora, "Maximum power point tracking methodologies for solar PV systems – A review," *Renewable and Sustainable Energy Reviews,* vol. 70, pp. 1154-1177, 2017.

[12] D. Fensel, F. V. Harmelen, M. Klein, and H. Akkermans, "On-To-Knowledge: Ontology-based Tools for Knowledge Management," p. 7, 2000.

[13] B. Sun, Y. Li, T. Ye, and Y. Ren, "A novel ontology approach to support design for reliability considering environmental effects," *Scientific World Journal,* vol. 2015, p. 734984, 2015.

[14] N. F. Noy and D. L. McGuinness, "Ontology Development 101: A Guide to Creating Your First Ontology," Stanford University, Stanford, CA,2001.
[15] L. Ostrowski, M. Helfert, and N. Gama, "Ontology engineering step in design science research methodology: a technique to gather and reuse knowledge," *Behaviour & Information Technology,* vol. 33, no. 5, pp. 443-451, 2013.
[16] S. Kendal and M. Creen, *An Introduction to Knowledge Engineering*. Springer-Verlag Ltd, London, 2007.
[17] I. Sommerville, *Software Engineering*. Pearson Education Limited, UK., 2007.
[18] *PV Case Studies and Validation*, N. R. E. Laboratory, 2014.
[19] W. Na, T. Carley, L. Ketcham, B. Zimmer, and P. Chen, "Simple DSP Implementation of Maximum Power Pointer Tracking and Inverter Control for Solar Energy Applications," *Journal of Power and Energy Engineering,* vol. 04, no. 09, pp. 61-76, 2016.
[20] M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, "Effective Utilization of Available PEV Battery Capacity for Mitigation of Solar PV Impact and Grid Support With Integrated V2G Functionality," *IEEE Transactions on Smart Grid*, pp. 1-10, 2015.
[21] MathWorks. (2016). *PV Array*. Available: https://www.mathworks.com/help/physmod/sps/powersys/ref/pvarray.html
[22] P. A. Kumari and P. Geethanjali, "Parameter estimation for photovoltaic system under normal and partial shading conditions: A survey," *Renewable and Sustainable Energy Reviews*, vol. 84, pp. 1-11, 2018.
[23] V. J. Chin, Z. Salam, and K. Ishaque, "Cell modelling and model parameters estimation techniques for photovoltaic simulator application: A review," *Applied Energy,* vol. 154, pp. 500-519, 2015.
[24] A. Reza Reisi, M. Hassan Moradi, and S. Jamasb, "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review," *Renewable and Sustainable Energy Reviews,* vol. 19, pp. 433-443, 2013.
[25] K. Ishaque and Z. Salam, "An improved modeling method to determine the model parameters of photovoltaic (PV) modules using differential evolution (DE)," *Solar Energy,* vol. 85, no. 9, pp. 2349-2359, 2011.
[26] B. A. Alsayid, S. Y. Alsadi, J. f. S. Jallad, and M. H. Dradi, "Partial Shading of PV System Simulation with Experimental Results," *Smart Grid and Renewable Energy,* vol. 04, no. 06, pp. 429-435, 2013.
[27] F. Salem and M. A. Awadallah, "Detection and assessment of partial shading in photovoltaic arrays," *Journal of Electrical Systems and Information Technology,* vol. 3, no. 1, pp. 23-32, 2016.
[28] M. Seyedmahmoudian *et al.*, "Simulation and Hardware Implementation of New Maximum Power Point Tracking Technique for Partially Shaded PV System Using Hybrid DEPSO Method," *IEEE Transactions on Sustainable Energy,* vol. 6, no. 3, pp. 850-862, 2015.
[29] R.-l. Tang, Z. Wu, and Y.-j. Fang, "Maximum power point tracking of large-scale photovoltaic array," *Solar Energy,* vol. 134, pp. 503-514, 2016.

[30] R. Ramabadran and B. Mathur, "MATLAB Based Modelling and Performance Study of Series Connected SPVA under Partial Shaded Conditions," *Sustainable Development*, vol. 2, no. 3, pp. 10, 2009.

[31] M. Mani and R. Pillai, "Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 9, pp. 3124-3131, 2010.

[32] M. D. Ross and E. P. Usher, "Modelled and Observed Operation of a Passive Melting Technology for Photovoltaic Arrays," presented at the &th International Workshop on Atmosphoric Icing of Structures, Chicoutimi, Quebec, 1996. Available: www.RERinfo.ca

[33] B. P. Jelle, "The challenge of removing snow downfall on photovoltaic solar cell roofs in order to maximize solar energy efficiency—Research opportunities for the future," *Energy and Buildings*, vol. 67, pp. 334-351, 2013.

[34] A. R. Jordehi, "Maximum power point tracking in photovoltaic (PV) systems: A review of different approaches," *Renewable and Sustainable Energy Reviews*, vol. 65, pp. 1127-1138, 2016.

[35] T. Instruments. (2017). *Energy Harvesting: Solar*. Available: www.ti.com/solar

[36] W. Shireen, "A DSP-BASED POWER ELECTRONICS INTERFACEFOR ALTERNATE/RENEWABLE ENERGY SYSTEMS," U.S. Department of Energy, www.oit.doe.gov2000.

[37] R. Sridhar, S. Jeevananthan, S. S. Dash, and N. T. Selvan, "Unified MPPT Controller for Partially Shaded Panels in a Photovoltaic Array," *International Journal of Automation and Computing*, vol. 11, no. 5, pp. 536-542, 2015.

[38] G. Petrone, G. Spagnuolo, and M. Vitelli, "TEODI: A new technique for Distributed Maximum Power Point Tracking PV Applications," *IEEE*, pp. 982-6, 2010.

[39] S. Lyden and M. E. Haque, "Maximum Power Point Tracking techniques for photovoltaic systems: A comprehensive review and comparative analysis," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 1504-1518, 2015.

[40] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "A new analog MPPT technique: TEODI," *PROGRESS IN PHOTOVOLTAICS: RESEARCH AND APPLICATIONS*, vol. 18, no. 12, pp. 28-41, 2010.

[41] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," *IEEE Trans. Sustain. Energy*, pp. 89-99, 2013.

[42] A. Gupta, Y. K. Chauhan, and R. K. Pachauri, "A comparative investigation of maximum power point tracking methods for solar PV system," *Solar Energy*, vol. 136, pp. 236-253, 2016.

[43] M. A. Elgendy, B. Zahawi, and D. J. Atkinson, "Assessment of the incremental conductance maximum power point tracking algorithm," *IEEE Transactions on Sustainable Energy*, vol. 4, p. 9, 2013.

[44] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey Wolf Optimizer," *Advances in Engineering Software*, vol. 69, pp. 46-61, 2014.

[45] S. Mirjalili, S. Saremi, S. M. Mirjalili, and L. d. S. Coelho, "Multi-objective grey wolf optimizer: A novel algorithm for multi-criterion optimization," *Expert Systems with Applications*, vol. 47, pp. 106-119, 2016.

[46] Z. Salam, J. Ahmed, and B. S. Merugu, "The application of soft computing methods for MPPT of PV system: A technological and status review," *Applied Energy*, vol. 107, pp. 135-148, 2013.

[47] S. Saravanan and N. Ramesh Babu, "Maximum power point tracking algorithms for photovoltaic system – A review," *Renewable and Sustainable Energy Reviews,* vol. 57, pp. 192-204, 2016.

[48] F. Khosrojerdi and N. H. Golhkandan, "Microcontroller-based Maximum Power Point Tracking Methods in Photovoltaic systems," in *9th Power Electronic and Drive Systems and Technologies Conference (PEDSTC)*, Tehran, Iran, 2018: IEEE.

[49] A. R. Reisi, M. H Moradi, and S. Jamasb, "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review," *Renewable and Sustainable Energy Reviews,* vol. 19, pp. 433-443, 2013.

[50] R. Storn and K. Price, "Differential Evolution – A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces," *Journal of Global Optimization,* vol. 11, pp. 341-359, 1997.

[51] K. Ishaque and Z. Salam, "A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 475-488, 2013.

[52] P. Bhatnagar and R. K. Nema, "Maximum power point tracking control techniques: state-of-the-art in photovoltaic applications," *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 224-241, 2013.

[53] N. Khaehintung, P. Sirisuk, and W. Kurutach, "A Novel ANFIS Controller for Maximum Power Point Tracking in Photovoltaic Systems," Ministry of Energy, Thailand2000.

[54] T. Boutabba, S. Drid, and M. Benbouzid, "Maximum Power Point Tracking Control for Photovoltaic System Using Adaptive Neuro- Fuzzy "ANFIS"," presented at the Eighth International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), Monaco, Monaco, March, 2013.

[55] K. S. Tey, S. Mekhilef, H.-T. Yang, and M.-K. Chuang, "A Differential Evolution Based MPPT Method for Photovoltaic Modules under Partial Shading Conditions," *International Journal of Photoenergy,* vol. 2014, pp. 1-10, 2014.

[56] M. Sheraz and M. A. Abido, "An Efficient Approach for Parameter Estimation of PV Model Using DE and Fuzzy Based MPPT Controller," *IEEE*, p. 5, 2014.

[57] M. Sheraz and M. A. Abido, "An Efficient MPPT controller Using Differential Evolution and Neural Network," presented at the IEEE International Conference on Power and Energy (PECon), Kota Kinabalu Sabah, Malaysia, 2012.

[58] A. Shamekhi, "An Improved Differential Evolution Optimization Algorithm," *IJRRAS*, vol. 15, no. 2, p. 14, 2013.

[59] M. A. K. Azad and M. G. P. Fernandes, "Modified Constrained Differential Evolution for Solving Nonlinear Global Optimization Problems," in *Computational Intelligence*no. 465): Studies in Computational Intelligence, 2011, pp. 85-100.

[60] J. M. O. Velazquez, C. A. C. Coello, and A. Arias-Monta˜no, "Multi-Objective Compact Differential Evolution," *IEEE*, p. 8, 2014.

[61] M. A. M. Ramli, K. Ishaque, F. Jawaid, Y. A. Al-Turki, and Z. Salam, "A modified differential evolution based maximum power point tracker for photovoltaic system under partial shading condition," *Energy and Buildings,* vol. 103, pp. 175-184, 2015.

[62] J. Liu and J. Lampinen, "A Fuzzy Adaptive Differential Evolution Algorithm," in *IEEE TENCON'O2*, 2002, pp. 606-611.

[63] H. Rezk, A. Fathy, and A. Y. Abdelaziz, "A comparison of different global MPPT techniques based on meta-heuristic algorithms for photovoltaic system subjected to partial shading conditions," *Renewable and Sustainable Energy Reviews,* vol. 74, pp. 377-386, 2017.

[64] Y.-H. Liu, S.-C. Huang, J.-W. Huang, and W.-C. Liang, "A Particle Swarm Optimization-Based Maximum Power Point Tracking Algorithm for PV Systems Operating Under Partially Shaded Conditions," *IEEE Transactions on Energy Conversion,* vol. 27, no. 4, pp. 1027-1035, 2012.

[65] A. s. Benyoucef, A. Chouder, K. Kara, S. Silvestre, and O. A. sahed, "Artificial bee colony based algorithm for maximum power point tracking (MPPT) for PV systems operating under partial shaded conditions," *Applied Soft Computing,* vol. 32, pp. 38-48, 2015.

[66] S. Mohanty, B. Subudhi, and P. K. Ray, "A New MPPT Design Using Grey Wolf Optimization Technique for Photovoltaic System Under Partial Shading Conditions," *IEEE Transactions on Sustainable Energy,* vol. 7, no. 1, pp. 181-188, 2016.

[67] K. Ishaque and Z. Salam, "A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," *Renewable and Sustainable Energy Reviews,* vol. 19, pp. 475-488, 2013.

[68] A. A. Elbaset, A. E. Hussein, A. Brisha, and R. M. Mostafa, "Implementation of a PIC-based, Photovoltaic Maximum Power Point Tracking Control System," *International Journal of Emerging Technology and Advanced Engineering,* vol. 4, no. 5, p. 10, 2014.

[69] S. Müller, F. Möller, J. Meyer, A. J. Collin, and S. Z. Djokic, "Characterisation of harmonic interactions between electric vehicle battery chargers and PV inverters," *IEEE,* p. 5, 2014.

[70] P. S. Shenoy, Kim K. A., J. B. B., and K. P. T., "Differential power processing for increased energy production and reliability of photovoltaic systems," *IEEE TransPowerElectron,* vol. 68, no. 6, 2013.

[71] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "A new analog MPPT technique: TEODI," *Progress in Photovoltaics: Research and Applications,* vol. 18, no. 1, pp. 28-41, 2010.

[72] P. Bhatnagar and R. K. Nema, "Maximum power point tracking control techniques: State-of-the-art in photovoltaic applications," *Renewable and Sustainable Energy Reviews,* vol. 23, pp. 224-241, 2013.

[73] F. H. Abanda, J. H. M. Tah, and D. Duce, "PV-TONS: A photovoltaic technology ontology system for the design of PV-systems," *Engineering Applications of Artificial Intelligence*, vol. 26, no. 4, pp. 1399-1412, 2013.
[74] T. P. Project, "Protege Short Course - Protege vs. Databases," ed, 2010.
[75] J. Brank, M. Grobelnik, and D. Mladenić, "A survey of ontology evaluation techniques," p. 4, 2005.
[76] A. R. Hevner, S. Ram, S. T. March, and J. Park, "Design Science in Information Systems Research," *MIS Quarterly*, vol. 28, no. 1, pp. 75-105, 2004.
[77] E. Kontopoulos, G. Martinopoulos, D. Lazarou, and N. Bassiliades, "An ontology-based decision support tool for optimizing domestic solar hot water system selection," *Journal of Cleaner Production*, vol. 112, pp. 4636-4646, 2016.
[78] T. Burger and E. Simperl, "Measuring the benefits of ontologies. IN: On the Move to Meaningful Internet Systems," in *OTM 2008 Workshops*, Monterrey, Mexico, 2008.
[79] M. Hepp, P. De Leenheer, A. De Moor, and Y. Sure, "Ontologies: state of the art, business potential, and grand challenges," *Ontology Management*, vol. 7, p. 22, 2008.
[80] T. R. Gruber, "A Translation Approach to Portable Ontology Specifications," in "Knowledge Systems Laboratory," Computer Science Department Stanford University, Knowledge Acquisition1992, vol. 5.
[81] T. R. Gruber, "A translation approach to portable ontologies," *Knowledge Acquisition*, vol. 92, no. 71, pp. 199-220, 1993.
[82] M. Rospocher, C. Ghidini, and L. Serafini, "An ontology for the Business Process Modelling Notation," *Artif. Intell.*, 2014.
[83] T. Berners-Lee, J. Hendler, and O. Lassila, "The Semantic Web," *Scientific American*, 2001.
[84] W3C. (2013, 19 June 2013). *W3C Semantic Web Activity*. Available: https://www.w3.org/2001/sw/
[85] D. L. McGuinness and F. VanHarmelen, "OWL Web Ontology Language, W3C Recommendation," 2004.
[86] C. Walton, *Agency and the Semantic Web*. Oxford University Press, Oxford, UK, 2007.
[87] I. Horrocks, P. F. Patel-Schneider, H. Boley, S. Tabet, B. Grosof, and M. Dean. (2004). *SWRL: A Semantic Web rule language combining OWL and RuleML*. Available: https://www.w3.org/Submission/SWRL/
[88] C. Golbreich and E. K. Wallace. (2012). *OWL 2 Web Ontology Language New Features and Rationale (Second Edition)*. Available: https://www.w3.org/TR/2012/REC-owl2-new-features-20121211/
[89] A. Gómez-Pérez, M. C. Suárez-Figueroa, and B. Villazón, "Introduction to the Semantic Web Tutorial: Ontological Engineering," 2008.
[90] R. Mizoguchi, "Tutorial on ontological engineering," *New Generation Computing*, vol. 27, no. 3, pp. 363-384, 2003.
[91] E. Sirin, B. Parsia, B. C. Grau, A. Kalyanpur, and Y. Katz, "Pellet: A practical OWL-DL reasoner," *Journal of Web Semantics*, vol. 5, no. 2, pp. 51-53, 2007.

[92] M. O'Conner and A. Das, "SQWRL: a Query Language for OWL," in *OWL: Experiences and Directions*, Stanford Center for Biomedical Informatics Research, 2009.

[93] M. Uschold and M. Gruninger, "Ontologies: Principles, Methods and Applications," *Knowledge Engineering Review,* vol. 11, no. 2, p. 69, 1996.

[94] W. EL-Kass, "Integrating Semantic Web and Unstructured Information Processing Environments: A Visual Rule-Based Approach," Information Science and Technology, UNIVERSITÉ DU QUÉBEC EN OUTAOUAIS, 2018.

[95] E. Munoz, E. Capon-García, J. M. Laínez, A. Espuna, and L. Puigjaner, "Considering environmental assessment in an ontological framework for enterprise sustainability," pp. 149-164, 2013.

[96] A. M. Macris and D. A. Georgakellos, "A new teaching tool in education for sustainable development: ontology-based knowledge networks for environmental training," *Cleaner Production,* vol. 14, no. 9-11, pp. 855-867, 2006.

[97] N. Trokanas, F. Cecelja, and T. Raafat, "Semantic approach for pre-assessment of environmental indicators in industrial symbiosis," *Cleaner Production,* vol. 96, no. 1, pp. 349-361, 2015.

[98] N. O. Bajnaid, R. Benlamri, A. Pakstas, and S. Salekzamankhani, "An Ontological Approach to Model Software Quality Assurance Knowledge Domain," *Lecture Notes on Software Engineering,* vol. 4, no. 3, p. 6, 2016.

[99] R. Valverde and M. Toleman, *Chapter 3-Ontologycal Evaluation of Business Models: Comparing Traditional and Component-based Paradigms in Information Systems Re-engineering* (Springer's Integrated Series in Information Systems). 2007.

[100] R. Valverde, M. Toleman, and A. Cater-Steel, *A Case Study in Information Systems Re-Engineering* (Improving IT-Enabled Sense and Respond Capabilities). IGI Global, 2010.

[101] R. Valverde, M. Toleman, and A. Cater-Steel, "A method for comparing traditional and component-based models in information systems re-engineering," *Information Systems and e-Business Management,* vol. 9, no. 1, pp. 89-107, 2010.

[102] M. Kara, O. Lamouchi, and A. Ramdane-Cherif, "Ontology Software Quality Model for Fuzzy Logic Evaluation Approach," *Procedia Computer Science,* vol. 83, pp. 637-641, 2016.

[103] H. Zhu, D. Liu, I. Bayley, A. Aldea, Y. Yang, and Y. Chen, "Quality Model and Metrics of Ontology for Semantic Descriptions of Web Services," *TSINGHUA SCIENCE AND TECHNOLOGY,* vol. 22, no. 1007-0214ll03/09, pp. 254–272, 2017.

[104] A. Avédissian, R. Valverde, and S. Barrad, "An Extension Proposition for the Agent-Based Language Modeling Ontology for the Representation of Supply Chain Integrated Business Processes," *WSEAS TRANSACTIONS on BUSINESS and ECONOMICS,* vol. 12, p. 18, 2015.

[105] A. Daouadji, K. K. Nguyen, M. Lemay, and M. Cheriet, "Ontology-based resource description and discovery framework for low-carbon grid networks," presented at the Int. Conf. on Smart Grid Communications (SmartGridComm), Gaithersburg, MD, 2010.

[106] B. Bonino and F. Corno, "DogOnt - ontology modeling for intelligent domotic environments," in *The Semantic Web - ISWC 2008*, Berlin Heidelberg, 2008, pp. 790-803: Springer.

[107] A. Rossello-Busquet, L. J. Brewka, J. Soler, and L. Dittmann, "OWL Ontologies and SWRL Rules Applied to Energy Management," presented at the 2011 UKSim 13th International Conference on Modelling and Simulation, 2011.

[108] J. Keirstead, N. Samsatli, and N. Shah, "SynCity: an integrated tool kit for urban energy systems modeling," in *5th Urban Research Symposium*, Marseille, France, 2009.

[109] J. Keirstead and K. H. Van Dam, "A comparison of two ontologies for agent-based modelling of energy systems," in *1st Int. Workshop on Agent Technologies for Energy Systems (ATES 2010) at AAMAS*, Toronto, Canada, 2010.

[110] W. C. O. W. Group. (2012). *OWL 2 Web Ontology Language - W3C Recommendation*.

[111] *Semantic Web - XML2000, Slide 10*, 2008.

[112] T. Berners-Lee, "Semantic Web - XML2000, slide 10," W3C2008, Available: https://www.w3.org/2000/Talks/1206-xml2k-tbl/slide10-0.html.

[113] (2019). *Semantic Web Stack*. Available: https://en.wikipedia.org/wiki/Semantic_Web_Stack

[114] B. Motik, P. F. Patel, and B. C. Grau. (2012). *OWL 2 Web Ontology Language Direct Semantics (Second Edition)*. Available: https://www.w3.org/TR/2012/REC-owl2-direct-semantics-20121211/

[115] M. O'Connor, "The Semantic Web Rule Language," Stanford Center for Biomedical Informatics Research, Stanford University2009.

[116] J. Raad and C. Cruz, "A Survey on Ontology Evaluation Methods," presented at the 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, 2018.

[117] M. Rospocher, C. Ghidini, and L. Serafini, "An ontology for the Business Process Modelling Notation," *Artif. Intell. Appl.*, pp. 133–146, 2014.

[118] S. Hubner *et al.*, "Ontology-Based Integration of Information-A survey of Existing Approaches," 2001.

[119] R. Subhashini and J. Akilandeswari, "A Survey on Ontology Constructions Methodologies," *International Journal of Enterprise Computing and Business Systems (Online)*, vol. 1, no. 1, p. 14, 2011.

[120] M. R. Bautista-Zambrana, "Methodologies to Build Ontologies for Terminological Purposes," *Procedia Soc. Behav. Sci.*, pp. 173, 264–269., 2015.

[121] M. Fernández-López, "Overview of methodologies for building ontologies. ," in *In Proceedings of the Workshop Ontologies and Problem-Solving Methods: Lessons Learned and Future Trends de la Conferencia International Joint Conference for Artificial Intelligence (IJCAI'99)*, Stockholm, Sweden,, 1999.

[122] R. Iqbal, M. A. Murad, A. Mustapha, and N. M. Sharef, "An Analysis of Ontology Engineering Methodologies: A Literature Review," *Res. J. Appl. Sci. Eng. Technol*, pp. 2993–3000, 2013.

[123] H. Ajami, "Modèle Ontologique Contextuel pour les patients atteints de la maladie pulmonaire obstructive chronique," PhD, Université du Québec à Chicoutimi, 2019.

[124] A. K. Podder, N. K. Roy, and H. R. Pota, "MPPT methods for solar PV systems: a critical review based on tracking nature," *IET Renewable Power Generation,* vol. 13, no. 10, pp. 1615-1632, 2019.

[125] C. Muro, R. Escobedo, L. Spector, and R. Coppinger, "Wolf-pack (Canis lupus) hunting strategies emerge from simple rules in computational simulation.," *Behav Process,* vol. 88, p. 7, 2011.

[126] L. Chouksey, P. A. Pattanaik, and R. K. Saket, "Maximum Power Point Tracking of Photovoltaic System Using Two Input and Two Output Fuzzy System," vol. 326, pp. 245-253, 2015.

[127] R. K. Kharb1, M. F. Ansari, and S. L. Shimi, "Design and Implementation of ANFIS based MPPT Scheme with Open Loop Boost Converter for Solar PV Module," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* vol. 3, no. 1, pp. 1-8, 2014.

[128] G. Spagnuolo, S. Kouro, and D. Vinnikov, "Photovoltaic Module and Submodule Level Power Electronics and Control," *IEEE Transactions on Industrial Electronics,* vol. 66, no. 5, pp. 3856-3859, 2019.

[129] Y. Poissant and L. Dignard-Bailey, "Photovoltaic technology status and prospects Canadian annual report 2015," CanmetENERGY, Natural Resources Canada & Canadian Solar Industries Association (CanSIA)2015.

[130] NREL. (2010). *Welcome to SAM*.

[131] J. Freeman, J. Whitmore, N. Blair, and A. P. Dobos, "Validation of Multiple Tools for Flat Plate Photovoltaic Modeling Against Measured Data," NREL2014.

[132] P. Gilman, "SAM Photovoltaic Model Technical Reference," National Renewable Energy Laboratory (NREL) at2016.

[133] SAM. (2010). *Performance Model Documentation*. Available: https://sam.nrel.gov/performance

[134] M. Ferndndez, A. Gomez-Perez, and N. Juristo, "Methontology: From Ontological Art Towards Ontological Engineering," 1997.

[135] M. C. Suárez-Figueroa, A. Gómez-Pérez, and M. Fernández-López, "The NeOn Methodology for Ontology Engineering," in *Ontology Engineering in a Networked World*, 2012, pp. 9-34.

[136] K. Breitman, M. A. Casanova, and W. Truszkowski, *Semantic Web Concepts, Technologies and Applications*. Springer-Verlag Ltd., London, UK, 2007.

[137] Protégé. (2020). *Protégé Products*. Available: https://protege.stanford.edu/products.php

[138] F. M. Zaihidee, S. Mekhilef, M. Seyedmahmoudian, and B. Horan, "Dust as an unalterable deteriorative factor affecting PV panel's efficiency: Why and how," *Renewable and Sustainable Energy Reviews,* vol. 65, pp. 1267-1278, 2016.

[139] Ali Omar Mohamed and A. Hasan, "Effect of Dust Accumulation on Performance of Photovoltaic Solar Modules in Sahara Environment," *Journal of Basic and Applied Scientific Research,* p. 7, 2012. TextRoad Publication

[140] Hassan A. H., Rahoma U., Elminir H., and F. A. M., "Effect of airborne dust concentration on the performance of PV modules," presented at the Astron Soc Egypt 2005.

[141] Fouada M. M., Lamia A. S., and E. I. M., "An integrated review of factors influencing the performance of photovoltaic panels. ," *Renew Sustain Energy Rev,* pp. 80:1499–511, 2017.

[142] Kalogirou S. A., Agathokleous R, and P. G., "On-site PV characterization and the effect of soiling on their performance," *Elsevier J Energy,* pp. 439–46, 2013.

[143] Zorrilla-Casanova J *et al.*, "Analysis of dust losses in photovoltaic modules," *Photovoltaic technology world renewable energy congress, Sweden,* 2011.

[144] Adinoyi M. J. and S. SAM., "Effect of dust accumulation on the power outputs of solar photovoltaic modules.," *Elsevier J Renew Energy* pp. 633–6, 2013.

[145] I. A. J., "Effect of shadow and dust on the performance of silicon solar cell," *Basic Appl Sci Res,* pp. 222–30, 2011.

[146] Mohandes BMA, El-Chaar L., and L. L. A., "Application study of 500W photovoltaic (PV) system in the UAE," *Appl Sol Energy,* pp. 242–7, 2009.

[147] Touati F and M. A., "Effects of environmental and climatic conditions on PV efficiency in Qatar," presented at the International conference on renewable energies and power quality (ICREPQ'13), Bilbao, Spain, 2013.

[148] B. E., "The effect of settling dust in the arava valley on the performance of solar photovoltaic panels," 2011.

[149] Julius T, David P, Jonathan W, Tania U, and T. P., "The contribution of dust to performance degradation of PV modules in a temperate climate zone.," *Elsevier J Sol Energy and Buildings,* pp. 147–57, 2015.

[150] Mastekbayeva G. A. and K. S., "Effect of dust on the transmittance of low density polyethylene glazing in a tropical climate," *Sol Energy,* vol. 2, no. 68, pp. 135–41, 2003.

[151] M. Piliougine, J. Carretero, M. Sidrach-de-Cardona, D. Montiel, and P. Sánchez-Friera, "Comparitive analysis of the dust losses in photovoltaic modules with different cover glasses," presented at the 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, 2008.

[152] Loren Powers, Jeff Newmiller, and T. Townsend, "Measuring and modeling the impact of snow on photovoltaic system performance," *IEEE,* p. 6, 2010.

[153] Hussein A Kazem, Tamer Khatib, K. Sopian, Frank Buttinger, Wilfried Elmenreich, and A. S. Albusaidi, "Effect of Dust Deposition on the Performance of Multi-Crystalline Photovoltaic Modules Based on Experimental Measurements," *INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH,* vol. 3, no. 4, p. 4, 2013.

[154] S. Nakagawa, T. Tokoro, T. Nakano, K. Hayama, H. Ohyama, and T. Yamaguchi, "An effect of snow for electric energy generation by 40kw PV system," presented at the 3rd World Cotfiwrrce on Photovoltaic Energy Conversion, Osaka, Japan, 2003.

[155] Gerd Becker, Bruno Schiebelsberger, Walter Weber, Christian Vodermayer, Mike Zehner, and G. Kummerle, "An approach to the impact of snow on the yield of grid connected PV systems," p. 4, 2005.
[156] Rob W. Andrews and J. M. Pearce, "Prediction of Energy Effects on Photovoltaic Systems due to Snowfall Events," *IEEE*, p. 6, 2011.
[157] B. Stridh, "Evaluation of economical benefit of cleaning of soiling and snow in PV plants at three European locations," *IEEE*, p. 4, 2011.
[158] R. W. Andrews, A. Pollard, and J. M. Pearce, "The effects of snowfall on solar photovoltaic performance," *Solar Energy*, vol. 92, pp. 84-97, 2013.
[159] B. Marion, R. Schaefer, H. Caine, and G. Sanchez, "Measured and modeled photovoltaic system energy losses from snow for Colorado and Wisconsin locations," *Solar Energy*, vol. 97, pp. 112-121, 2013.
[160] M. Sandell, "The effect of snowfall on the power output of photovoltaic solar panels in Halifax, NS," Environmental Science, DALHOUSIE UNIVERSITY, 2012.
[161] A. A. Babatunde, S. Abbasoglu, and M. Senol, "Analysis of the impact of dust, tilt angle and orientation on performance of PV Plants," *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 1017-1026, 2018.
[162] Elminir H. K., Ghitas A. E., Hamid R. H., El-Hussainy F., and B. M. M., "Effect of dust on the transparent cover of solar collectors," *Elsevier J Energy Convers Manag*, pp. 3192–203, 2006.
[163] M. Mehrtash, D. R. Rousse, and G. Quesada, "Effects of surroundings snow coverage and solar tracking on photovoltaic systems operating in Canada," *Journal of Renewable and Sustainable Energy*, vol. 5, no. 5, p. 053119, 2013.
[164] J. Volker, D. Vrandecic, Y. Sure, and A. Hotho, "AEON-an approach to the automatic evaluation of ontologies," *Application of Ontology*, vol. 3, pp. 41-62, 2008.
[165] J. Freeman, J. Whitmore, L. Kaffine, N. Blair, and A. P. Dobos, "System Advisor Model: Flat Plate Photovoltaic Performance Modeling Validation Report," National Renewable Energy Laboratory2013, Available: www.nrel.gov/publications.
[166] NREL. (2014). *NREL PV Validation 2013*.
[167] Sunpower, "Installation Plan - Parking Structure Metal Roof Photovoltaic Array Golden, CO," in "NREL Parking Lot Structure," 2010, Available: https://sam.nrel.gov/photovoltaic/pv-validation.html.
[168] N. Blair *et al.*, "System Advisor Model, SAM 2014.1.14: General Description," National Renewable Energy Laboratory2014.
[169] Michael J. Wagner, Nate Blair, and A. Dobos, "A Detailed Physical Trough Model for NREL's Solar Advisor Model," presented at the SolarPACES 2010, Perpignan, France, 2010.
[170] N. Blair *et al.*, "System Advisor Model (SAM) General Description (Version 2017.9.5)," 2018.
[171] "2012 Air Quality Data Report Air Pollution Control Division," Colorado Department of Public Health and Environment2013, Available: http://www.colorado.gov/airquality/tech_doc_repository.aspx.

[172] "2018 Air Quality Data Report," 2019, Available: http://www.colorado.gov/airquality/tech_doc_repository.aspx.
[173] C. Osorio, "pv_mppt_inverter.slx," 2017, Available: https://www.mathworks.com/.