Faculty of Engineering

FUZZY TOPSIS BASED SOLAR PV DESIGN OPTIMIZATION

Dunkcurn Niem Anak Dakeh

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FUZZY TOPSIS BASED SOLAR PV DESIGN OPTIMIZATION

Fuzzy Topsis Based Solar Pv Design Optimization

DUNKCURN NIEM ANAK DAKEH

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
Electrical and Electronics Engineering with Honours

Faculty of Engineering

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ABSTRACT

Due to the Sarawak Corridor of Renewable Energy (SCORE) development plan with collaboration of Sarawak Energy Berhad, Sarawak pledged to begin the implementation of clean energy resources. Other than abundant resources of hydro, solar energy is one of the preferred renewable energy as the sun is an endless clean energy source. Thus, solar PV design has been researched and studied broadly decades before with solar technologies seeing stable improvements in efficiency and reliability over the years to cope with the demand. Solar PV design is dependent on several parameters which includes the capacity of power needed, availability of solar energy within the area all year, power losses within the system, and sizing of the required components. Inevitable technological shortcoming and the appropriate configuration and sizing of a solar PV system must be considered while maintaining financial cost. This research project aims to create a conceptual computer model that simplifies the task of evaluating design options for off-grid photovoltaic system applications using MATLAB environement. A smart and ergonomic optimization algorithm is designed by using Fuzzy-TOPSIS technique which selects the optimal design of an off-grid photovoltaic system. Thus, an ergonomic solar PV Design Optimization software is developed by using MATLAB AppDesigner. The software design displayed the input and output data of the PV system with Fuzzy TOPSIS algorithm. Hence, the off-grid solar PV system designed in MATLAB AppDesigner is viable and readily available for future use.

ABSTRAK

Disebabkan pelaksanaan Sarawak Corridor of Renewable Energy (SCORE) dengan kerjasama Sarawak Energy Berhad, Sarawak berjanji untuk memulakan pelaksanaan sumber tenaga bersih. Selain daripada sumber hidro yang banyak, tenaga suria merupakan tenaga yang boleh diperbaharui kerana matahari adalah sumber tenaga bersih yang tidak berkesudahan. Oleh itu, reka bentuk PV solar telah dikaji dan dikaji secara meluas beberapa dekad sebelum ini dengan teknologi solar menyaksikan peningkatan yang mantap dalam kecekapan dan kebolehpercayaan selama bertahun-tahun untuk menampung permintaan. Reka bentuk PV solar bergantung kepada beberapa parameter yang merangkumi kapasiti kuasa yang diperlukan, ketersediaan tenaga suria dalam kawasan sepanjang tahun, kehilangan kuasa dalam sistem, dan saiz komponen yang diperlukan. Kekurangan teknologi yang tidak dapat dielakkan, dan konfigurasi dan saiz yang sesuai bagi sistem PV solar mesti dipertimbangkan untuk mengekalkan kos kewangan. Projek penyelidikan ini bertujuan untuk konsep model komputer yang memudahkan tugas menilai pilihan reka bentuk untuk aplikasi sistem fotovoltaik luar grid menggunakan aplikasi MATLAB. Selain itu, algoritma pengoptimuman pintar dan ergonomik direka dengan menggunakan teknik Fuzzy-TOPSIS yang memilih reka bentuk optimum sistem fotovoltaik luar grid. Oleh itu, perisian Pengoptimuman Reka Bentuk PV solar ergonomik dibangunkan dengan menggunakan MATLAB AppDesigner. Reka bentuk perisian memaparkan data input dan output sistem PV dengan algoritma Fuzzy TOPSIS. Oleh itu, sistem PV suria luar grid yang direka dalam MATLAB AppDesigner adalah berdaya maju dan sedia tersedia untuk kegunaan masa hadapan.

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LIST OF ABBREVIATIONS

AC	:	alternating current
AHP	:	analytical hierarchy process
BOS	:	balance of system
CO_2	:	carbon dioxide
CSA	:	cross-sectional area
DC	:	direct current
DEMATEL	:	decision making trial and evaluation laboratory
FNIS	:	fuzzy negative ideal solution
FPIS	:	fuzzy positive ideal solution
GCPV	:	grid-connected photovoltaic
GUI	:	graphical user interface
MCDM	:	multi criteria decision making
MPPT	:	maximum power point tracking
Ni-Cad	:	nickel-cadmium
NOCT	:	nominal operating cell temperature
OGPV	:	off-grid connected photovoltaic
PIS	:	positive ideal solution
PV	:	photovoltaic
PWM	:	pulse-width modulation
RTL	:	resource to load ratio
STC	:	standard test condition
Sub VI	:	sub virtual instruments
TOPSIS	:	technique for order of preference by similarity to ideal solution
VIKOR	:	*VIseKriterijumska Optimizacija I Kompromismo Resenje*

CHAPTER 1

INTRODUCTION

1.1 Background

Over the past two decades, the proportion of renewable energy sources in the world's power supply has progressively increased due to the optimization and worldwide adoption of these systems as the need for clean, renewable energy increases. REN21 (2022) report [1] states that the renewable power capacity additions increased 17% in 2021 to a new record exceeding 314 gigawatts (GW) of installed capacity, despite supply chain disruptions, shipping delays, and rising prices for wind and solar energy components during the pandemic time [2].

The sun plays a key part of a future powered by sustainable energy with its limitless supply of solar energy. Solar energy, in contrast to traditional energy sources, has no carbon imprint after implementation and is an endless global resource with no carbon dioxide (CO_2) emissions [3]. Photovoltaic, thermal, and hybrid photovoltaic/thermal technologies are primarily used to gather solar energy [4]. A system using photovoltaic cells to convert solar radiation into electricity is referred to as a photovoltaic technology [5].

The number of countries considering clean solar as a reliable alternative energy source has expanded significantly, and this has progressively led to an increase in PV installations worldwide. Between 2020 and 2024, the amount of clean solar power was expected to rise from 586 GW to 765 GW, according to the International Energy Agency's (IEA) Renewable 2019 study. The upward tendency in annual installation of PV system, as shown in **Figure 1.1**, provides justification for this trend. Additionally, governments are being encouraged to adopt PV technologies due to the decrease in battery cost by 85% between 2010 and 2018 [6].

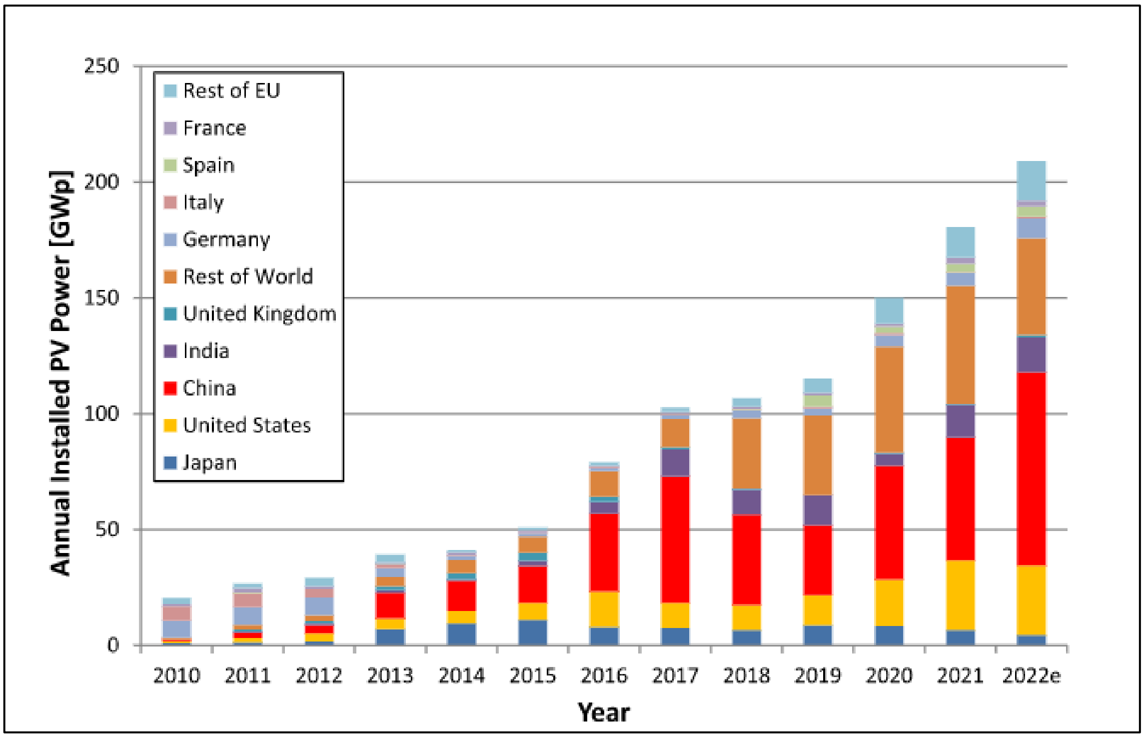

Figure 1.1: Annual installed PV power from 2010 to 2022 [6].

This pattern correlates with the financial sustainability of solar PV power production, where energy efficiency is crucial. Solar PV system design is essential to achieve the best possible deployment costs and optimize power losses within the system. By increasing the DC operating voltage, the modules connected in series will lower the system's current losses. Thus, it is essential to implement a suitable design within each installation environment for achieving an effective solar PV system.

The required power capacity, the year-round availability of solar energy in the area, power losses within the system, and the sizing of the necessary components are all important factors to take into account before designing a solar PV system. It is necessary to pre-plan to evaluate the components required to adhere to the important parameters. This will guarantee that safety standards are met and the design will be financially advantageous.

1.2 Problem Statement

A solar PV system design has been researched and studied for a number of decades, and the design is based on a number of crucial factors. A system can only be optimised to maximise financial gains and system longevity, due to technological limitations like battery and inverter efficiency. Hence, it is crucial to thoroughly evaluate these parameters to provide an optimized design depending on the implementation.

These parameters include the required power capacity, the availability of solar energy within the area throughout the year, power losses within the system, and the sizing of the required components [7]. Important factors to consider when implementing an optimised solar PV system includes the DC and AC load profile, resource to load ratio (RTL), balance of system sizing (BOS), component specification, and component sizing. These factors are crucial in ensuring that power requirements are met as well as the system's financial viability.

As a result, the design of solar PV systems is dependent on these parameters, and it requires a critical and proper designing of a system. On the other hand, this will result in significant inefficiency and safety risks if it fails to follow the right parameters. Common problems throughout the design and planning stages such as inaccurate energy yield predictions and improper system sizing might be improved if a proper guideline is followed.

1.3 Objectives

This research project aims to create a conceptual computer model that make the task of evaluating design options for off-grid photovoltaic system applications simpler and easier by using MATLAB. Additionally, in order to complete this project, it is necessary to state the following objectives:

i. To simulate a working solar PV system design under MATLAB environment.
ii. To design a smart and ergonomic optimization algorithm by using Fuzzy-TOPSIS technique which selects the optimal design of an off-grid photovoltaic system.
iii. To develop an ergonomic solar PV optimization software by using MATLAB AppDesigner.

1.4 Thesis Outlines

The research encompasses five chapters, which includes the introduction, literature review, methodology, results and discussion, and the conclusion.

Chapter 1 states the background of using Solar PV as renewable energy resources, problem statements, and objectives of the study.

Chapter 2 reviews the research on solar PV implementations. It covers the theoretical aspects of the research into the specifics of installing solar PV systems.

Chapter 3 examines the methodology to meet the objectives. The chapter illustrates the design of a solar PV system. The conversion of mathematical modelling to MATLAB AppDesigner is further discussed within this chapter. The software design's graphical interface is examined.

Chapter 4 reports the validation of the software modelled using real-world data and case study to obtain the result and analysis.

Chapter 5 summarises the research and highlights its findings and accomplishments. This chapter also makes suggestions for future works to be carried out.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter focuses on the design principle of a solar PV system, including its design steps and major components. This chapter also includes previous research on the design and implementation of solar PV systems to obtain a better understanding of solar PV system design.

2.2 Solar irradiation

Solar energy viability within the proposed area must be taken into account before any solar PV system implementation. Photovoltaic technology harnesses the sun's electromagnetic radiation to generate electrical energy. The principles behind these solar cell designs focus on harnessing energy from visible light.

It has been determined that increased solar irradiation significantly improves the overall output of a photovoltaic module. **Figure 2.1** depicts the photovoltaic power potential in Malaysia. A viable area with high average solar irradiance is potential to implement solar PV technology.

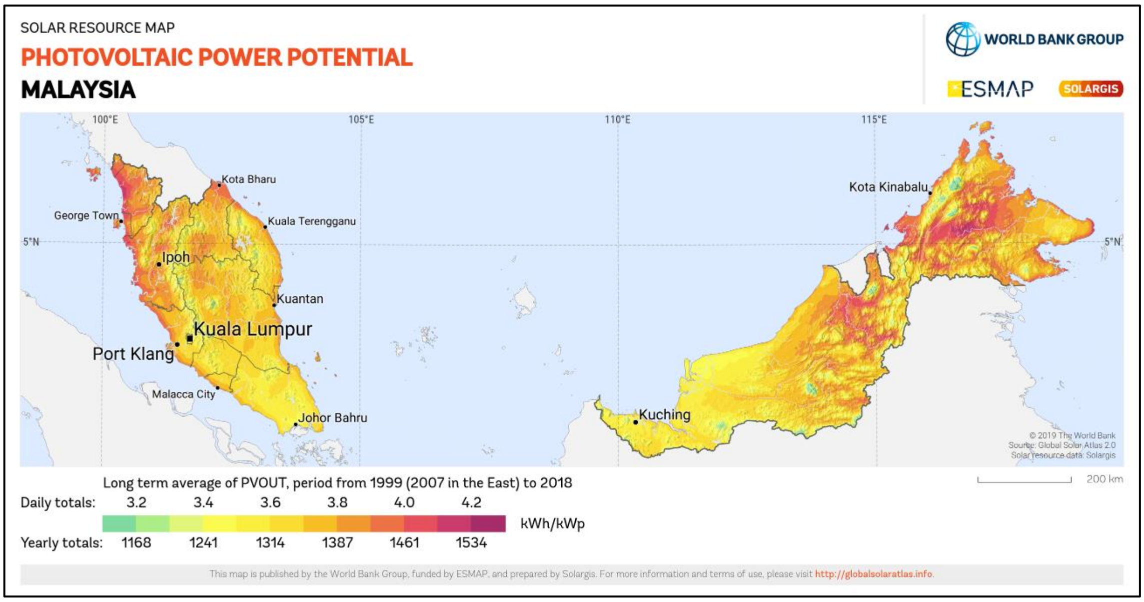

Figure 2.1: Photovoltaic Power Potential in Malaysia [8].

2.3 General Principle of Photovoltaic Systems

There are two types of photovoltaic systems which are stand-alone or off-grid connected PV systems (OGPV) and grid-connected PV systems (GCPV). This categorization is based on component's configuration, operating requirements, and load demands.

2.3.1 Off-Grid Connected Systems (Standalone systems)

The standalone or off grid connected system (OGPV) is a solar photovoltaic system that generates electricity in a designated area that is not connected to any other electricity networks [9]. Instead of being fed into the main grid, the generated electrical energy is stored in battery arrays. OGPV systems are implemented in areas where a power source is not available due to expensive grid expansions, primarily due to location, particularly in rural areas. This system can charge the batteries during the day when there is excess electricity produced after meeting load demands and discharge them at where there is none [10]. The size and configuration of this system can be greatly varied depending on the implementation and needs. This system typically consists of batteries, a charging controller, an inverter (for alternating current loads), and PV arrays. The charging controller is used to prevent the system from over-discharging and overcharging. **Figure 2.2** depicts the OGPV design methodology.

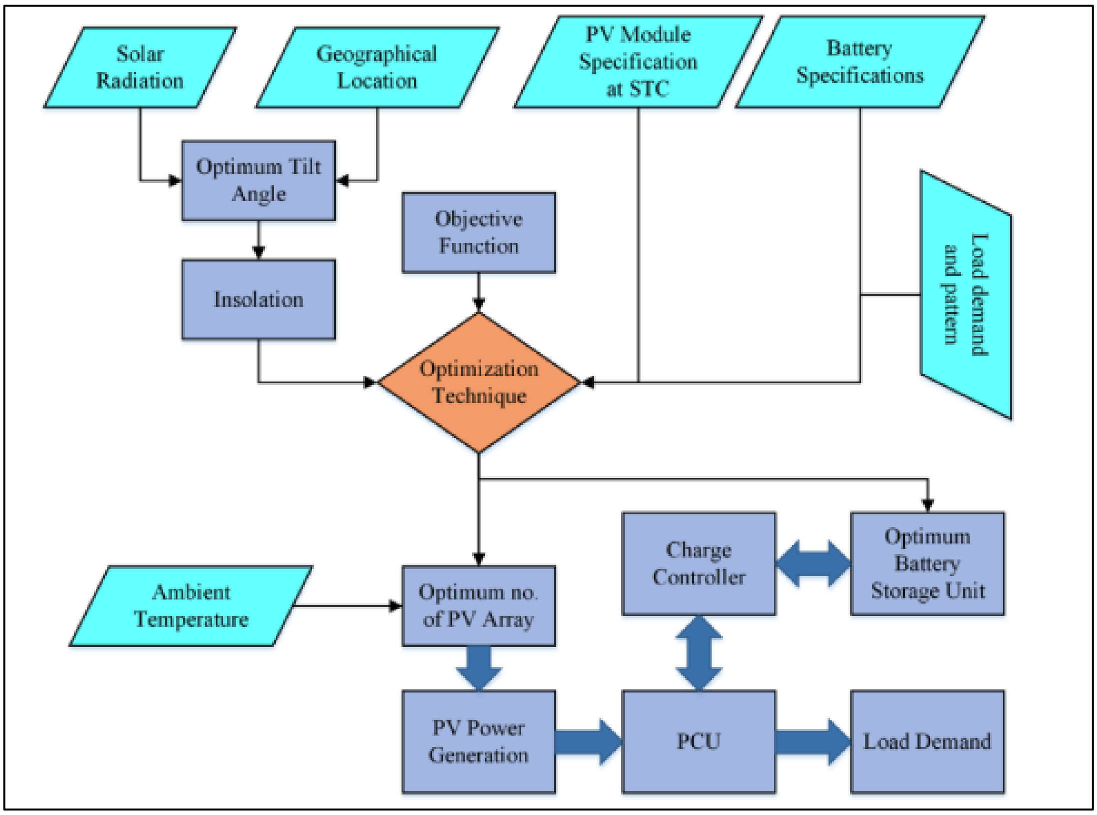

Figure 2.2: Design methods of an OGPV system [10].

2.3.2 Grid Connected Systems

Grid connected systems (GCPV) are solar photovoltaic systems that feed their generated electricity back into the grid for immediate transmission, distribution, and consumption. The complexity of system sizing and cost viability of a GCPV system is reduced by excluding storage components. When connected to the grid, power systems components like inverters and transformers must be increased in complications to reduce harmonic distortions and synchronise frequency and voltage [10]. The inverter should minimize harmonic distortions and offer islanding detection and prevention. Common components of this system include a DC/DC converter with MPPT, an inverter, a transformer, and PV arrays. The transformer and auxiliary controllers are frequently built within the inverters. The GCPV design methodology is depicted in **Figure 2.3**.

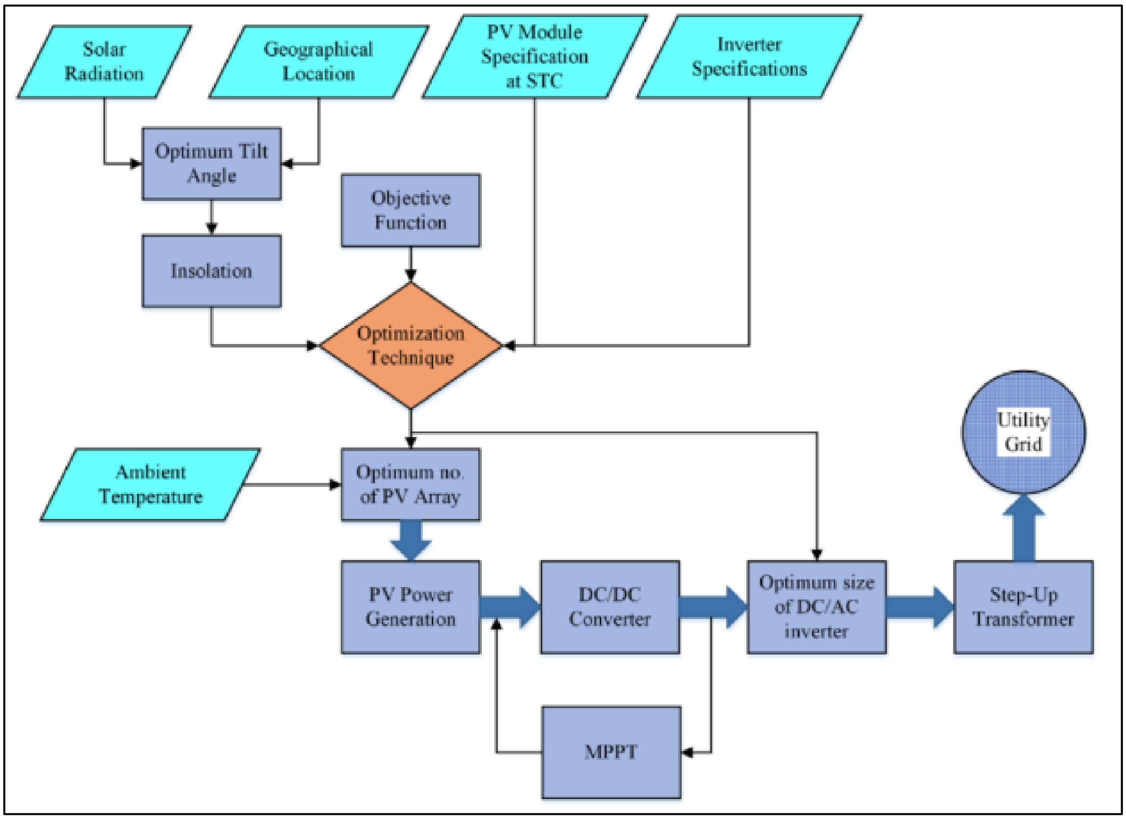

Figure 2.3: Design method of a GCPV system [10].

2.4 Components of Photovoltaic System

A solar PV system consists of several vital components that are needed before designing a viable system. These components include the solar photovoltaic panel, inverter, batteries, and charge controllers.

2.4.1 Photovoltaic Modules

Photovoltaic modules contain photovoltaic cells that convert the energy from the sun directly into electricity. Each of these cells generates 0.5V to 0.6V. Multiple cells are connected in series to boost voltages, while parallel-connected to boost current. Photovoltaic modules typically use monocrystalline silicon, polycrystalline silicon and thin-film technology are shown in **Figure 2.4**. The various cell types that can be used in a system are distinguished by cost, performance, and degradation. Both mono crystalline and poly crystalline silicon cell makes up 90 percent of global PV production while thin-film technology covers the remaining 10 percent.

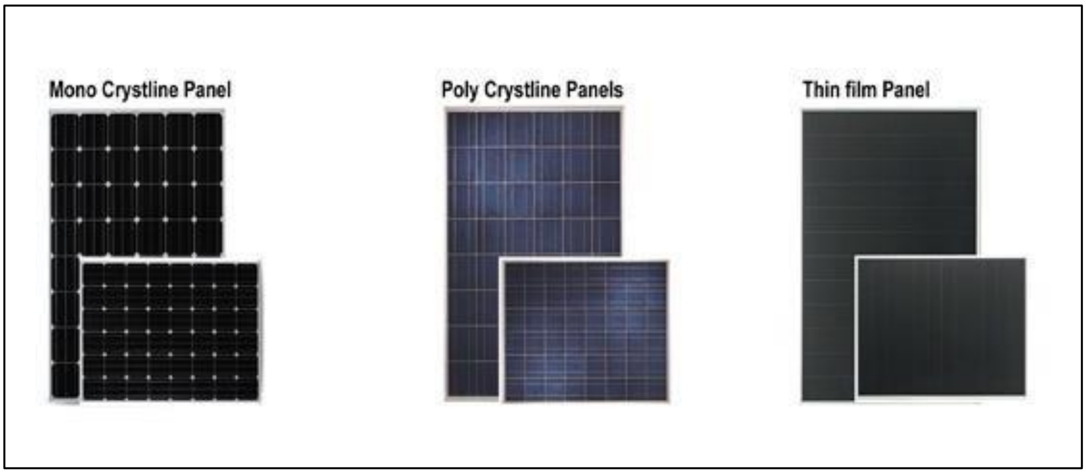

Figure 2.4: Photovoltaic modules [11].

The intensity of the sun's radiation, dust, and temperature can all cause photovoltaic modules' energy efficiency to decrease. The energy efficiency of photovoltaic modules will increase if water cooling systems successfully lower the temperature of the solar cells [12]. Most PV panels come with a 25-year warranty, during which time they will slowly deteriorate. The early deterioration of PV panels is frequently caused by issues with poor quality materials, flawed designs, and manufacturing problems.

Maximum power point, short circuit current, and open circuit voltage are three crucial PV characteristic factors. The characteristics between current and voltage are shown in the **Figure 2.5**, where point P_{MP} represents the PV cell's maximum output power. These details are often available in the manufacturer's datasheet and are adequate to build a rudimentary model of the module to test power converters.