Faculty of Engineering

PARTICLE SWARM OPTIMIZATION MAXIMUM POWER POINT TRACKING FOR PARTIALLY SHADED SOLAR PV

Alvin Ngu Tien Leong

Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

UNIVERSITI MALAYSIA SARAWAK

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Final Year Project Report ☑

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PARTICLE SWARM OPTIMIZATION MAXIMUM POWER POINT TRACKING FOR PARTIALLY SHADED SOLAR PV

Particle Swarm Optimization Maximum Power Point Tracking For Partially Shaded Solar Pv

ALVIN NGU TIEN LEONG

A dissertation submitted in partial fulfilment
of the requirement for the degree of
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ABSTRACT

Renewable energy sources are becoming increasingly popular to address the problem of global warming by reducing the amount of carbon in the atmosphere. Solar energy is one of the RES that is widely used for generating electricity through a photovoltaic generating system (PGS). Partial shading phenomenon occurs when the solar irradiation or ambient temperature received by the PV modules varies. The maximum power point tracking (MPPT) is crucial to extract the maximum power from PV modules under partial shading circumstances (PSC). However, several MPPT techniques are less effective under PSC due to the multiple peaks on the P-V curve of PGS in terms of the robustness, complexity, and efficiency. This study proposes a particle swarm optimization (PSO) algorithm based on MPPT for the PGS to operate under PSC. The objectives of this thesis are to synthesis, simulate and evaluate the robustness of PSO algorithm for MPPT under PSC. The energy conversion system and PSO algorithm were simulated in MATLAB/Simulink. The simulation results demonstrate the viability of the developed PSO method because the PSO-based MPPT controller can maximize power from the solar panel under a solar irradiation variation. Through the simulations, the proposed PSO-MPPT algorithm can provide high tracking accuracy and low tracking speed of global maximum power point.

Keywords: MATLAB, MPPT, PGS, PSC, PSO

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LIST OF ABBREVIATIONS

AC	:	Alternating Current
ACO	:	Ant Colony Optimization
ACO-MRLR	:	Ant Colony Optimization-Modified Robust Linear Regression
AF-P&O	:	Alpha Scaling Factor Perturb & Observe
ANN	:	Artificial Neural Network
AP-PSO	:	Adaptive Particle Swarm Optimization
CV	:	Constant Voltage
DC	:	Direct Current
DE	:	Differential Evolution
DPSO	:	Deterministic Particle Swarm Optimization
FLC	:	Fuzzy Logic Controller
GCPV	:	Grid Connected Photovoltaic
GMPP	:	Global Maximum Power Point
INC	:	Incremental Conductance
ISE	:	Integral Square Error
I-V	:	Current versus Voltage
LI	:	Lagrangian Interpolation
LMPP	:	Local Maximum Power Point
MPP	:	Maximum Power Point
MPPT	:	Maximum Power Point Tracker
OGPV	:	Off Grid Photovoltaic
OP	:	Operating Point
P-ANFIS	:	Particle-Adaptive Neuro Fuzzy Interference System

P&O	:	Perturb & Observe
PSC	:	Partial Shading Condition
PSO	:	Particle Swarm Optimization
PSO-OCC	:	Particle Swarm Optimization- One Cycle Control
PSO-RB	:	Particle Swarm Optimization- Reducing Search Boundaries
PV	:	Photovoltaic
P-V	:	Power versus Voltage
PWM	:	Pulse Width Modulation
SMC	:	Sequential Monte Carlo, Sliding Mode Controller
SP	:	Shading Parameters

CHAPTER 1

INTRODUCTION

1.1 Background

The world energy demand is increasing annually. The problem of global warming can be solved by reducing the amount of carbon in the atmosphere by using renewable energy sources. The renewable energy sources (RES) are growing exponentially due to its advantages. Since they are widely deployed, they become cheaper due to huge supply chains and economics scale. There are several benefits of RES such us energy efficiency, environmentally friendly, job opportunity and economic growth. Solar energy is one of the vital RES which is utilized for the generation of electricity. The most abundant source of energy on the planet is solar energy. An estimated 173,000 *TW* of solar energy strikes the surface of the globe each day [1]. Due to its straightforward layout, solar PV systems are currently dominating among various renewable energy sources. According to Renewable Energy Statistics 2022, the world installed PV capacity in 2021 reached 843.1 *GW* with a significant increase compared to 72.7 *GW* in 2011 [2]. In Malaysia, the installed PV power is gradually increasing from 0.1 *GW* until 1.8 *GW* in 2020 as demonstrated in Figure 1.1.

Renewable energy: Solar capacity

Installed photovoltaic (PV) power* Gigawatts	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Growth rate per annum 2021	Growth rate per annum 2011-21	Share 2021
Canada	0.6	0.8	1.2	1.8	2.5	2.7	2.9	3.1	3.3	3.3	**3.6**	8.9%	19.2%	0.4%
Mexico	†	0.1	0.1	0.2	0.3	0.6	1.1	2.5	4.4	5.1	**7.0**	36.8%	66.7%	0.8%
US	5.2	8.1	11.8	16.0	21.7	33.0	41.4	49.8	59.1	73.8	**93.7**	27.3%	33.6%	11.1%
Total North America	5.8	9.0	13.1	18.0	24.5	36.3	45.4	55.4	66.8	82.3	**104.4**	27.2%	33.4%	12.4%
Argentina	†	†	†	†	†	†	†	0.2	0.4	0.8	**1.1**	40.6%	96.4%	0.1%
Brazil	†	†	†	†	†	0.1	1.2	2.4	4.6	7.9	**13.1**	66.1%	115.3%	1.5%
Chile	–	†	†	0.2	0.6	1.1	1.8	2.1	2.7	3.2	**4.4**	36.4%	na	0.5%
Honduras	†	†	†	†	0.4	0.4	0.5	0.5	0.5	0.5	**0.5**	0.3%	60.7%	0.1%
Other S. & Cent. America	0.2	0.3	0.4	0.6	0.9	1.1	1.8	2.2	2.8	3.2	**3.8**	20.3%	36.0%	0.5%
Total S. & Cent. America	0.2	0.4	0.5	0.8	1.9	2.8	5.3	7.5	11.0	15.5	**22.8**	47.2%	61.6%	2.7%
Austria	0.2	0.3	0.6	0.8	0.9	1.1	1.3	1.5	1.7	2.0	**2.7**	32.1%	31.5%	0.3%
Belgium	2.0	2.6	2.9	3.0	3.1	3.3	3.6	4.0	4.6	5.6	**6.6**	18.4%	12.8%	0.8%
Bulgaria	0.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	**1.2**	8.4%	22.7%	0.1%
Czech Republic	1.9	2.0	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	**2.1**	0.1%	1.0%	0.3%
Denmark	†	0.4	0.6	0.6	0.8	0.9	0.9	1.0	1.1	1.3	**1.5**	18.4%	56.9%	0.2%
France	3.0	4.4	5.3	6.0	7.1	7.7	8.6	9.7	10.8	12.0	**14.7**	22.7%	17.2%	1.7%
Germany	25.9	34.1	36.7	37.9	39.2	40.7	42.3	45.2	48.9	53.7	**58.5**	9.1%	8.5%	6.9%
Greece	0.6	1.5	2.6	2.6	2.6	2.6	2.6	2.7	2.8	3.3	**3.5**	7.7%	19.2%	0.4%
Hungary	†	†	†	0.1	0.2	0.2	0.3	0.7	1.4	2.1	**2.1**	0.3%	87.3%	0.3%
Italy	13.1	16.8	18.2	18.6	18.9	19.3	19.7	20.1	20.9	21.7	**22.7**	5.1%	5.6%	2.7%
Netherlands	0.1	0.3	0.7	1.0	1.5	2.1	2.9	4.6	7.2	10.9	**14.2**	30.5%	57.8%	1.7%
Poland	†	†	†	†	0.1	0.2	0.3	0.6	1.5	4.0	**6.3**	58.6%	137.2%	0.7%
Portugal	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.9	1.1	**1.8**	64.2%	26.5%	0.2%
Romania	†	†	0.8	1.3	1.3	1.4	1.4	1.4	1.4	1.4	**1.4**	1.4%	106.3%	0.2%
Slovakia	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	**0.5**	0.3%	0.8%	0.1%
Spain	4.3	4.6	4.7	4.7	4.7	4.7	4.7	4.8	8.8	10.3	**13.6**	33.1%	12.3%	1.6%
Sweden	†	†	†	0.1	0.1	0.2	0.2	0.4	0.7	1.1	**1.6**	42.9%	62.9%	0.2%
Switzerland	0.2	0.4	0.8	1.1	1.4	1.7	1.9	2.2	2.5	3.0	**3.4**	16.3%	31.5%	0.4%
Turkey	†	†	†	†	0.2	0.8	3.4	5.1	6.0	6.7	**7.8**	17.5%	102.6%	0.9%
Ukraine	0.2	0.4	0.7	0.8	0.8	1.0	1.2	2.0	5.9	7.3	**8.1**	10.3%	45.6%	1.0%
United Kingdom	1.0	1.8	2.9	5.5	9.6	11.9	12.8	13.1	13.3	13.5	**13.7**	2.0%	29.9%	1.6%
Other Europe	0.1	0.3	0.5	0.6	0.7	0.8	1.0	1.1	1.6	2.3	**3.0**	28.7%	35.9%	0.4%
Total Europe	53.6	71.7	81.9	88.8	97.5	104.6	113.3	124.2	146.0	167.0	**191.1**	14.7%	13.6%	22.7%
Russian Federation	†	†	†	†	0.1	0.1	0.2	0.5	1.3	1.4	**1.7**	16.7%	206.1%	0.2%
Other CIS	†	†	†	0.1	0.2	0.2	0.3	0.7	1.3	1.9	**3.3**	69.7%	109.5%	0.4%
Total CIS	†	†	†	0.1	0.2	0.3	0.5	1.2	2.6	3.3	**4.9**	47.1%	118.1%	0.6%
Israel	0.2	0.3	0.4	0.6	0.8	0.9	1.0	1.3	1.8	2.2	**2.3**	4.0%	28.4%	0.3%
Jordan	†	†	†	†	†	0.3	0.4	0.7	1.2	1.4	**1.5**	5.3%	185.0%	0.2%
United Arab Emirates	†	†	†	†	†	†	0.3	0.5	1.8	2.2	**2.6**	18.4%	70.2%	0.3%
Other Middle East	†	†	0.1	0.1	0.2	0.3	0.5	0.8	0.9	1.1	**1.5**	33.8%	73.8%	0.2%
Total Middle East	0.2	0.3	0.5	0.7	1.0	1.5	2.1	3.3	5.7	7.0	**8.0**	13.7%	44.0%	0.9%
Algeria	–	–	–	†	†	0.2	0.4	0.4	0.4	0.4	**0.4**	0.3%	na	0.1%
Egypt	†	†	†	†	†	†	0.2	0.7	1.6	1.7	**1.7**	0.3%	60.1%	0.2%
Morocco	†	†	†	†	†	†	†	0.2	0.2	0.2	**0.2**	21.1%	32.4%	0.0%
South Africa	†	†	0.3	1.1	1.3	2.0	3.1	4.4	4.4	5.5	**5.7**	4.5%	99.7%	0.7%
Other Africa	0.2	0.3	0.4	0.5	0.6	0.7	1.0	1.4	1.8	1.9	**2.3**	17.1%	25.6%	0.3%
Total Africa	0.3	0.3	0.7	1.6	1.9	3.0	4.7	7.2	8.4	9.7	**10.3**	6.5%	44.1%	1.2%
Australia	2.5	3.8	4.6	5.3	5.9	6.7	7.4	8.6	13.0	17.3	**19.1**	10.3%	22.7%	2.3%
China	3.1	6.7	17.7	28.4	43.5	77.8	130.8	175.0	204.6	253.4	**306.4**	21.2%	58.3%	36.3%
India	0.6	1.0	1.4	3.4	5.4	9.7	17.9	27.1	34.9	39.0	**49.3**	26.7%	56.4%	5.9%
Japan	4.9	6.6	13.6	23.3	34.2	42.0	49.5	56.2	63.2	69.8	**74.2**	6.6%	31.2%	8.8%
Malaysia	†	†	0.1	0.2	0.3	0.3	0.4	0.5	0.9	1.5	**1.8**	20.8%	124.7%	0.2%
Pakistan	†	†	0.1	0.2	0.3	0.6	0.7	0.7	0.8	0.9	**1.1**	26.3%	50.1%	0.1%
Philippines	†	†	†	†	0.2	0.8	0.9	0.9	1.0	1.1	**1.4**	29.8%	91.9%	0.2%
South Korea	0.7	1.0	1.6	2.5	3.6	4.5	5.8	8.1	12.0	14.6	**18.2**	24.9%	37.9%	2.2%
Taiwan	0.1	0.2	0.4	0.6	0.9	1.2	1.8	2.7	4.1	5.8	**7.7**	32.7%	50.4%	0.9%
Thailand	0.1	0.4	0.8	1.3	1.4	2.4	2.7	3.0	3.0	3.0	**3.0**	2.3%	44.1%	0.4%
Vietnam	†	†	†	†	†	†	†	0.1	5.0	16.7	**16.7**	0.3%	127.3%	2.0%
Other Asia Pacific	0.1	0.2	0.3	0.3	0.5	0.7	1.0	1.2	1.8	2.3	**2.8**	20.8%	37.3%	0.3%
Total Asia Pacific	12.1	20.0	40.6	65.6	96.2	146.8	218.8	284.2	344.1	425.3	**501.6**	18.3%	45.1%	59.5%
Total World	**72.2**	**101.7**	**137.2**	**175.6**	**223.2**	**295.2**	**390.2**	**483.0**	**584.7**	**710.3**	**843.1**	**19.0%**	**27.9%**	**100.0%**

Figure 1.1: Solar capacity in the world [2]

1.1.1 Photovoltaic (PV) system

A solar panel is a collection of photovoltaic solar cells arranged on a rectangular frame. The production of a photovoltaic (PV) module entails the connection of multiple solar cells in a series configuration. These PV modules are then interconnected either in parallel or series to generate the desired output current and voltage. The enduring benefits and minimal maintenance demands of solar photovoltaic (PV) energy systems have resulted in their widespread adoption and commercialization across numerous nations. To deal with the nonlinear properties of PV arrays is the main problem that comes with deploying PV power generation systems. Temperature and solar irradiance both affect the PV's properties. Due to cloud shading, nearby structures, or nearby trees, a PV array suffers varying levels of irradiance. There are grid-connected photovoltaic system and standalone photovoltaic system.

1.1.2 Grid-Connected Photovoltaic (GCPV) system

The electrical utility grid system incorporates the GCPV systems. In GCPV, inverters convert the array's DC power into AC power that meets the utility grid's voltage and power quality criteria. With the aid of an inverter, a bi-directional interface is created between the PV system and the utility power output. When the PV system's power output exceeds the consumer demand, the bi-directional interface or features allow the PV panels to supply AC loads and deliver excess electricity back to the grid [3]. The excess electricity produced by GCPV system is sent back to the electrical grid, which then supplies power when there is not enough sunlight. Figure 1.2 represents the schematic diagram for the GCPV system.

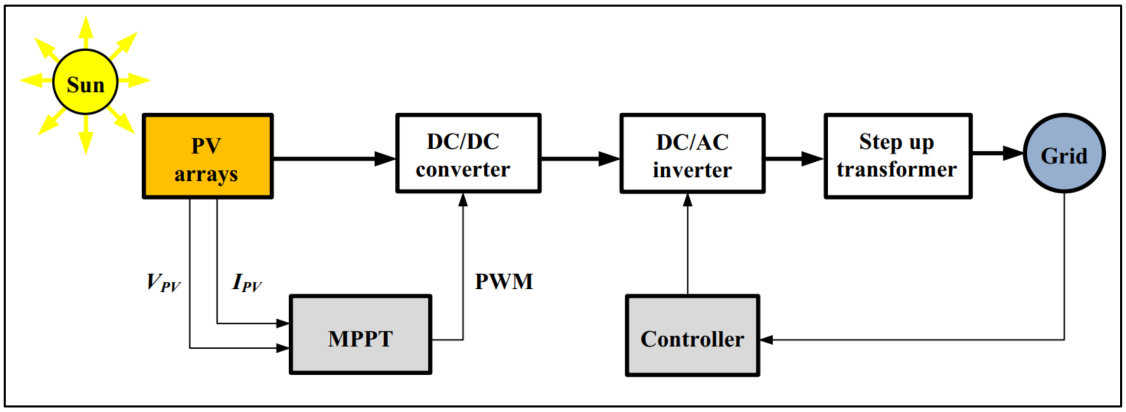

Figure 1.2: Block diagram of GCPV [4]

1.1.3 Off-Grid Photovoltaic (OGPV) system

A standalone PV system is also known as off-grid solar system which is not connected to the power grid. OGPV systems are beneficial in remote areas, where the connection to the grid system is problematic. Due to their independence from energy storage, these systems are suitable for powering devices like water pumps, cooling fans, and solar thermal heating systems. The independent PV system with backup batteries can provide people access to energy when there isn't any sunshine, as at night or when it is overcast. A typical standalone PV system would have PV modules, batteries, and a solar charge controller. Additionally, an inverter may also be a part of the system, converting the DC power from the PV modules to the AC power needed by standard electrical appliances. Figure 1.3 shows a schematic illustration of a standalone system.

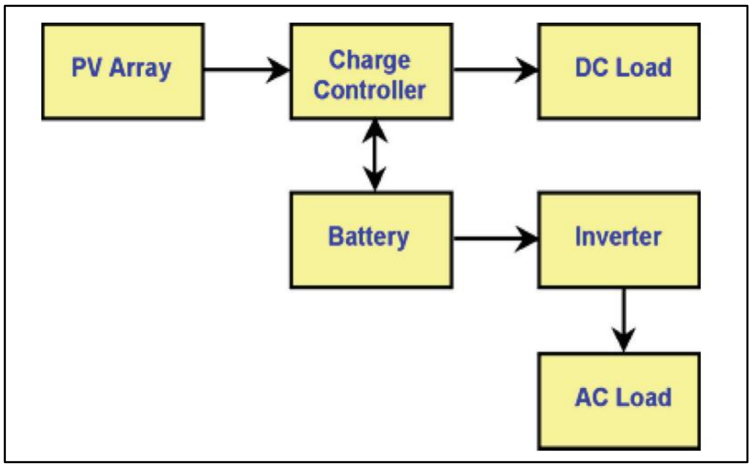

Figure 1.3: Block diagram of OGPV [5]

1.1.4 Maximum Power Point Tracking (MPPT) on PSC

A single PV cell generates 1 or 2 W of power [6]. A combination of PV cells known as PV module are connected in series. Modules are then connected to form arrays which are the fundamental items of the PV system. A solar PV array contains bypass diodes and blocking diodes. When a PV module in a string is malfunctioning, blocking diodes impede the electric current from flowing backward while bypass diodes behave as open circuits. The PV module characteristics curve contains a maximum power point (MPP) where the PV system can function at its peak efficiency. Figure 1.4 shows the combination of power-voltage and current-voltage curve. MPP is the area of a power (I-V) curve where the product of the corresponding current and voltage, or the maximum power output, is greatest.

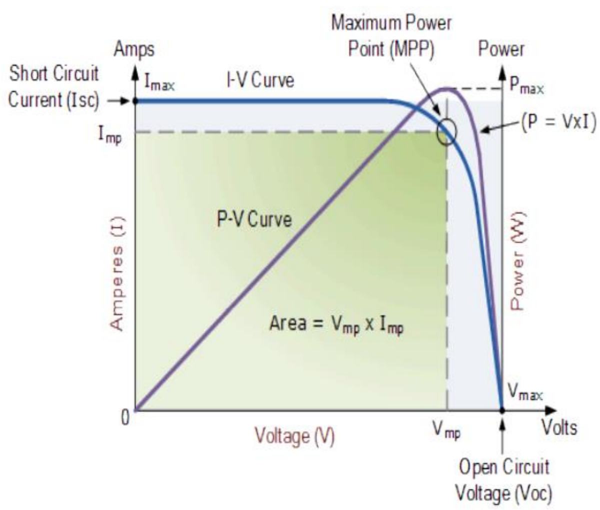

Figure 1.4: MPP curve [7]

Regarding to the different solar irradiance and temperature, the power-voltage and current-voltage curves of PV panels exhibit a non-linear pattern. as shown in Figure 1.5 and Figure 1.6. For PV modules, there is only real MPP where it generates the most power under the solar temperature circumstances [8].

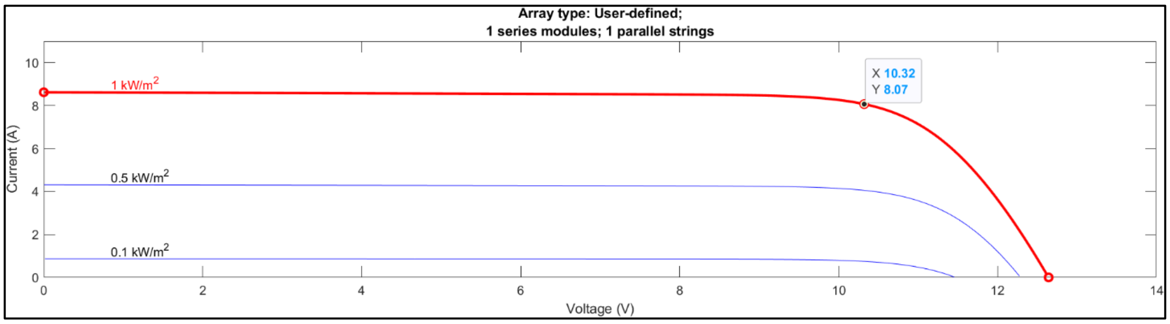

Figure 1.5: I-V Characteristics Curve

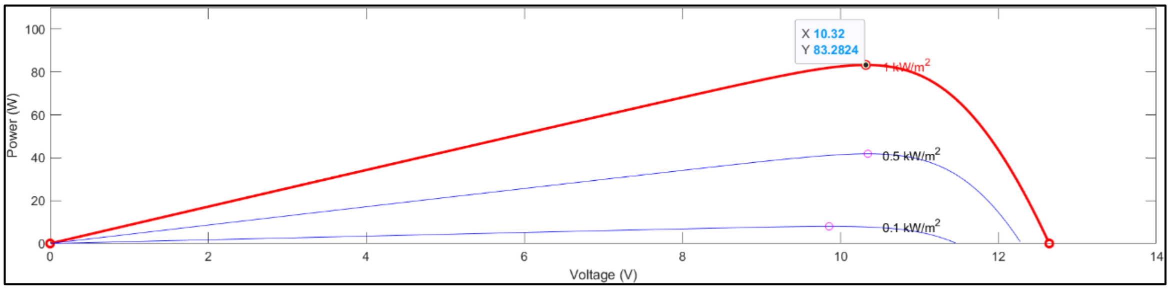

Figure 1.6: P-V Characteristics Curve

However, the partial shading condition of PV modules occur when an object is moving and blocking the sunlight from the PV arrays, PV modules will receive lesser solar irradiation, thereby decreasing the output current generated by PV modules. This situation is known as partial shading condition (PSC) which each of them experience different irradiation and temperature. PV modules under PSC experience non-uniform illumination and generate heat known as hot-spot effect [9]. The cells will be damaged under high temperature, turning it into an open circuit. Hence, for the partially shaded PV modules, the bypass diode conducts and behave as an open circuit and minimize power loss caused by the shading effect. Under PSC, the PV arrays are bypassed, thereby forming several peaks in the I-V and P-V characteristic curve. There will only be one global MPP (GMPP) among all the peaks, with the remaining peaks being local MPPs as illustrated in Figure 1.7 [10]. The local MPP represents the individual peak power point for a specific shaded or partially illuminated section of the PV system, allowing it to operate at its maximum efficiency despite shading effects.

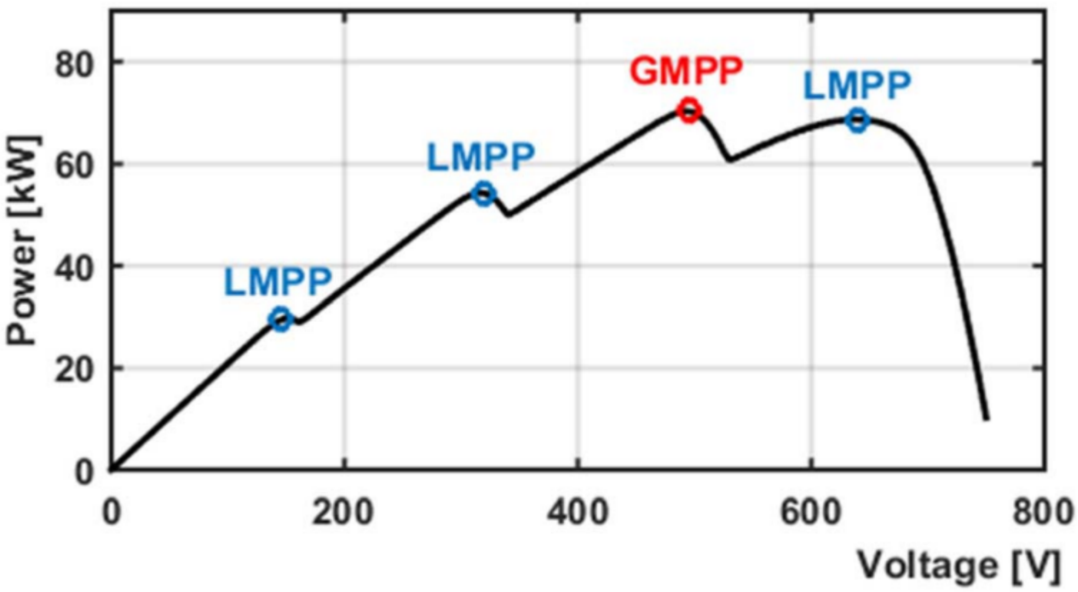

Figure 1.7: P-V curve under PSC [10]

In order to maximize the power output of a PV system, the MPP can be tracked using a maximum power point tracking (MPPT) algorithm, which adjusts the operating point of the PV array to follow the MPP as the solar irradiance and other operating conditions change. Maximum power point tracker (MPPT) is typically used in conjunction with the power converter to optimize the utilization of large arrays of PV modules. The MPPT approach helps the PV system produce the highest amount of output power from the PV arrays.

1.2 Problem Statement

Particularly in low irradiation conditions, the efficiency of PGS-based energy generation is poor (9–17%), and the amount of electricity produced by solar arrays frequently varies with the weather, which is a key drawback for PV generation systems. There are numerous MPPT algorithms such as incremental conductance, perturb and observe (P&O), fractional open circuit voltage and ripple correlation which have been proposed over the years. These techniques perform well under constant solar irradiance and temperature. The P-V characteristics curve, however, will exhibit several peaks and become more complex under PSC. Since PV modules in the same string undergo different solar irradiance, the performance of the conventional MPPT algorithms is less efficient. These techniques obey the hill climbing principle and only locate a local MPP as the P-V curve is multimodal. Although the structures are simple and are easy to be implemented, the PV system may not function at the MPP as the solar power from the PV arrays are not fully utilized under the conditions of partial shading. Therefore, the utilization of a suitable maximum power point tracking (MPPT) algorithm is crucial in enhancing the efficiency and extracting the maximum available power from the photovoltaic (PV) system..

1.3 Objectives

The objective of this project is to present a maximum power point tracking (MPPT) approach, which investigates the output characteristics of a photovoltaic (PV) system under partial shading conditions of the PV array. The following goals must be attained for this project to achieve its intended goals:

i. To synthesize a Particle Swarm Optimization algorithm for solar PV under partial shading condition
ii. To simulate a PSO algorithm on MATLAB environment
iii. To evaluate the robustness of PSO algorithm under various working conditions

1.4 Research Questions

There are some of the research questions for this study are guided by the following questions:

i. Is the PSO manage to track the GMPP under PSC?
ii. Does the MATLAB software applicable in the real working condition of PSC?
iii. What parameters are used in order to evaluate the robustness of PSO?

1.5 Thesis Outlines

Introduction, literature reviews, methodology, results, and discussion, as well as conclusion and recommendations, comprise the five chapters of this report.

Chapter 1 covers the project's background, present global concerns, aims, and project outlines. The objectives of this project explain the goal.