MAXIMUM POWER POINT TRACKING TECHNIQUE UNDER PARTIAL SHADING CONDITION FOR PHOTOVOLTAIC SYSTEMS

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To my family for their ever loving support over the years.

To my friends for their never ending motivational and support.

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ABSTRACT

Maximum Power Point Tracking (MPPT) technique extracts the maximum available power from the photovoltaic array (PV). Perturb and Observe (P&O) is the most preferable type of MPPT algorithm due to its simplicity, accuracy and low cost. However, when partial shading condition occurs, it produces multiple local maximum power points (MPPs) on the PV characteristics curve. This causes confusion for the conventional P&O algorithm to track the true MPP. This thesis studies the impact of partial shading on the PV system and to improve the P&O algorithm by adding a checking algorithm into the variable step size. This checking algorithm determines the global maximum power by first comparing all existing peak points before the P&O algorithm identifies the voltage at MPP to calculate the duty cycle of the boost converter. The PV power and voltage rating used for this research are 42 W and 17 V, respectively. The boost converter can double the PV output voltage. The simulation results have proven that the proposed algorithm is able to track the global MPP with a tracking efficiency of 99.96%. This has been verified by hardware implementation of the proposed algorithm using Arduino Mega 2560. The proposed MPPT algorithm also provides better stability with less percentage error on the PV output voltage and power compared to using the conventional P&O MPPT algorithm.

ABSTRAK

Teknik Penjejakan Titik Kuasa Maksimum (MPPT) boleh mendapatkan kuasa maksimum dari tatasusun fotovolta (PV). Algoritma Usik dan Perhati (P&O) adalah satu teknik yang sangat berkesan memandangkan ianya mudah, tepat dan kos rendah. Walau bagaimanapun, apabila keadaan separa teduh berlaku, ianya menghasilkan lebih dari satu titik kuasa maksimum (MPP) pada lengkungan ciri PV. Ini akan menyebabkan kekeliruan kepada teknik algoritma konvensional P&O untuk mengesan titik sebenar MPP. Tesis ini mengkaji kesan PSC kepada sistem PV dan menambahbaik algoritma P&O MPPT dengan menambah algoritma semakan ke dalam saiz langkah yang berubah. Algoritma semakan ini menentukan kuasa maksimum global dengan membandingkan semua puncak maksimum yang wujud sebelum algoritma P&O bertindak untuk mengesan voltan pada MPP bagi mengira kitar tugas untuk penukar galak. Kadar kuasa dan voltan PV yang digunakan untuk kajian ini ialah masing-masing 42 W dan 17 V. Penukar galak boleh menggandakan voltan output PV. Keputusan simulasi telah membuktikan algoritma yang dicadangkan mampu mengesan MPP global dengan kadar keberkesanan sebanyak 99.96%. Ini ditentusahkan dengan keputusan ujian perkakasan menggunakan Arduino Mega 2560. Algoritma MPPT yang dicadangkan juga lebih stabil dengan dengan peratusan ralat yang lebih rendah pada voltan output PV berbanding penggunaan algoritma konvensional P&O MPPT.

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Δi_L	-	Difference in inductor current
ΔP	-	Difference in power
ΔV	-	Difference in voltage
ΔV_o	-	Difference in output voltage
C	-	Capacitor
D	-	Duty cycle
d	-	Diode
d_{min}	-	Minimum distance
f_s	-	Switching frequency
G	-	Irradiation
G_m	-	Irradiation obtained from solar energy
G_{ref}	-	1000 W/m^2 (standard irradiation)
I_{D1}	-	Diode current 1
I_{D2}	-	Diode current 2
i_L	-	Inductor current
I_L	-	Load current
I_m	-	Measured current
I_{MPP}	-	MPP current
I_n	-	Reference current
I_{n-1}	-	Previous reference current
I_{PV}	-	PV current
I_{r0}	-	Irradiance used for measurement
I_{ref}	-	Reference current or current produce by the photoelectric effect
I_s	-	Reverse saturation current
I_{sc}	-	Short circuit current
I_{sh}	-	Shunt current
k	-	Boltzmann’s constant

k_i	-	Short circuit current temperature coefficient
k_v	-	Open circuit voltage temperature coefficient
L	-	Inductor
L_{min}	-	Minimum inductor
N	-	Quality factor
n_d	-	Number of bypass diode
N_p	-	Number of particle
N_s	-	Number of cells in series
$P_{available}$	-	Output power obtained from simulation and hardware results
P_{in}	-	Input power
P_{MPP}	-	MPP power
$P_{MPP, ref}$	-	Reference power during STC
$P_{MPP,m}$	-	Measured MPP power
P_{mpp_new}	-	New MPP power
P_n	-	Reference power
P_{n-1}	-	Previous reference power
P_o	-	Output power
P_{peak}	-	Peak power
P_{PV}	-	PV power
$P_{PV,average}$	-	Average PV power
r	-	Load resistor
r_C	-	Internal series resistor of capacitor
$r_{DS(ON)}$	-	Drain – source resistor during ON state of power MOSFET
r_L	-	Internal series resistor of inductor
R_{CE}	-	Variable resistance in MOSFET
R_s	-	Inherent resistance in series
R_{sh}	-	Inherent resistance in parallel
T	-	Temperature
T_m	-	Temperature caused by the solar energy
T_{OFF}	-	Time when switch is opened
T_{ON}	-	Time when switch is closed
T_{ref}	-	Cell temperature (specified by the manufacturer)
T_t	-	Time period

V	-	Step size in algorithm
V_{avg}	-	Average voltage
V_{ce}	-	voltage across collector-emitter junction
V_{dc}	-	Direct current voltage
V_f	-	Forward voltage
V_m	-	RMS line to line voltage for 3 phase supply
V_{max}	-	Maximum voltage
V_{min}	-	Minimum voltage
V_{MPP}	-	MPP voltage
V_{mpp_new}	-	New MPP voltage
V_n	-	Reference voltage
V_{n-1}	-	Previous reference voltage
V_o	-	Output voltage
V_{oc}	-	Open circuit voltage
V_{PV}	-	PV voltage
V_s	-	Input voltage / Source voltage
V_t	-	Thermal voltage
$V_{updated}$	-	Updated voltage for new reference
η	-	Efficiency
$\eta_{tracking}$	-	Tracking efficiency
η_{conv}	-	Conversion efficiency
$\eta_{overall}$	-	Overall efficiency
α	-	Ideality factor modified

LIST OF ABBREVIATIONS

ADC	-	Analog to Digital Conversion
ANN	-	Artificial Neural Network
BIPV	-	Building Integrated Photovoltaic
CCM	-	Continuous Current Mode
CPSO	-	Complex Particle Swarm Optimization
DC	-	Direct current
DC-AC	-	Direct current to alternating current
DC-DC	-	Direct current to direct current
DCM	-	Discontinuous Current Mode
FLC	-	Fuzzy Logic Control
FOCV	-	Fractional Open Circuit Voltage
FSCC	-	Fractional Short Circuit Current
GMPP	-	Global Maximum Power Point
IGBT	-	Insulated Gate Bipolar Transistor
IncCond	-	Incremental Conductance
I-V	-	current-voltage
LED	-	Light Emitting Diode
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
MPP	-	Maximum Power Point
MPPT	-	Maximum Power Point Tracking
P&O	-	Perturb and Observe
PSC	-	Partial Shading Condition
PSO	-	Particle Swarm Optimization
PV	-	Photovoltaic
P-V	-	power-voltage
PWM	-	Pulse Width Modulation
RMS	-	Root Mean Square

SEPIC	-	Single Ended Primary Inductor Converter
SMPS	-	Switched Mode Power Supply
STC	-	Standard Test Condition

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the last two decades, the electricity demand from the people all over the world has introduced renewable energies into the industry. Among all types of the renewable energies, solar is one of the most popular energy that has been used by the people until this day.

The energy is harvest through the Photovoltaic (PV) System which converts the solar energy to the electrical power. With the sun as the source, it said to be the most promising renewable energy. However, the installation cost for solar PV is quite high and the conversion efficiency is very low which in the range of 12% ~ 20% [1]. Plus, the output power is highly depending on the solar irradiation and the panel temperature. The irradiation level will affect the level of output power and the high temperature would contribute to high power loss [2, 3]. This had made the solar energy to become the unattractive choice for the electricity user. Therefore, many studies have been done by the researchers focusing on improving the solar PV's efficiency.

One of the control technique use to extract the utmost available power from the PV array is Maximum Power Point Tracking (MPPT) [4]. MPPT is valid for any PV configuration – PV module, PV panel or PV array, but most of the MPPT implementation is in array level. MPPT is placed between the solar PV and DC-DC converter as shown in Figure 1.1.

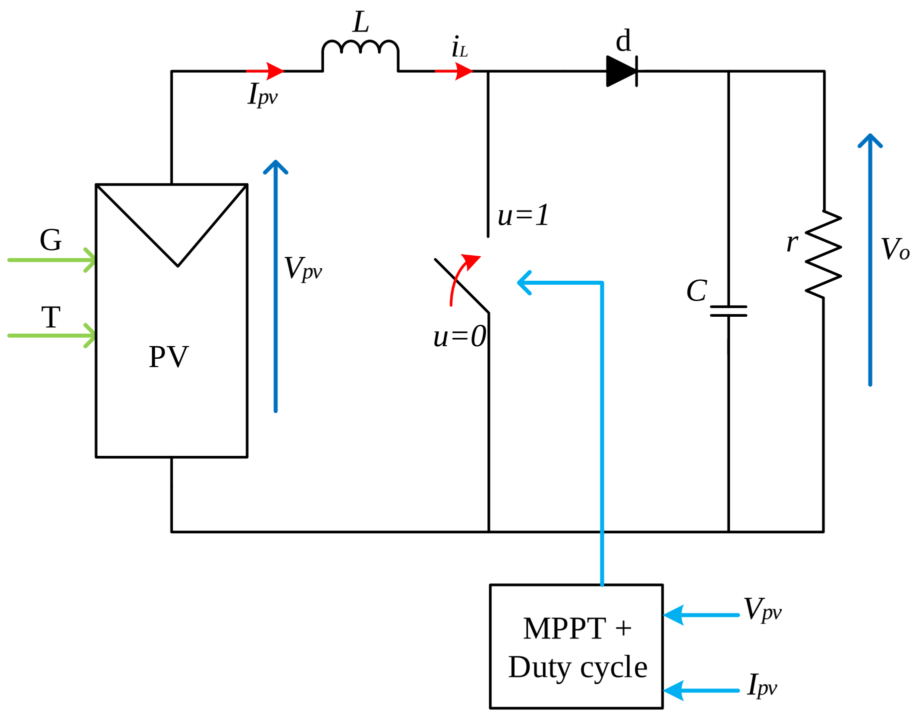

Figure 1.1: Configuration of Maximum Power Point Tracking (MPPT) system

Figure 1.1 shows a standard MPPT system whereby irradiance, G and temperature T act as the stimulant towards the PV outputs. The PV voltage, V_{PV} and PV current, I_{PV} used as the inputs for the MPPT algorithm to produce optimum duty cycle for the DC-DC converter. There were several MPPT techniques that have been proposed and implemented such as Perturb and Observe (P&O) algorithm, Incremental Conductance (IncCond) and Fractional Open Circuit Voltage [4].

All techniques differ in terms of complexity, accuracy, and speed. Every technique has its own control variable: voltage, current, or duty cycle [5]. Most of the researchers were normally using a P&O algorithm since it was much simpler and cost-effective compared to the other methods [6]. Yet, it also had steady-state oscillation problem and unable to track the true Maximum Power Point (MPP) under partial shading condition (PSC) [7-11].

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1.2 Problem Statement

Perturb and Observe (P&O) is a most preferable type of MPPT algorithm due to the simplicity, better accuracy and low cost. P&O algorithm is using power and voltage as the control variable. The idea of the P&O algorithm is basically perturbing or shifting the solar PV operating point based on the sign of the PV power last increment. As the PV power is increasing, the perturbation will be in the same direction and once the it starts to decrease, the perturbation is reverse [12].

Figure 1.2 illustrates the working principle of the P&O algorithm in tracking the MPP. The initial tracking point could be any point on the PV curve depends on the set up algorithm. It will increase continuously with the given step size until the sign of increment starts to be in negative, the tracking will reverse its direction. It will be keep oscillating at that area with a constant step size until the end of operation and thus become the critical weakness for P&O MPPT algorithm. Hence, an accurate MPP is difficult to obtain due to the oscillation problem and eventually contribute to power losses. Larger step size would give faster response, but higher power loss. In contrast, smaller step size would contribute to the low power loss but slower response [13]. Nevertheless, these problems can be solved by having a variable step size of P&O algorithm [14].

Another major drawback of the conventional P&O MPPT algorithm is its inability to extract the maximum power from the partially shaded of solar PV [15]. Figure 1.3 depicts the characteristic of the PV curve when the solar PV in partial shading condition (PSC). Two peak-points occurred on the PV curve; local and global MPP respectively. The MPPT algorithm extract the real peak-point, global MPP while local MPP is another peak-point existed due to the PSC. The number of peak-points appeared on the PV curve is depending on the number of bypass diode used in the solar PV [16]. These multiple peak-points had caused confusion to the P&O MPPT due to the PV's non-linear characteristic. When the same tracking process occurred again, but this time the algorithm is oscillating and trapped at the local MPP. Consequently, the solar PV would yield lower power outputs for the system. The process of perturbing and observing cannot continue because of the algorithm itself; whenever, the power starts to decrease, the perturbation will be in reverse direction.

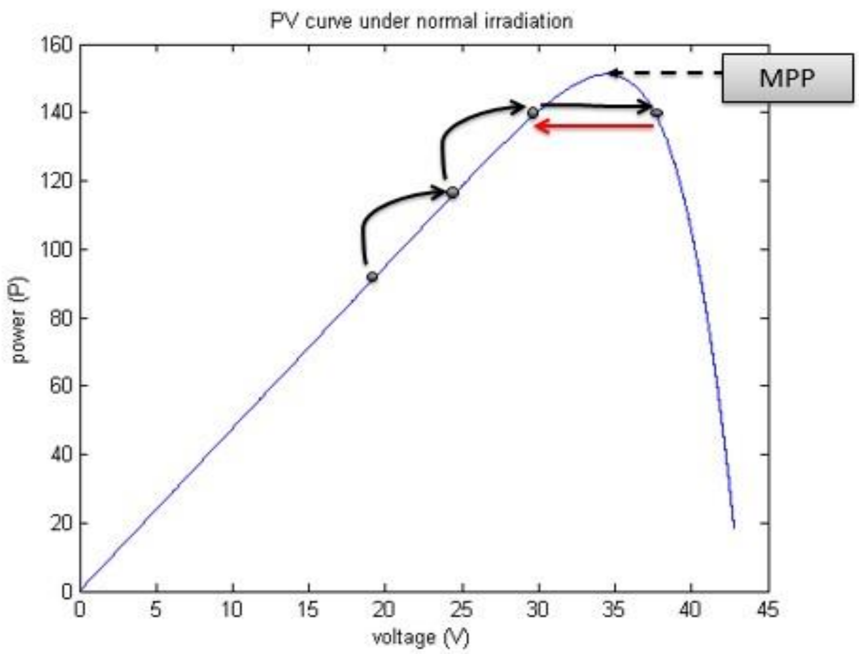

Figure 1.2: PV curve under constant irradiation with P&O MPPT

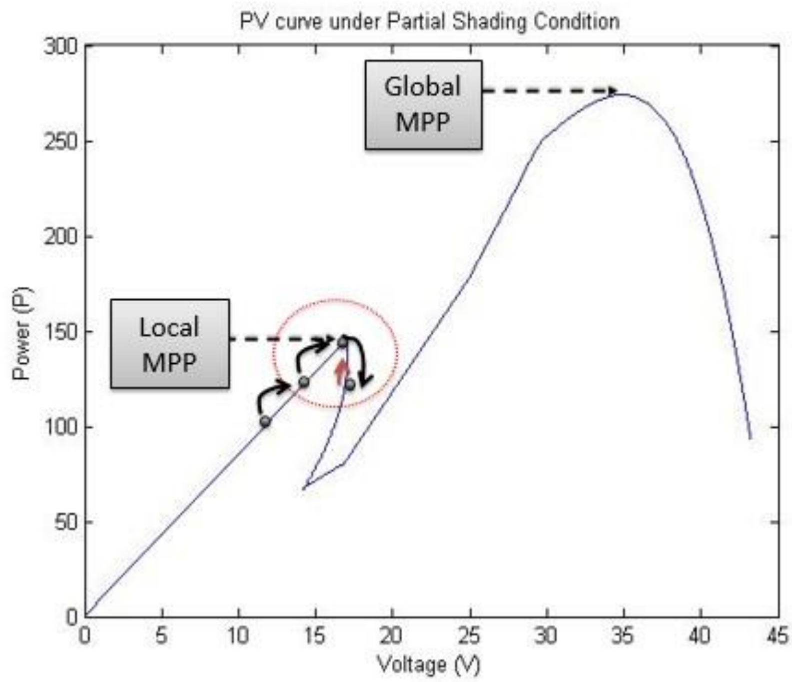

Figure 1.3: PV curve under partial shading condition with P&O MPPT algorithm

The partial shading on PV system cause some of the solar cells unable to receive any sunlight and the shaded cells become reverse biased by the other cells exhibiting high resistance. Consequently, the non-uniform temperature would occur over the whole cell area [15].

PSC could also contribute to the enormous power dissipation in a small area due to the breakdown in localize region in the cell p-n junction. Besides, PSC becomes a major problem for large PV array since it will alter the PV parameters such as short circuit current, open circuit voltage, fill factors and some other aspects [17].

Concisely, the conventional P&O MPPT algorithm establish two major issues; steady state oscillation problem and unable to track true MPP under PSC. These problems give impact on the maximum available power extracted by the MPPT. Therefore, the tracking algorithm should be modified so that it can be work efficiently under any irradiation level.

Many researchers had come out with various modifications on the algorithm to overcome these two issues [18]. Thus, this work will proposes an improved modified P&O algorithm with much simpler and lower cost compares to the others.

1.3 Objectives

The objectives of this project are:-

1. To modify and improve the tracking efficiency of the conventional Perturb and Observe algorithm under partial shading condition.
2. To analyze the stability and the response of the MPPT system under partial shading condition.

1.4 Scope of Research

The work in the thesis basically proposes a better way to overcome the drawbacks of conventional Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) especially during partial shading condition (PSC). An MPPT system with the solar module, MPPT algorithm and boost converter are modeled using MATLAB/ Simulink and implemented using Arduino Mega 2560. A total of 36 solar cells are arranged in a series configuration for the solar module with 42 W PV power and 17 V PV voltage rating. The solar simulator has been designed as displayed in Appendix A for the hardware implementation purpose. In this work, the boost converter operates in open loop condition with the boosted voltage set at 32 V, twice the input voltage with the assumption that the maximum input voltage is 16 V. This research will only focus on the irradiation factor. The temperature factor is neglected because the change in ambient temperature does not significantly affect the PV cell and the dynamic response [19-22].

1.5 Structure of Thesis

The thesis is organized as follows:

Chapter 1 discusses the general idea of the project and briefly introducing the background of the study, the objective, the scope of the project and the methodology that will be taken.

Chapter 2 reviews more on the parts of MPPT system: solar PV, DC-DC converter and MPPT algorithms. Several MPPT algorithms are elaborated thoroughly as well as the explanation on the effects of having partial shading condition towards the solar PV.

Chapter 3 would cross on the method used for this research. The methodology includes the simulation works using MATLAB/ Simulink and hardware implementation.

Chapter 4 depicts all results obtained from the MPPT system tested under different types of P&O algorithms and the tracking efficiency. Furthermore, detail discussion on the obtained results are discussed and explained.

Chapter 5 provides the conclusion and some recommendation for the future researchers to have a better idea. Besides, this section also highlights this research contribution in solar PV field.

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