



UNIVERSITI PUTRA MALAYSIA

***EFFICIENCY IMPROVEMENT OF A STANDALONE PHOTOVOLTAIC
SYSTEM USING FUZZY-BASED MAXIMUM POWER POINT
TRACKING ALGORITHM***

EHSAN MOHSIN OBAID ALHAMDAWEE

FK 2016 90



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By

EHSAN MOHSIN OBAID ALHAMDAWEE

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfillment of the Requirements for the Degree of
Master of Science**

September 2016

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DEDICATION

The efforts spent on this work are dedicated to all family members including father, mother, and beloved nephews for their patience and prayer, and to all friends who gave a full support. Their moral support and professional guidance were a source of inspiration, in the fulfillment of this project.



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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September 2016

Chairman : Nashiren Farzilah Binti Mailah, PhD
Faculty : Engineering

The global trend on harvesting the green energies from solar cells gains more attention in recent years as compared to fossil fuel. The Photovoltaic (PV) system represents a clean, sustainable, and free renewable energy source, yet the efficiency of the PV cells is affected by the daily environmental effects on its non-linear current-voltage (I-V) and power-voltage (P-V) characteristics. Given these shortcomings, a maximum power point tracking (MPPT) algorithm is a viable part of tracking the optimum power point despite the fluctuation of temperature and irradiance. The MPPT algorithms imply the optimal duty ratio to drive the matching converter for optimal maximum power tracking. MPPT algorithms can be categorized into classical methods and artificial intelligence-based methods. Among the conventional techniques, perturb and observe (P&O) is the most common method due to its simplicity of operation and easiness of implementation. However, it increments and decrements the duty ratio in fixed step sizes which impose inherited drawbacks such as slow response time and continuous oscillation around the maximum power point (MPP). As a result, low efficiency ratio is obtained. The artificial intelligent MPPT techniques have the advantage of the adaptive nature to control the non-linear systems. Fuzzy logic controller (FLC), as adaptive MPPT method, adaptively modifies the duty ratio variations which lead to faster convergence time, low oscillation, and higher output power ratio. However, an FLC of an inaccurate design of input parameters like the error (E) and the error derivative (CE) contribute to high oscillation, slow response time towards the MPP, and less efficiency.

This thesis proposes a FLC controller that calculates the E and the previous duty ratio variations (ΔD_{n-1}) as input parameters to adaptively modify the output duty ratio (Δd). The controller aims to eliminate the drawbacks of both conventional (FLC, P&O) algorithms in term of response time, settling time, oscillation level, and maximum power ratio. MATLAB/SIMULINK environment is used to design and develop the PV module, DC-DC boost converter, and MPPT algorithms. The steady state test and dynamic tests were used to test the performance of the algorithms. The simulation

results at steady state conditions show the proposed FLC has better performance than the conventional algorithms in term of response time, settling time, oscillation around the MPP, and maximum efficiency. A further test on dynamic conditions shows the proposed FLC has a better transient response at low irradiance conditions. The experimental results validated the performance of the MPPT algorithms at steady state conditions in term of response time, oscillation, and MPP ratio. In conclusion, the proposed FLC has fulfilled the objectives of the study by eliminating the drawbacks of the conventional algorithms and achieved more efficient PV system.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

**PENAMBAHBAIKAN KECEKAPAN SISTEM FOTOVOLTA BERDIRI
SENDIRI MENGGUNAKAN ALGORITMA PENJEJAKAN TITIK
KUASA MAKSIMUM BERASASKAN KABUR**

Oleh

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September 2016

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Tren sedunia dalam menuai tenaga hijau dari sel suria telah menarik perhatian sejak ke belakang ini berbanding dengan bahan api fosil. Sistem Fotovolta (FV) mewakili satu sumber tenaga boleh diperbaharui yang bersih, mampan dan percuma, namun kecekapan sel FV ini dipengaruhi oleh kesan alam sekitar seharian terhadap ciri arus-voltan (A-V) dan kuasa-voltan (K-V) tidak lurus. Berikutan kelemahan ini, algoritma penjejakan titik kuasa maksimum (PTKM) adalah merupakan suatu bahagian yang berdaya maju dalam penjejakan titik kuasa optimum walaupun terdapat turun-naik dalam suhu dan sinaran. Algoritma PTKM mengenakan nisbah tugas optimum untuk memacu penukar sepadan untuk penjejakan optimum kuasa maksimum. Algoritma PTKM boleh dikategori kepada kaedah klasik dan kaedah berasaskan kepintaran buatan. Di antara teknik konvensional, usik dan cerap (U&C) adalah teknik yang paling biasa kerana operasinya yang ringkas dan pelaksanaan yang mudah. Walaubagaimanapun, kenaikan dan penurunan nisbah tugas dalam saiz langkah tetap telah mengenakan kelemahan yang diwarisi seperti masa tindakbalas yang perlahan dan ayunan yang berterusan sekitar titik kuasa maksimum (TKM). Kesannya, nisbah kecekapan yang rendah akan diperolehi. Teknik kepintaran buatan PTKM mempunyai kelebihan dari segi sifat penyesuaian dalam mengawal sistem tidak lurus. Pengawal logik kabur (PLK), sebagai teknik PTKM boleh suai, mengubah suai perubahan nisbah tugas di mana ia membawa kepada masa penumpuan yang lebih pantas, ayunan yang rendah, dan nisbah kuasa keluaran yang tinggi. Walaubagaimanapun, satu PLK yang mempunyai rekabentuk parameter masukan seperti ralat, R dan ralat terbitan, RT yang tidak tepat boleh menyumbang kepada ayunan yang tinggi, masa tindakbalas yang perlahan terhadap TKM, dan kecekapan yang berkurangan.

Tesis ini mencadangkan suatu pengawal PLK yang mengira R dan perubahan nisbah tugas terdahulu, $\Delta K-1$ sebagai parameter masukan untuk mengubah suai nisbah tugas keluaran, Δd . Pengawal ini bertujuan untuk menghapuskan kelemahan kedua-dua algoritma konvensional (PLK, U&C) dari segi masa tindakbalas, masa penetapan,

tahap ayunan, dan nisbah kuasa maksimum. Persekitaran MATLAB/SIMULINK digunakan untuk merekabentuk dan membangunkan modul FV, penukar galak AT-AT, dan algoritma PTKM. Ujian keadaan mantap dan ujian dinamik telah digunakan untuk menguji prestasi algoritma tersebut. Keputusan penyelakuan pada keadaan mantap menunjukkan PLK yang dicadangkan mempunyai prestasi yang lebih baik dari algoritma konvensional dari segi masa tindakbalas, masa penetapan, ayunan sekitar TKM, dan kecekapan maksimum. Ujian keadaan dinamik seterusnya menunjukkan PLK yang dicadangkan mempunyai tindakbalas fana yang lebih baik pada keadaan sinaran yang rendah. Keputusan ujikaji telah mengesahkan prestasi algoritma PTKM pada keadaan mantap dari segi masa tindakbalas, ayunan dan nisbah TKM. Kesimpulannya, PLK yang dicadangkan telah mencapai objektif dengan menghapuskan kekurangan algoritma konvensional dan memperolehi sistem PV yang lebih cekap.



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I certify that a Thesis Examination Committee has met on 21 September 2016 to conduct the final examination of Ehsan Mohsin Obaid Alhamdawe on his thesis entitled "Efficiency Improvement of a Standalone Photovoltaic System using Fuzzy-Based Maximum Power Point Tracking Algorithm" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

A	Ideality Factor
ADC	Analog to Digital Converter
ANN	Artificial Neural Network
ANFIS	Artificial Neuro-Fuzzy Inference System
CC	Constant Current Method
CCM	Continuous Conduction Mode
CFLC	Conventional Fuzzy Logic Controller
C_{min}	Minimum Capacitor μF
COA	Center of Area
COG	Center of Gravity
D	Duty Ratio
DC	Direct Current
DCM	Discontinuous Conduction Mode
DSP	Digital Signal Processing
ePWM	Enhanced Pulse Width Modulation
FLC	Fuzzy Logic Controller
F_s	Switching Frequency KHZ
G	Irradiation W/m^2
GA	Genetic Algorithm
GHG	Greenhouse Gasses
G_i	Current Gain
G_v	Voltage Gain
HC	Hill Climbing

I-V Curve	Current -Voltage Curve
I_M	Module's Output Current A
I_{MPP}	Current at Maximum Power Point A
I_o	Reverse Saturation Current A
I_{pv}	Photovoltaic Current A
I_{sc}	Short Circuit Current A
K	Boltzmann's Constant
K_i	Current Temperature Coefficient
K_v	Voltage Temperature Coefficient
L_p	Minimum Inductor μH
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
N_p	Number of Parallel -Connected Cells
N_s	Number of Series-Connected Cells
OV	Open Circuit Voltage
P&O	Perturb and Observe
P-V Curve	Power- Voltage Curve
PFLC	Proposed Fuzzy Logic Controller
PID	Proportional Integral Derivative
P_{MPP}	Power at Maximum Power Point W
PV	Photovoltaic
PWM	Pulse Width Modulation
RE	Renewable Energy
R_i	Input Impedance Ω
R_L	Load Resistor Ω

R_{MPP}	Resistance at Maximum Power Point Ω
R_s	Series Resistance Ω
R_{sh}	Shunt Resistance Ω
T	Temperature $^{\circ}\text{C}$
T_s	Switching Time (ms)
V_i	Input Voltage V
V_{MPP}	Voltage at Maximum Power Point V
V_o	Output Voltage V
V_{OC}	Open Circuit Voltage V
V_{pv}	Photovoltaic Voltage V
ΔT	Change of Temperature Kelvin

CHAPTER 1

INTRODUCTION

1.1 Background

Climate changes and its devastating influence on nature are the biggest challenging issues the world is most concern about (Valkila and Saari, 2010). The consumption of conventional energy sources such as fossil fuels and its emitted amount of greenhouse gasses (GHG) is the major reason for the devastating climate changes. Simultaneously, and due to highly increasing population, world energy consumption is expected to increase about 60% for the duration from 2002 to 2030 which imposes increased GHG as highlighted by (Olejarnik, 2010). Furthermore, conventional energy sources such as oil, natural gas, and coal reserve will be exhausted by 2040, 2060 and 2300 respectively as detailed in the publication by (Chang et al., 2003). Consequently, renewable energy (RE) sources have drawn much positive attentions and funding since the last two decades. Among these RE technologies are solar cells, geothermal, hydro, wind, biomass, and the use of fuel cell technology is included as well. In particular, the photovoltaic technology has high potential due to its reliability, sustainability, and nature-friendliness as illustrated by (Bennett and Zilouchian, 2011).

Photovoltaic (PV) technology plays a significant role as part of RE sources. It is forecasted to be the major contributor with significant dependence ratio that renewable energies provide to the world's energy reservation by 2040 (Li and He, 2011). The reason behind the promising investment in solar technology is that the amount of energy radiated by the sunlight toward earth is 10,000 times more than the world's required energy. In contrast, only 1% of this energy would be enough to cover the necessary energy needs as illustrated in the publication by (Copper and Sproul, 2013). Moreover, the total cost for solar projects implementations is decreasing while the fossil fuels cost is increasing which motivates the investment in the solar market (Bose, 2010). Furthermore, the solar technology depends on the advancement of involved technologies in the creation of the PV system, such as the photovoltaic cell, power electronic switches, and microcontroller technology.

The solar cell has some weaknesses to be a dominant source such as the intermittent generation during the sunrise only and nonlinear characteristics. The non-linear characteristics of the PV cell depend on the variations of irradiation and temperature, which affect the PV generated current and voltage. Figure 1.1 shows the non-linear characteristics curves of power-voltage (P-V) and current-voltage (I-V) of the PV cell, where I_{MPP} , V_{MPP} , and P_{MPP} are the generated current, voltage, and power at maximum power point (MPP) respectively. MPP is the intersection point at which the maximum power is generated. These nonlinear characteristics of the solar cell can be the major reason for the increase in per KW installation cost and decrease in the PV efficiency as substantiated in recent research publication by (Dincer, 2011).

However, many types of research have been done to extract maximum power and increase the efficiency of the PV cells. The two commonly utilized methods are the maximum power point tracking (MPPT) and the physical sun tracking as presented by (Mousazadeh et al., 2009). A survey shows that physical sun tracking algorithms enable the PV system to harvest energy within 30% - 40% more than PV system without sun tracking algorithm as presented by (Gules et al., 2008). The utilization of the MPPT increases the extracted energy to almost 97% as compared to only the 31% of directly connected PV system to the load (Bhatnagar and Nema, 2013).

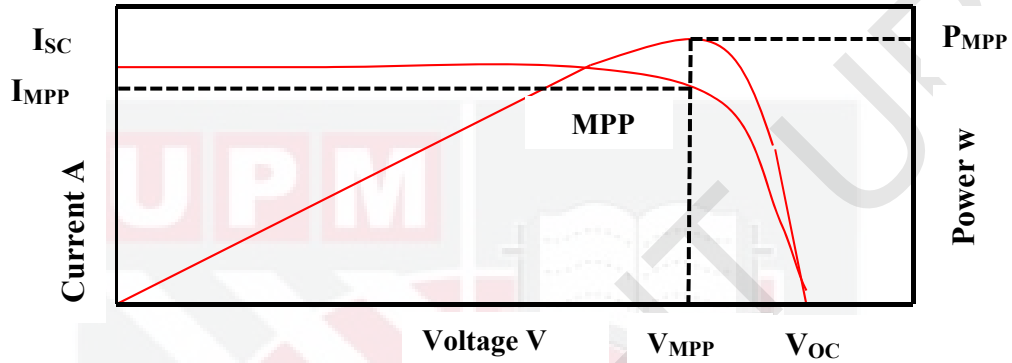


Figure 1.1 : P-V and I-V characteristics curve of PV module.

Figure 1.2 displays the block diagram of a standalone PV system that includes a PV source, DC-DC converter, and MPPT algorithm. The generated power from PV module depends on both of the irradiance intensity of the sun and the ambient temperature. These weather conditions directly affect the generated voltage and current of the PV source. Therefore, the output power is affected. In order to guarantee the PV module delivers its maximum power despite weather conditions, a DC-DC step up or step down converter is located between the PV module and the load. The tasks of the matching converter are basically to locate a point on the P-V curve at which the PV panel generates its maximum power known as the maximum power point (MPP) and driving the operating point of the PV panel to the located MPP. Therefore, the function of the power converter is to match the impedance of the PV source to the impedance of the load so that the PV source generates its maximum power as mentioned by (Taghvaei et al., 2013).

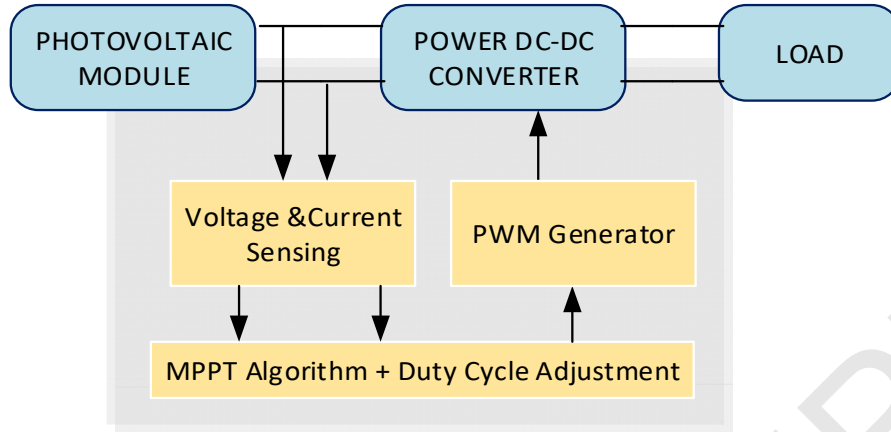


Figure 1.2 : Block diagram of the PV system

The last part of the PV system is the MPPT controller, which drives the matching DC-DC converter. The major functions of the MPPT algorithm are the periodic measurement of the output current and voltage of the PV source and generate an appropriate duty ratio to drive the DC-DC converter. Thus, the maximum power of the PV source continuously extracted. MPPT algorithm is a viable part of the PV system to not only maximize the efficiency but also to minimize the cost of generated power per hour as stated by (Singh, 2013).

MPPT algorithms can be categorized into conventional and artificial intelligence based algorithms. Many aspects can be considered when comparing the MPPT algorithms including the response speed, simplicity, and hardware implementation. The classical MPPT algorithms have a simple principle of work and ease of practical application. The most common classical MPPT algorithms are constant voltage (CV) method (Aganah and Leedy, 2011; Chen et al., 2015), constant current (CC) method (Masoum and Sarvi, 2008), incremental conductance (IC) (Esrām and Chapman, 2007; Azadeh Safari and Mekhilef, 2011), and the most commonly used perturb and observe (P&O) method (Hohm and Ropp, 2000; Houssamo et al., 2010).

The artificial intelligence based MPPT algorithms have accurate decision and fast convergence speed, yet they are more complicated than conventional algorithms. Many of these algorithms are cited in the literature including fuzzy logic based MPPT control (FLC) (Takun et al., 2011), artificial neural network (ANN) based control, and artificial neuro-fuzzy based control (ANFIS) (Chaouachi et al., 2010; Kharb et al., 2014).

1.2 Problem Statement

The high installation cost and low conversion efficiency of the expensive PV system have imposed the need for more efficient MPPT algorithm to act as a viable contributor to extract the maximum power from the PV source. However, the performance of the PV system is still not satisfyingly efficient due to low conversion

efficiency which is around 20% and the drawbacks of MPPT algorithms. For example, the conventional P&O MPPT algorithm has drawbacks such as slow convergence towards MPP, continuous oscillation around MPP at steady state conditions (Subudhi et al., 2013), and tradeoff between the response time and the oscillation percentage of the output power. Hence, P&O has lower efficiency. (Kjær, 2012; Reza Reisi et al., 2013).

Artificial intelligence based-MPPT algorithm such as FLC has higher stability and faster response time at steady state as compared to P&O algorithm. However, the choice of input parameters for designing the FLC controller can contribute to some drawbacks; such as the error (E) and error derivative (CE) that require calculation process after each sampling period. The calculation process may impose some limitations. For example, slow response time, oscillation around the MPP, and less accuracy to track the MPP particularly at the low irradiance levels (Alajmi et al., 2011). A further disadvantage of such fuzzy controller occurs when the duty ratio variations are not included as an input parameter for FLC design. As a result, the controller mislead the direction of tracking and the operating point diverges from the MPP at sudden irradiance changes (Simdes and Franceschetti, 1999).

1.3 Hypothesis of Research

The proposed FLC based MPPT algorithm will be compared to the conventional MPPT algorithms to verify its performance whether it can achieve the following hypothesized points.

- i. Whether Fuzzy logic based MPPT controller can overcome the drawbacks of conventional P&O algorithm in term of response time and continuous oscillation at steady state conditions (Esram and Chapman, 2007).
- ii. If FLC can improve the efficiency of the PV system when the tradeoff property between response time and maximum power oscillation of P&O is reduced (Ishaque and Salam, 2013).
- iii. The Proposed FLC with new input parameters can reduce the drawbacks of conventional FLC in term of response time, oscillation percentage, settling time, and maximum power ratio.
- iv. Considering the duty ratio variations as the input parameter to improve the dynamic response of the proposed FLC (Alajmi et al., 2011).

1.4 Research Objectives

This work aims to develop a standalone photovoltaic system with the proposed FLC based MPPT algorithm to address the above -mentioned problems with the following objectives.

- i. To design appropriate DC-DC boost converter that functions based on the input voltage and current of the PV module so that the output voltage is step up for the resistive load of the PV system.

- ii. To develop and integrate the proposed FLC and conventional MPPT algorithms with the DC-DC boost converter.
- iii. To simulate and compare the performance of the proposed FLC and the conventional MPPT algorithms.
- iv. To develop an hardware circuit that verifies the performance of the MPPT algorithms.

1.5 Scope of Research

In order to simulate and implement the proposed FLC MPPT controller at various irradiance levels and constant temperature of 25°C the following limitations be utilized.

- i. KC200GT PV module mathematically modeled and simulated in MATLAB /SIMULINK environment. The module tested under many levels of irradiance and STC temperature of (25 °C) to match its characteristic curves with the datasheet of the real PV module.
- ii. A DC-DC boost converter was designed to work under various irradiance conditions
- iii. The PV system with the MPPT algorithms will be tested, compared, and validated at different irradiance conditions and STC temperature of 25°C.

1.6 Layout of the Thesis

Chapter 1 Introduces a background about the concept of the research topic and the need for applying the MPPT algorithms in the PV system. The problem statement, the research hypothesis, the research objectives, and scope of research all elaborated in details.

Chapter 2 Reviews the basic parts of the PV system, which include the operation of the solar cells, types of solar cells, and mathematical integration of PV cell to a PV Module and array. The DC-DC converter was briefly introduced in term of modes of operation, the principle of operation, and design. The last part critically reviews the literature about the classical and artificial intelligence based MPPT algorithms. The weakness and advantages of these MPPT algorithms were investigated to date with emphasis on P&O and FLC MPPT algorithm.

Chapter 3 Elaborates the procedure that set to achieve the hypothesized research objectives. The methodology procedure explains the mathematical modeling of the PV module, the design and simulation of the DC-DC boost converter, the design and developing of both the proposed FLC and the conventional MPPT algorithms, and the prototype of the hardware circuit.

Chapter 4 Displays the collected results of the simulation and experimental parts. The MPPT algorithms are simulated and compared at steady state and dynamic state conditions. The proposed FLC controller achieves the set objectives in term of response time, stability, and MPP ratio. The experimental results are discussed and validated the performance of the proposed FLC at steady state conditions.

Chapter 5 Concludes the hypothesis of research and the achieved objectives through a set of procedure steps. The contribution of the study is highlighted and the future works were suggested for further improvement in this area of research.

1.7 Summary

This chapter clarifies the importance, the basic concept, and the challenges of this research topic with the highlight on the common problem statements and its effects on the PV system efficiency. A FLC- based MPPT algorithm is proposed to address the common drawbacks of conventional P&O and FLC algorithms in term of response time, stability, and maximum power ratio. The subsequent chapter will thoroughly review the recent work in the literature about several MPPT algorithms, where the drawbacks and advantages of earlier applied MPPT methods will be investigated to improve the performance of the proposed MPPT method.

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