

CONTROL OF A PHOTOVOLTAIC SOURCE EMULATOR
USING ARTIFICIAL NEURAL NETWORK

WONG KUNG NGIE

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School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

This project report is dedicated in thankful appreciation for support to my program coordinator Prof. Ir. Dr. Mohd Wazir Mustafa, my supervisor Ir. Dr. Tan Chee Wei, my family and also to all my course mates and individuals that contribute to this project report.

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ABSTRACT

The photovoltaic (PV) emulator is a nonlinear power supply that produces a similar current-voltage characteristic of the PV module. However, the PV emulator output is volatile due to the nonlinear characteristic of the PV module. Conventionally, the overdamped PV emulator is required to prevent instability but results in slow dynamic response. On the other hand, the dynamic response of the PV emulator varies with changes in solar irradiance, ambient temperature and output resistance. The researches carried out in recent years for the control techniques include direct calculation method, look-up table method, piecewise linear method, neural network method, and curve segmentation method. Each of the method has advantages and disadvantages in terms of processing burden, memory required, accuracy, adaptability and independency. This research project focuses on the simulation of a combination of interleaved buck converter with two-stage inductor and capacitor filter to improve the dynamic performance of the PV emulator. Artificial neural network is used to overcome the complexity in the adaptive proportional-integral (PI) controller to achieve a stable and fast dynamic response of the PV emulator. The proposed control technique is simulated using MATLAB/Simulink® simulation package with varied output resistance and irradiance. ANFIS Editor toolbox is used for the training and learning process. The PI gains of the conventional method are set to limit output current overshoot under various output resistance. By comparison to conventional method during start-up response, the proposed control technique shows improvement of 40% to 90% faster in dynamic performance of the output current.

ABSTRAK

Emulator photovoltaic (PV) adalah bekalan kuasa tak lancar yang menghasilkan ciri voltan semasa yang sama dengan modul PV. Walau bagaimanapun, output emulator PV tidak menentu kerana ciri tidak linear modul PV. Secara konvensional, emulator PV yang overdamped diperlukan untuk mencegah ketidakstabilan tetapi mengakibatkan respons dinamik yang lambat. Sebaliknya, tindak balas dinamik emulator PV berbeza-beza dengan perubahan dalam sinar matahari, suhu dan rintangan output. Penyelidikan yang dijalankan dalam beberapa tahun kebelakangan untuk teknik kawalan termasuk kaedah pengiraan langsung, kaedah jadual paparan, kaedah linear piecewise, kaedah rangkaian neural, dan kaedah segmentasi lengkung. Setiap kaedah mempunyai kelebihan dan kekurangan dari segi beban pemrosesan, memori yang diperlukan, ketepatan, kebolehsuaian dan kebebasan. Projek penyelidikan ini memberi tumpuan kepada simulasi gabungan penukar buck interleaved dengan dua induktor dan penapis kapasitor untuk meningkatkan prestasi dinamik emulator PV. Rangkaian neural tiruan digunakan untuk mengatasi kerumitan dalam pengawal penyepadanan berkadar proporsional (PI) untuk mencapai tindak balas dinamik yang stabil dan cepat terhadap emulator PV. Teknik kawalan yang dicadangkan ini disimulasikan menggunakan pakej simulasi MATLAB / Simulink® dengan rintangan output yang berbeza dan irama. Kotak alat editor ANFIS digunakan untuk proses latihan dan pembelajaran. Keuntungan PI dari kaedah konvensional ditetapkan untuk mengehendkan keluaran semasa overshoot di bawah pelbagai rintangan output. Sebagai perbandingan dengan kaedah konvensional semasa tindak balas permulaan, teknik kawalan yang dicadangkan menunjukkan peningkatan 40% hingga 90% lebih cepat dalam prestasi dinamik arus keluaran.

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LIST OF ABBREVIATIONS

ANFIS	-	Adaptive Neuro-Fuzzy Inference Systems
ANN	-	Artificial Neural Network
CCM	-	Continuous Current Mode
DCM	-	Discontinuous Current Mode
GNG	-	Growing Neural Gas
IC	-	Integrated Circuit
MPPT	-	Maximum Power Point Tracking
PI	-	Proportional Integral
PV	-	Photovoltaic
PWM	-	Pulse Width Modulator
SMPS	-	Switch Mode Power Supply
STC	-	Standard Test Condition
TSIBC	-	Two-stage Interleaved Buck Converter
TSLCF	-	Two-stage Inductor Capacitor Filter

LIST OF SYMBOLS

V	-	Voltage
A	-	Ampere
°C	-	Celsius
W/m ²	-	Watt per meter square
K _p	-	Proportional gain
K _i	-	Integral gain
k	-	Kilo
m	-	milli
μ	-	Micro
Ω	-	ohm
Hz	-	Hertz

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CHAPTER 1

INTRODUCTION

1.1 Background of Problem

Solar energy was developed and studied using a real PV module or high-power light source. Electricity generated by PV module is subject to exposure to solar radiation and temperature, and required maximum power point tracking (MPPT) devices and power conditioning system to extract maximum power. However, conducting the research and setup of this experiment is complicated, expensive and time consuming. In addition, the nature of experiment tests is a repetitive process thus becomes impractical and inefficient. The PV emulator offers an alternative solution and it can produce current-voltage characteristics similar to the PV module [8, 13].

In general, PV emulator can be break down into three main parts which are the PV model, the control technique, and the power converter as shown in Figure 1.1 [13].

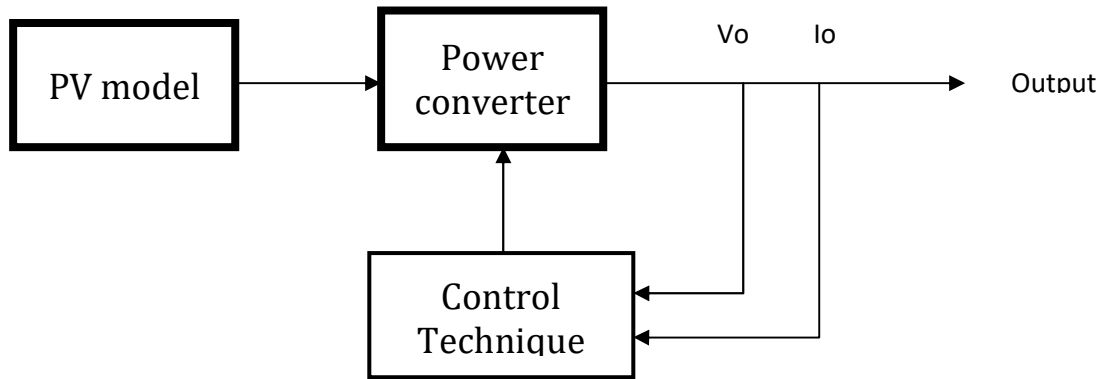


Figure 1.1: The components in PV emulator [9]

PV model is used to generate signal that can resemble the I-V characteristics of the PV module. This signal needs to be converted and enhanced into real current and voltage having the similar magnitude and characteristic of a PV module. This can be achieved by using closed-loop power converter system [19].

The PV model can be modeled and represented into an equivalent electrical circuit (single diode model) as shown in Figure 1.2 [5, 6, 13, 15, 16, 22].

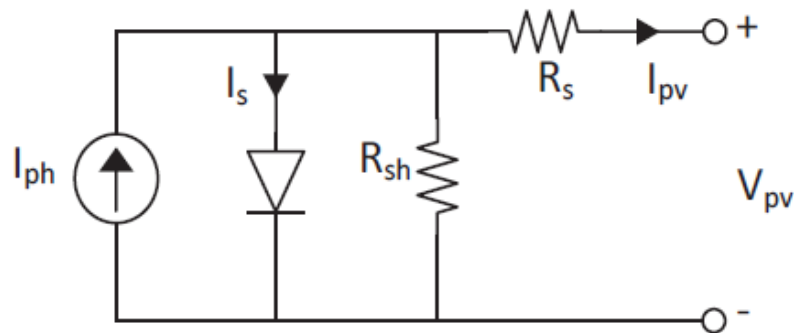


Figure 1.2: PV model representation in electrical circuit (single diode model) [5]

The function of control technique is to connect PV model with power converter system. It detects the signal generated by the PV model and referencing to power converter. On the other hand, it also received feedback from the output generated by

power converter and continuously adjusting PV model input parameter. The control technique is continuously finding the operating point of the PV emulator in real time corresponding to the changes in output resistance, irradiance and temperature. A good control technique exhibits the following characteristics:

- Ability to track the signal generated by the PV model precisely and fast in response
- Maintain a stable PV emulator output in all conditions
- Low hardware requirements such as processing power and memory storage
- Ability to suit and adapt to various types of PV modules
- Independency where it does not affect the power converter system or the load

The research and development works carried out in recent years can be classified and mainly to direct calculation method, look-up table method, piecewise linear method, neural network method, and curve segmentation method. Each of the method has advantages and disadvantages [6].

Artificial neural network (ANN) is a computing system inspired by the way human brain works. Generally, ANN is an interconnected group of nodes similar to biological neurons. It is a network that has two layers of feed-forward that work to fit multi-dimensional mapping. It consists of input, hidden layer, output layer and output as shown in Figure 1.3 [1, 7].

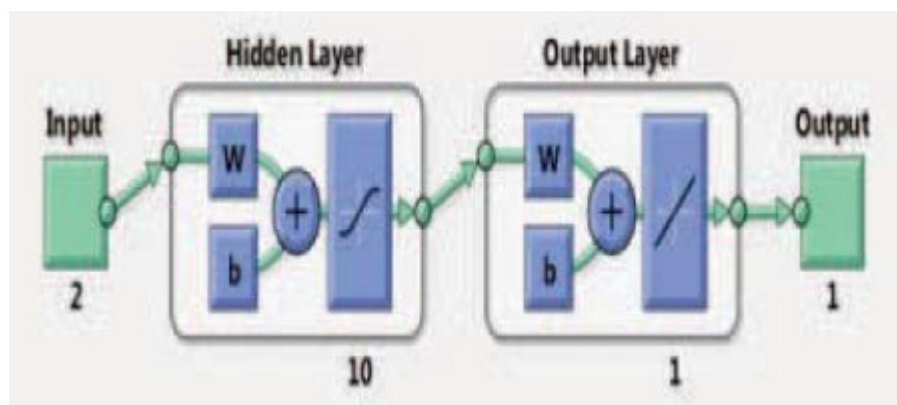


Figure 1.3: ANN control technique

In this thesis, the proposed two inputs are solar irradiance (G) and temperature (T). Meanwhile, the output is duty ratio (D) which triggers the pulse width modulator (PWM) [10, 11].

The function of power converter is detects signal produced by the PV model and transforms it into the I-V characteristic similar to the PV module and is capable of transmitting power. In the PV emulator system, DC-DC converter is used and a conventional buck converter circuit diagram is shown in Figure 1.4 below [5, 6, 15, 16, 18].

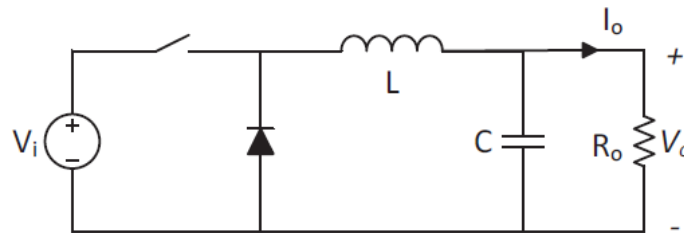


Figure 1.4: Conventional buck converter [13]

The inductance and capacitance value of the conventional buck converter need to be properly calculated and designed in order to determine that it operates in continuous current mode (CCM). CCM has a simpler design and faster transient response compare to discontinuous current mode (DCM). The formula to calculate the inductance and capacitance value are:

$$L = \frac{(1-D)R_{o(max)}}{2f}$$

$$C = \frac{1-D}{8Lr_{Vo}f^2}$$

by considering lowest irradiance, highest temperature and lowest duty cycle value [6, 13, 15, 16].

1.2 Statement of Problem

The conventional control technique adopts Proportional Integral (PI) controller. The PI controller is used to interface with PV model and closed-loop power converter as shown in Figure 1.5. However, using PI controller resulted in slow dynamic response and caused unstable output [9].

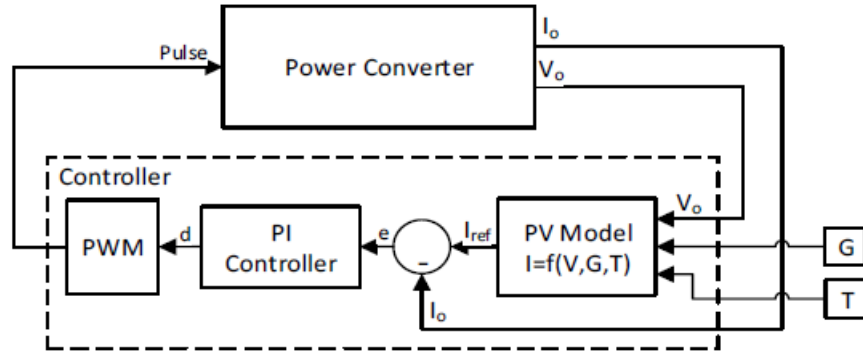


Figure 1.5: The PI controller [9]

There are three disadvantages of using conventional control technique. Firstly, changes in output resistance can affect the dynamic response of the PV emulator. In order to achieve minimum voltage ripple, capacitance value is increased. However, large capacitance will result in poor dynamic performance.

Secondly, when the PV emulator with current controlled system functions in constant voltage region, a small variation in output voltage will result in large change in reference current as shown in Figure 1.6 (a). The reference point will become oscillates and causes instability to the PV emulator output. Hence to overcome this drawback, the PV emulator is required to work in overdamped condition. Again, it has negative impact on the performance of the PV emulator. Therefore, the PI controller's gains need to be adjusted to suit the constant current region and constant voltage region of the PV I-V characteristic curve [9, 16].

Lastly, solar irradiance and temperature affect the output resistance of the PV emulator. To achieve stability, the PV emulator is designed such that when the output resistance is below critical value, the PV emulator operates in critically damped condition. On the other hand, if the output resistance is above critical value, the PV emulator operates in overdamped condition. The critical resistance value is the output resistance between the boundary of the constant current region and constant voltage region. Figure 1.6 (b) demonstrates different value of irradiance will result in different critical point. It can be concluded that it is difficult for the PI controller to decide when the PV emulator needs to operate in critically damped or overdamped condition [9].

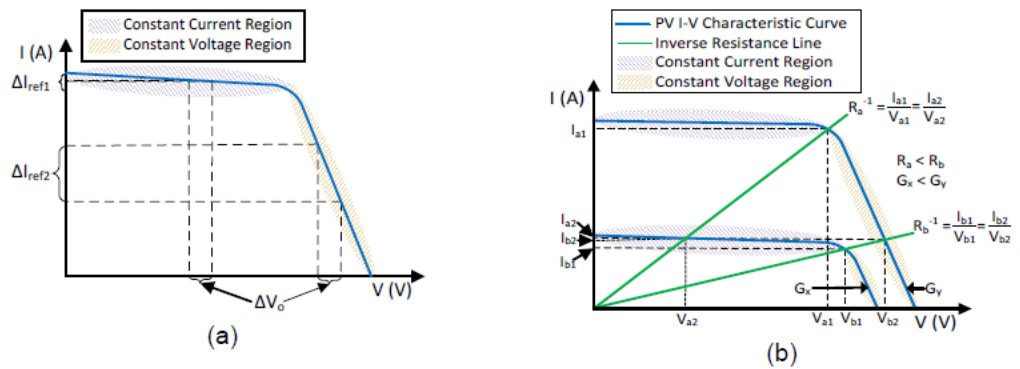


Figure 1.6 (a) The effect of output voltage variation to reference current. b) The effect of irradiance variation to critical point value [9, 15].

Realizing the above mentioned weaknesses and limitations of conventional buck converter, a two-stage interleaved buck converter (TSIBC) is introduced. TSIBC is able to generate smaller inductor current ripple thus allowing a lower capacitance required to maintain the similar output ripple. Since the capacitance value is lower, dynamic response is improved. On top of that, a two-stage inductor and capacitor filter (TSLCF) is also proposed in order to improve the bandwidth of the PV emulator system [4].

In summary, oscillating nature of the output resistance, solar irradiance and temperature can affect the dynamic response and stability of the PV emulator system. This control technique required to consider these factors will become complicated. In

order to overcome this complexity, ANN is proposed to achieve stability and fast dynamic response of the PV emulator [9, 16].

1.3 Objectives of Study

This research work engages on the following objectives:

1. To get an accurate and stable output as well as a good dynamic performance of the PV emulator using artificial neural network.
2. To design and simulate the PV emulator system using MATLAB/Simulink®.
3. To evaluate the performance of the proposed control technique against conventional control method.

1.4 Scope of Study

The research work conducted is focus on the following aspects:

1. Design the power converter using a combination of interleaved buck converter with two-stage inductor and capacitor filter.
2. Design the control technique using artificial neural network.
3. Simulate PV emulator system using MATLAB/Simulink®.

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