DEVELOPMENT OF A MODULAR PHOTOVOLTAIC MAXIMUM POWER POINT TRACKING CONVERTER

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Specially for :

my beloved wife, sons and daughter,
for their tireless support, sacrifice and consideration.

Together with my fourth kid who is expected in October this year.

And to my relatives and my friends,
for their inspiration, motivation and encouragement.

And also to the office staffs who have worked tirelessly in providing information,
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ABSTRACT

The solar photovoltaic (PV) as a renewable energy source is gaining popularity as it is free, clean and abundantly available. However, it main hindrance are low efficiency and high capital cost. To address the problem, the maximum power point tracking (MPPT) techniques are proposed to track the optimum voltage and current at the maximum power point. A DC-DC converter can be used to vary the duty ratio according to the control signal to force the load line to intersect with the I-V curve at the maximum power point. Therefore, the problem statement here is to design a MPPT algorithm that can track the optimum voltage and current corresponding to the maximum power point. Various MPPT techniques had been discussed in the literature and all have their advantages and disadvantages. Moreover, the I-V or P-V characteristics is highly non-linear with the left hand side of MPP have low process gain while at the right hand side of MPP, the process gain is significantly greater. Consequently using constant PI parameters will result in slow response or oscillations around MPP. Finally, the design of a DC-DC converter will require careful selection of component ratings, such as inductor and MOSFET to minimize power loss. Therefore, this project is aimed at designing and developing a software and hardware to implement the Incremental Conductance algorithm, evaluating the performance of MPPT under various light irradiation level and comparing its performance with the maximum power calculated from theoretical methods. In the research methodology, MPPT technique (Incremental Conductance), non-linear PI control using Luyben control technique and Amigo tuning rules for PI parameters are used. The control signal is converted to PWM output at PIC16F877A. The hardware of the microcontroller, IR-2117 and buck-boost converter circuit are designed and fabricated. This hardware was tested. The program is written in C language in MPLAB IDE v8.60 environment. Successful compilation generates hex file (machine code) that was downloaded into the mirco-controller through PICKIT2 and hardware In-Circuit Serial Programming (ICSP). The maximum power point values calculated by theoretical methods, solar output voltage and current, reference voltage and current tracked by MPPT, duty ratio were displayed and recorded. The test was repeated for different sunlight radiation levels. The result demonstrated that the reference voltage and current tracked by the MPPT deviates from the actual maximum power point by less than 5% under different radiation conditions, Additionally, the maximum power calculated by the MPPT algorithm developed also performed better than the maximum power calculated by theoretical manner.

ABSTRAK

Tenaga solar sebagai sumber tenaga boleh baharu semakin mendapat sambutan kerana ia adalah percuma, bersih and kaya. Namun demikian, kesulitan yang dihadapi adalah kecekapan penukaran yang rendah and kos pelaburan yang tinggi. Untuk menyelesaikan masalah kecekapan penukaran yang rendah, pelbagai teknik maximum power point tracking (MPPT) telah dicadangkan dalam literature yang lepas untuk mengesan voltan and arus yang optimum pada maximum power point. Sebuah penukar DC-DC boleh digunakan untuk mengubah nisbah duti (duty ratio) untuk memaksa titik operasi pada persilangan garisan beban dengan lengkung I-V atau P-V di maximum power point. Maka, masalah di sini adalah untuk merekabentuk sebuah algorithma MPPT yang boleh mengesan voltan and arus optimum pada maximum power point. Pelbagai teknik MPPT sudah diperbincangkan dalam literature and setiap satu mempunyai kelebihan and kelemahan tersendiri. Tambahan lagi, ciri-ciri I-V atau P-V adalah tidak lurus, bermakna sebelah kiri MPP memiliki process gain yang rendah sementara sebelah kanan MPP memiliki process gain yang jauh lebih tinggi. Ini boleh mengakibatkan respons kawalan yang perlahan atau ayunan di sekitar titik MPP. Akhir sekali, rekabentuk sebuah DC-DC converter memerlukan penentuan kadar komponen yang tepat, seperti inductor atau MOSFET, untuk meminimumkan kehilangan kuasa. Justeru itu, projek ini bertujuan untuk merekabentuk dan membangunkan sesuatu software and hardware untuk melaksanakan algorithm MPPT Incremental Conductance, menguji pretasi MPPT di bawah pebagai intensiti matahari, membandingkan prestasi MPPT dengan kuasa maksima yang dikira secara teori. Dalam methodoloji kajian, teknik MPPT Incremental Conductance, kawalan tidak linear PI meggunakan cara Luyben and cara penalaan PID dari Amigo akan digunakan. Isyarat kawalan ini akan ditukar ke PWM output pada PIC16F877A. Perkakasan pengawal mikro, IR-2117 dan penukar buck-boost akan direkabentuk dan dibangunkan. Perkakasan tersebut akan diuji. Program ini akan ditulis menggunakan C and diprogramkan dalam MPLAB IDE v8.60. Apabila program tersebut berjaya dikompilkan, fail hex (kod mesin) akan dijanakan dan akan diturunmuatkan dalam kawalan mikro melalui PICKIT2 dan perkakasan In-Circuit Serial Programming (ICSP). Nilai kuasa maksima yang dikira secarea teori, voltan and arus keluran papan solar, arus and voltan optimum dikesan oleh MPPT serta nisbah duti akan dipamerkan dan dicatitkan. Ujian ini akan diulangi untuk pelbagai intensiti sinaran. Keputusan menunjukkan bahawa nilai arus dan voltan optimum yang dikesan oleh MPPT berbeza dari maximum power point yang sebenar sebanyak kurang dari 5% di bawah pelbagai sinaran intensiti. Tambahan lagi, kuasa maksima yang dikesan oleh MPPT juga menunjukkan prestasi yang lebih baik daripada kuasa maksima yang dikira secara teori.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

As the conventional energy sources are rapidly depleting, the roles of photovoltaic (PV) system as an alternative energy source increases prominently. Because it is clean, pollution-free, free, renewable and abundantly available, it is regarded as having great potential to substitute fossil fuels like natural gas, oil and coal in Malaysia. In future, more than 45% of the necessary energy in the world will be generated by the photovoltaic array. Therefore, future efforts will be focused in minimizing the application costs as well as enhancing their performance to make them competitive compared to other renewable energy sources.

At present, the main hindrance to the penetration and reach of PV solar systems is their low efficiency (14-25 %) and high capital cost. The low conversion efficiency results in large foot print area for installation while its capital high cost is caused by requirement to convert direct electricity (DC) to alternating electricity (AC) through inverters as well as battery storages to ensure continuous supply to grid.

In addressing the first challenge, the power output can be increased by two methods, these are to increase the solar radiation level and tracking the maximum power point of the system [10]. Option one will require a sun track to track the sun position in order to increase the solar radiation on the panel. While option two requires a power point tracking (MPPT) technique to locate the maximum power point (MPP) and draw the peak power generation from the solar array. Among the MPPT technique that had been developed are Constant Voltage Tracking (CVT), fraction open-circuit voltage (OCV), Perturb and Observe (P&O), Incremental Conductance (IC), Variable Step Size (VSS), Ripple Correlation Control (RCC), Artificial Neural Network (ANN). The comparative study of various MPPT methods were done in the past by researchers like Go *et. al.* [26], Dolara *et. al.* [18], Hairul *et. al.* [27]. Improvement on techniques was done by Kumari *et. al.* [35] for P&O and Younis *et. al.* [69] on Artificial Neural Network.

This present work introduces the design, development and implementation of a mirco-controller based MPPT converter. The system consists of a PV module coupling a battery bank via a DC-DC converter. The input signals to the MPPT controller are the module current and module voltage. The controller compares the module voltage (current) with a reference voltage (current) computed from MPPT technique which corresponds to the MPP. An error is generated and the non-linear PI controller will send the control output to the power conditioner consisting of pulse width modulation, firing circuit and DC-DC converter. The duty cycle of the DC-DC converter is changed to vary the load impedance so that the input voltage is at the MPP. The rating of the components such as input capacitor, output inductor, output capacitor and diode, MOSFET transistor are carefully chosen to meet the design requirements and minimize the power loss.

The MPPT technique employed is incremental conductance that based on the principle that at the maximum power point $\frac{dP}{dV} = 0$ [28, 44].

1.2 Problem Statement

1.2.1 To address the issue of low efficiency, one of the solutions is to track the maximum power point (MPP) of a solar power generation. This MPP lies on the characteristic curve of V-I or V-P at which the entire system (array, inverter and etc) operates with maximum efficiency and produces its maximum power output. The MPPT technique is employed to maintain the PV operating system at its MPP under varying operating condition (varying irradiation level and ambient temperature). This is done by designing a mirco-controller based MPPT converter that is capable of locating the reference voltage and current at MPP consistently under different conditions.

1.2.2 Additionally, MPPT techniques like P&O algorithm, despite its simplicity, results in oscillations around the MPP and thus incurring power loss. Meanwhile, incremental conductance will sustain stable control under rapidly changing operating condition but constant tracking steps results in slower response. Therefore, a tradeoff between control stability and response rate is required.

1.2.3 Moreover, the characteristic curve of V-I or V-P is highly non-linear. Therefore the appropriate tuning of controller parameters (gain and integral time) are important to maintain control loop stability. Various non-linear control techniques are proposed by Luyben [39], Koo *et. al.* [34], Ala [3].

1.2.4 Competent design of a DC-DC converter to operate in the range of required power output (600W) will require careful selection of component ratings for input capacitor, output inductor, output capacitor and diode, MOSFET transistor to meet the design requirements and minimize the power loss. The current and voltage transducers are carefully selected to ensure fast response and minimize power loss. Additionally, optimum charging strategy for the battery shall be adopted.

1.3 Objectives

This project is aimed at achieving the following objectives :-

(i) To design and develop a software program implementing the Incremental Conductance (InC) MPPT algorithm.

(ii) To design, develop and construct a hardware in order to implement the MPPT algorithm.

(iii) To compare the effectiveness of the MPPT controller in tracking the maximum power production from solar panel under various solar irradiation level.

(iv) To compare the power production from solar panel with the implementation of MPPT controller and with theoretical maximum power point calculation.

1.4 Scope of Works

The workscope in this project will include the following :-

(i) A simple MPPT controller will be designed and tested. MPPT control algorithm, such as Incremental Conductance (InC) is used to determine the optimum voltage and current corresponding to the maximum power point (MPP) under varying irradiation level and surface temperature.

(ii) Subsequently, a simple non-linear PI controller applying simple PI parameter tuning technique is programmed. The programs are compiled and hex file is created. The hex file is burnt into the mirco-controller chip PIC16F877A. The mirco-controller loop also includes a crystal driver and clock input, liquid crystal display and ICSP communication.

(iii) Hardware construction includes setting up the buck-boost converter that comprises the input capacitor, MOSFET switch, output inductor, output capacitor and diode. RCD snubber is designed around the MOSFET switch and conduction diode to suppress spiking during switching on and off.

(iv) Construction of the micro-controller PIC16F877A control circuit, voltage booster circuit, MOSFET IC driver IR2117.

(v) The system is connected to PV panel. The theoretical maximum power generated under different irradiation level is calculated from equation. These are compared to the measured power output at the battery with the InC MPPT controller. The deviations between MPPT and maximum theoretical power are discussed.

1.5 Report Organization

This project is divided into the following chapters :-

(i) Chapter 1 presents the background of the study; problem statement; objectives of the project; scope of work involved.

(ii) Chapter 2 presents the literature reviews pertaining to the significance of solar power; history of solar system; solar cell PV characteristics; maximum power point tracking; various MPPT techniques; non-linear controller; buck boost converter.

(iii) Chapter 3 presents the software and hardware development relating to the MPPT controller algorithm; non-linear PI controller tuning and structure; PIC16F877A mirco-controller design; buck boost converter design; schematic flow diagram and research methodology.

(iv) Chapter 4 presents the hardware construction and implementation.

(v) Chapter 5 presents the results and discussion.

(vi) Chapter 6 summarizes the recommendations, conclusions and proposal for future study.

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