UNIVERSITI PUTRA MALAYSIA

PHOTOVOLTAIC-BASED SINGLE-ENDED PRIMARY-INDUCTOR CONVERTER WITH DUAL-FUZZY LOGIC CONTROL-BASED MAXIMUM POWER POINT TRACKING

TANASELAN RAMALU

PHOTOVOLTAIC-BASED SINGLE-ENDED PRIMARY-INDUCTOR CONVERTER WITH DUAL-FUZZY LOGIC CONTROL-BASED MAXIMUM POWER POINT TRACKING

By

TANASELAN RAMALU

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

May 2016

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

PHOTOVOLTAIC-BASED SINGLE-ENDED PRIMARY-INDUCTOR CONVERTER WITH DUAL-FUZZY LOGIC CONTROL-BASED MAXIMUM POWER POINT TRACKING

By

TANASELAN RAMALU

May 2016

Chairman : Mohd Amran Mohd Radzi, PhD
Faculty : Engineering

Among renewable energy sources, solar energy used in photovoltaic (PV) system is the most favorite list in renewable energy researches today. Due to its maintenance free, ease of implementation and free of pollution, its demand increases rapidly in residential and industrial applications. However, PV cell appears to have low power efficiency in the range of 15-30% and its market price is still expensive; these factors are the main disadvantages. Due to its nonlinear characteristic, a control technique, known as maximum power point tracking (MPPT), is a must in PV system in order to make sure that the output power of PV system is always staying at maximum power point (MPP). In general, MPPT can be divided into conventional and artificial intelligent algorithms. The most popular conventional algorithms are perturb and observe (P&O) and incremental conductance (IC). Their main weakness is these algorithms always fail to track MPP and high oscillation occurs whenever the sunlight (irradiance) changes frequently. Among artificial intelligent algorithms used in MPPT are neural network, fuzzy logic control (FLC) and genetic algorithm. In this work, FLC was selected because it is easy to be implemented and does not require mathematical model in its design.

Dc-dc converter is used in most PV systems where it is attached with PV together with MPPT to obtain the maximum power transfer. In this work, single-ended primary-inductor converter (SEPIC) is preferred due to the need to perform both boost and buck operations depending on the supplied duty cycle to the converter's switch. SEPIC also has explicit advantage over buck-boost converter where the output voltage polarity in SEPIC is not inverted as output voltage polarity in the buck-boost converter. Dual FLC MPPT is proposed in this work to support both operations of SEPIC. The first FLC part is for lower duty cycle (buck) and the second FLC part is for higher duty cycle (boost). Meanwhile, to realize dual-operation of SEPIC, dual-load approach has been applied by selecting suitable load resistance, which could achieve MPP with specific irradiance and duty cycle.

Simulation work has been done by using MATLAB/ Simulink software. The work scopes under simulation include the PV modelling, SEPIC configuration, designing dual FLC MPPT and also designing load switching controller. In hardware configuration, solar simulator is used instead of PV panel. To make sure that both loads have continuous supply of power, two DC supplies have been attached to respective loads with additional of two intermediate controllers which are designed to control the switching of DC supplies and SEPIC converter connections (from PV) to both loads. Based on both simulation and experimental works, the SEPIC with dual FLC MPPT has performed with much more stable, faster response time, less oscillation and less ripples output as compared to P&O algorithm. In addition, through its operation with dual loads, maximum power has been obtained at lower irradiance by using higher resistance load, and during high irradiance, lower resistance load is needed in order to achieve maximum power.

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

PENUKAR GALANGAN UTAMA TUNGGAL TERAKHIR BERASASKAN FOTOVOLTA DENGAN KAWALAN DWI-LOGIK KABUR

Oleh

TANASELAN RAMALU

Mei 2016

Pengerusi : Mohd Amran Mohd Radzi, PhD
Fakulti : Kejuruteraan

Antara sumber tenaga yang boleh diperbaharui, tenaga solar yang digunakan dalam sistem fotovolta merupakan pilihan utama dalam kajian sumber tenaga yang boleh diperbaharui. Disebabkan oleh sistem ini tidak perlu penyelenggaraan, mudah digunakan dan bebas pencemaran, permintaannya meningkat dengan pantas bagi kegunaan perumahan dan industri. Walau bagaimanapun, sel fotovolta menunjukkan kecekapan kuasa yang rendah dalam julat 15-30% dan harga pasaran yang masih mahal; faktor-faktor ini adalah kelemahan utamanya. Disebabkan cirinya tak linear, satu teknik kawalan, dikenali sebagai pengesanan titik kuasa maksimum, perlu bagi sistem fotovolta untuk memastikan kuasa keluaran maximum sentiasa berada pada titik kuasa maksimum. Umumnya, pengesanan titik kuasa maksimum boleh dibahagikan kepada algoritma konvensional dan pintar buatan. Algoritma konvensional yang paling popular adalah usik dan cerap, dan kealiran tambahan. Kelemahan utama kedua-duanya adalah sentiasa gagal untuk mengesan titik kuasa maksimum dan ayunan tinggi berlaku apabila cahaya matahari (sinaran) sering berubah. Antara algoritma pintar buatan yang digunakan dalam pengesanan titik kuasa maksimum adalah rangkaian neural, kawalan logik kabur dan algoritma genetik. Dalam kerja ini, kawalan logik kabur dipilih kerana ia mudah untuk dilaksanakan dan tidak memerlukan model matematik dalam reka bentuknya.

Penukar dc-dc digunakan dalam kebanyakan sistem fotovolta di mana ia dipasang dengan fotovolta bersama-sama dengan pengesanan titik kuasa maksimum untuk mendapatkan pemindahan kuasa maksimum. Dalam kerja ini, penukar galangan utama tunggal terakhir menjadi pilihan kerana keperluan untuk melaksanakan kedua-dua operasi lekuk dan galak yang bergantung kepada kitar tugas yang dibekalkan kepada suis penukar ini. Penukar ini juga mempunyai kelebihan yang jelas berbanding penukar lekuk-galak di mana kekutuban voltan keluaran dalam penukar ini tidak terbalik seperti kekutuban voltan keluaran dalam penukar lekuk-galak. Pengesanan titik kuasa maksimum dwi kawalan logik kabur dicadangkan dalam kerja ini untuk menyokong kedua-dua operasi penukar galangan utama tunggal terakhir. Bahagian kawalan logik kabur pertama adalah untuk kitar tugas yang lebih rendah (lekuk) dan bahagian kedua adalah untuk kitar tugas yang lebih tinggi (galak). Sementara itu, untuk merealisasikan

dwi operasi penukar, pendekatan dwi beban telah digunakan dengan memilih rintangan beban bersesuaian, yang boleh mencapai titik kuasa maksimum dengan sinaran tertentu dan kitar tugas.

Kerja simulasi telah dilakukan dengan menggunakan perisian MATLAB / Simulink. Skop kerja di bawah simulasi termasuk pemodelan fotovolta, konfigurasi penukar, mereka bentuk pengesanan titik kuasa maksimum dwi kawalan logik kabur dan juga mereka bentuk pengawal pensuisan beban. Dalam konfigurasi perkakasan, simulator solar digunakan dan bukannya panel fotovolta. Bagi memastikan bahawa kedua-dua beban mempunyai bekalan kuasa berterusan, dua bekalan DC telah dipasang pada beban masing-masing dengan tambahan dua pengawal perantaraan yang direka untuk mengawal penukaran sambungan bekalan DC dan penukar (dari fotovolta) kepada kedua-dua beban. Berdasarkan kedua-dua kerja simulasi dan eksperimen, penukar galangan utama tunggal terakhir dengan pengesanan titik kuasa maksimum dwi kawalan logik kabur telah beroperasi dengan lebih stabil, sambutan yang lebih pantas, kurang ayunan dan kurang keluaran riak, berbanding algoritma usik dan cerap. Tambahan pula, melalui operasinya dengan dwi beban, kuasa maksimum telah diperolehi pada sinaran yang lebih rendah dengan menggunakan beban rintangan yang lebih tinggi, dan pada sinaran tinggi, beban rintangan yang lebih rendah diperlukan untuk mencapai kuasa maksimum.

ACKNOWLEDGEMENTS

I would take this opportunity to express my full appreciation to my supervisors, Prof. Madya Dr. Mohd. Amran b. Mohd. Radzi, Dr. Noor Izzri b. Abd. Wahab and Dr. Ribhan Zafira bt. Abdul Rahman for their encouragement and patience during my research work. It has been a honor and privilege to work under their supervision. I would like to thank all staffs and my colleagues at the department of electric and electronic engineering and Centre for Advanced Power and Energy Research (CAPER) who supported and help me during my work. I also would like to express my sincere gratitude, thanks and love to my family for their continuous encouragement during my period of study. Finally, I would like to express my gratitude and thanks to all my friends for giving me morale support to finish my research work and my studies.

I certify that a Thesis Examination Committee has met on 27 May 2016 to conduct the final examination of Tanaselan a/l Ramalu on his thesis entitled "Photovoltaic-Based Single-Ended Primary-Inductor Converter with Dual-Fuzzy Logic Control-Based Maximum Power Point Tracking" 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.

Members of the Thesis Examination Committee were as follows:

Wan Fatinhamamah binti Wan Ahmad, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Nashiren Farzilah binti Mailah, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nowshad Amin, PhD
Professor
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 23 August 2016

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Mohd Amran Mohd Radzi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Noor Izzri Abd. Wahab, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ribhan Zafira Abdul Rahman, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ___________________

Name and Matric No.: Tanaselan Ramalu, GS37932

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________
Name of
Chairman of
Supervisory Committee: Associate Professor Dr. Mohd Amran Mohd Radzi

Signature: ______________________
Name of
Member of
Supervisory Committee: Dr. Noor Izzri Abd. Wahab

Signature: ______________________
Name of
Member of
Supervisory Committee: Dr. Ribhan Zafira Abdul Rahman

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SEPIC	single-ended primary-inductor converter
MPP	maximum power point
MPPT	Maximum Power Point Tracking
PV	photovoltaic
DC	Direct current
FLC	fuzzy logic controller
P&O	Perturb and Observe
DSP	Digital signal processor
	photocurrent
	series resistance
R_{sh}	shunt resistance
K_1	cell's short-circuit current temperature coefficient
λ	solar irradiance level (kW/m^2)
	cell's reference temperature
I_{SC}	cell's short-circuit current
	cell's working temperature
	open-circuit voltage,
	number of series connected solar cells in a module
	number of parallel connected solar cells in a module
	voltage output of PV module
D	duty cycle,
	Resistance value at maximum power point
ADC	analog to digital converter

CHAPTER 1

INTRODUCTION

1.1 Background

In these recent days, research works in renewable energy field has rapidly been increasing to find an ultimate solution for increasing fossil fuel price and diminishing fossil fuel storage. To empower the world in future, generation of energy with low cost and no pollutions is vital to cater critical problem like global warming. There are a few potential types of renewable energy, currently being used and researched, to obtain higher efficiency. Among them, solar energy is widely explored. In related to solar energy, photovoltaic (PV) technology has attracted strong interest due to its maintenance free, ease of implementation and free of pollution. Its demand increases rapidly for residential and industrial applications. However, PV cell appears to have low power efficiency in the range of 15-30% and its market price is still expensive, which contribute to significant disadvantages to this technology.

In a PV system, PV panels will usually be connected either to DC-DC converter or to DC-AC converter to obtain its maximum power. PV system can be divided into three categories, which are standalone, grid-connected and hybrid. Standalone PV system is usually connected to DC-DC converter in order to run certain type of loads such as DC motor, water pump, and lighting. Grid connected PV system will be connected to DC-AC converter to directly connect to power grid system. In PV hybrid system, other possible energy sources such as wind, biomass or/and fossil fuel generator will be connected together with PV system.

DC-DC converter is the converter that changes the direct current (DC) voltage level at its output either increases or decreases the voltage, so that the output voltage is suitable to supply the required voltage to the system. Among DC-DC converters, the popular configurations are buck, boost, buck-boost, CUK and single-ended primary-inductor converter (SEPIC) converters, and in this work, SEPIC converter was preferred due to its ability to step up and step down the output voltage. Furthermore, the output voltage polarity of SEPIC converter is the same as the input voltage polarity, unlike buck boost and CUK converters.

PV output power depends on two important factors, which are sun irradiance and ambient temperature. Sun irradiance is directly proportional to PV output current and power. Higher irradiance will produce higher PV output power and current. However, temperature has the opposite effect where its higher value will reduce the PV output power. Meanwhile, PV cell has nonlinear characteristics and the PV output power will be oscillating and not static at one point. In order to control the maximum power point (MPP), an algorithm called Maximum Power Point Tracking (MPPT) has been attached together. There are many previous research works have been done in the field of MPPT. Basically, MPPT can be divided into two categories, which are traditional and artificial intelligence algorithms. The traditional algorithm is a simple algorithm which uses comparison method and it is easier to be implemented. Examples of traditional MPPT are Perturb and Observe (P&O), incremental conductance, voltage based peak power tracking and current based peak power tracking (A. Rubaai et al., 2004). The most common MPPT is P&O due to its ease of implementation as compared to other algorithms.

Alternatively, implementations of artificial intelligence methods as MPPT algorithms are rapidly increasing due to high efficiency performance, and better and precise results, as compared to traditional algorithms. Among artificial intelligence techniques in development of MPPT are fuzzy logic controller (FLC), neural network, Neuro-fuzzy and genetic algorithm (Salah and Ouali, 2011; Messai et al., 2011). FLC is the most common technique to be used due to its ease of implementation and complicated mathematical model is not required.

1.2 Problem statement

Traditional algorithm such as P&O has its own drawbacks, even when the irradiance is stable at a certain time, it oscillates around MPP and the output power consists of noises due to the fluctuation. When there are rapid changes in irradiance, P&O definitely fails to track MPP and it has high settling time, rising time, and overshoot at the output power.

Since number of dc based equipment operated at various dc levels is growing higher, having dc-dc converter with ability to produce various dc outputs is preferable. Most DC-DC converters such as buck-boost and CUK have inverted polarity in their output value.

Switching a resistor load between two sources; non-linear source such as PV and linear source such as DC supply exhibit different voltage characteristics during switching at different irradiances. When the power supply of resistor load is switched from DC supply to PV at low irradiance, undershoot of voltage occurs during switching. However, during the switching from DC supply to PV at high irradiance, high overshoot voltage occurs. During the low irradiance, high resistance is used and during the high irradiance, low resistance is used. An algorithm is needed to cater both overshoot voltage problem and undershoot voltage problem.

1.3 Aim and objectives

The main aim of this work is to develop a standalone PV Based SEPIC with Dual FLC Based MPPT for Dual-Load Operation. The detailed objectives are as follows:

- To design and develop circuit topology of PV based SEPIC dc-dc converter which will integrate dual FLC MPPT algorithm.
- To design, develop and integrate load changing and intermediate controllers to control switching of dual-load operation.
- To evaluate dynamic performance of SEPIC converter during buck and boost operations in two different loads at different irradiance levels by applying dual FLC MPPT.

- To assess and analyze characteristics of output voltages of two resistance loads during switching from non-linear source to linear source (PV supply to DC supply) and also the switching from linear source to non-linear source (DC supply to PV supply).

Circuit was constructed and simulated with the proposed MPPT algorithm and the assigned loads. The proposed design was then examined and verified in the laboratory through development of the hardware prototype.

1.4 Scope and limitation of work

This thesis aims at simulating and implementing the dual FLC MPPT in PV based SEPIC converter for dual-load operation with two specific irradiances, where one for high irradiance (700 W/m^2) and one for low irradiance (200 W/m^2) are selected. For simulation purpose, the PV module and SEPIC converter were modeled in MATLAB/Simulink. In hardware implementation, PV simulator is used instead of real PV module due the requirement of performing rapid changing of the irradiance. Temperature is assumed to be fixed at 30℃ for simulation and hardware development. As compared to irradiance, change of temperature occurs very slowly, so the temperature effect can be neglected. Regarding loads, resistors are being used for both loads where one is high value resistor (50Ω) and another one is low value resistor (2Ω).

1.5 Thesis Outline

This subchapter explains briefly about the content of the thesis by chapters. There are other 4 chapters that will be covered in this thesis and is organized as such:

Chapter 2 defines PV technology, presents a survey of PV systems including topologies and principles or operation, discusses dual FLC MPPT algorithms applied to PV system, highlights and reviews previous and latest development of SEPIC dc-dc converter, and gives a brief introduction on DSP.

Chapter 3 describes methodology of modelling a PV module, development of SEPIC dc-dc converter, design of new MPPT algorithm which is named as Dual FLC MPPT algorithm, and integration of MATLAB/Simulink and DSP, in both simulation and experimental works.

Chapter 4 presents findings and results obtained in simulation and experimental works, including PV characteristics, maximum power, input and output voltages of the PV system, and time responses achieved through the developed MPPT.

Chapter 5 concludes the findings and recommends possible future works.

REFERENCES

Agorreta, J.L., Reinaldos, L. Gonzalez, R., Borrega, M. Balda, J. and Marroyo, L. 2009. Fuzzy Switching Technique Applied to PWM Boost Converter Operating in Mixed Conduction Mode for PV Systems. IEEE Transactions on Industrial Electronics, Vol 56, Issue 11.

Ahmad , A.N., and Rached , D. 2012. Efficiency Optimization of a DSP-Based Standalone PV System Using Fuzzy Logic and Dual-MPPT Control. Ieee Transactions On Industrial Informatics, Vol. 8, No. 3.

Ahmad , E.K., Nasrudin , A.R., Jeyraj , S., and Mohammad , N.U. 2013. Maximum power point tracking of single-ended primary-inductor converter employing a novel optimization technique for proportional-integral derivative controller. IET Power Electronics, Vol. 6, Issue. 6, pp. 1111–1121.

Ahmad, E.K., Nasrudin, A.R and Jeyraj, S. 2011. Fuzzy Logic Controller for MPPT SEPIC Converter and PV Single-Phase Inverter. IEEE Symposium on Industrial Electronics and Applications (ISIEA2011)

Ankit, K. and Pratima, W. 2015. Fuzzy Logic Controller for MPPT SEPIC Converter and PV Multilevel Inverter. Advanced Research in Electrical and Electronic Engineering.

Arnaldo, M., and Miguel, S. 2009. SEPIC Type DC-DC Converter Fuzzy Model**.** ICROS-SICE International Joint Conference.

Arshdeep, K., and Amrit, K. 2012. Comparison of Mamdani-Type and Sugeno-Type Fuzzy Inference Systems for Air Conditioning System. International Journal of Soft Computing and Engineering (IJSCE), ISSN: 2231-2307, Volume-2, Issue-2.

Arulmurugan, R., and Suthanthiravanitha, N., Tracking of photovoltaic power system with new Fuzzy Logic Control strategy. Journal of Electrical Engineering.

Chen, T.T., Hsiao, M.Y., Tsai, S.H., and Lin, C.N. 2011. Design of Digital Battery Charger System Based on PV-Module. IEEE International Conference on Fuzzy Systems

Chiang. S. J, Hsin, J. S. and Ming. C..C. 2009. Modeling and Control of PV Charger System With SEPIC Converter. Ieee Transactions On Industrial Electronics, Vol. 56, No. 11.

Chien . K.C., and Yu. K C.2002. A fuzzy-logic-controlled single-stage converter for PV-powered lighting system applications. IEEE Transactions on Industrial Electronics, Vol 47 Issue 2.

Current transducer LA 25-NP, LEM

David, S. M. 2010. Maximum Power Point Tracking Algorithms for Photovoltaic Applications. Aalto University School of Science and Technology.

Dongbing, Z. (2008).AN-1484 Designing A SEPIC Converter. Application Report. Texas Instruments Incorporated.

Elgendy. M.A., Bashar Z., and David J. A. 2012. Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications. IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 3, NO. 1.

Fatimah, Z.H., Abdul, A., and Mohd Yunus. 2012. Photovoltaic Array Modelling with P&O MPPT Algorithm in MATLAB. International Conference on Statistics in Science, Business, and Engineering (ICSSBE).

Fu bo, Y.l., Cheng, q., Cai , x., and Xing, x. 2012. A Photovoltaic MPPT Strategy by Modified Fuzzy Control. Applied Mechanics and Materials Vols. 128-129, pp 15-19.

Ganesh, S., Janani, J. and Besliya, A.G. 2014. A Maximum Power Point Tracker for PV Panels using SEPIC Converter. International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:8, No.2.

Gomathy, S., Saravanan,S., and Thangavel, S. 2012. Design and Implementation of Maximum Power Point Tracking (MPPT) Algorithm for a Standalone PV System. International Journal of Scientific & Engineering Research Volume 3, Issue 3.

Gonzalez, L.H., Brito, Z.B. Vazquez, E. D.S. 2005. Analysis, simulation and physical implementation: modified-SEPIC DC/DC converter.2nd International Conference on Electrical and Electronics Engineering.

Huan, L.T, Ci, S.T., and Yi, J.S. 2008. Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK. Proceedings of the World Congress on Engineering and Computer Science.

Ioan V.B., and Marcel. I. 2012. Modeling of Maximum Power Point Tracking Algorithm for Photovoltaic Systems. International Conference and Exposition on Electrical and Power Engineering (EPE).

IRG4PH40UD Insulated Gate Bipolar Transistor with Ultrafast Soft Recovery Diode Data Sheet International Rectifier.

Jayanthi, P., and Vinay, S.K. 2012. A Fuzzy Controlled Dual Output Photovoltaic System. International Journal of Scientific & Engineering Research Volume 3, Issue 5, ISSN 2229-5518

Jeff, F. 2008. Designing DC/DC converters based on SEPIC topology. Analog Applications Journal by Texas Instruments Incorporated.

Joung, H.P., Jun , Y.A, Bo , H.C., and Gwon J.Y. 2006. Dual-Module-Based Maximum Power Point Tracking Control of Photovoltaic Systems. Ieee Transactions On Industrial Electronics, Vol. 53, NO. 4, August 2006.

Jozwik, J.J. and Kazimierczuk, M.K. 2002. Dual sepic PWM switching-mode DC/DC power converter. IEEE Transactions on Industrial Electronics, Vol 36, Issue 1.

Kinal,K., Mukesh, P., and Makarand, L. 2011. MATLAB/Simulink Model of Solar PV Module and MPPT Algorithm. National Conference on Recent Trends in Engineering & Technology.

Krismadinata., Nasrudin, A.R., Hew, W.P., Jeyraj, S. 2013. Photovoltaic module modeling using simulink/matlab. Procedia Environmental Sciences 17, 537 – 546.

Kun, D., Xin, G.B., Hai, H.L., and Tao, P. 2012. MATLAB-Simulink-Based PV Module Model and Its Application under Conditions of Non-uniform Irradiance. IEEE Transactions On Energy Conversion. Vol. 27, No. 4.

Messaouda. A. 2012. Comparaison between MPPT P&O and MPPT Fuzzy Controls in Optimizing the Photovoltaic Generator. International Journal of Advanced Computer Science and Applications(IJACSA). Vol. 3, No. 12,

Mohd Zainuri, M.A.A, Mohd Radzi, M.A. Soh, A.C. and Rahim, N.A., 2012. Adaptive P&O-fuzzy control MPPT for PV boost dc-dc converter. IEEE International Conference on Power and Energy (PECon).

MPPT Technique for PV Module Using MATLAB/ SIMSCAPE. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. Vol. 2, Issue 9.

Multiplier Cell for Standalone PV Application. IEEE First Conference on Clean Energy and Technology CET.

Nicola, F., Giovanni, P., Giovanni, S., and Massimo, V. 2005. Optimization of Perturb and Observe Maximum Power Point Tracking Method. IEEE Transactions on Power Electronics, Vol. 20, No. 4.

Pragallapati, N. and Agarwal, V.. 2015. Distributed PV Power Extraction Based on a Modified Interleaved SEPIC for Nonuniform Irradiation Conditions. IEEE Journal of Photovoltaics.

Rasoul, R., Mehdi, M.S., Saad, M., and Rubiyah, Y. 2013. Implementation of Fuzzy Logic Maximum Power Point Tracking Controller For Photovoltaic System. American Journal of Applied Sciences, ISSN: 1546-9239.

Reddy, M.T., and Yugandhar, J. 2015. Fuzzy-Logic-Controller-Based Sepic Converter For Maximum Power Point Tracking. International Journal of Emerging Trends in Engineering and Development.

Sangita. S. K., and Vaidya. U.B. 2012. A Comparison of Two MPPT Techniques for PV System in Matlab Simulink. International Journal of Engineering Research and Development. Volume 2, Issue , PP. 73-79 .

Sarah A., And Rachid, E.B. 2014. A Perturb and Observe Method using Dual Fuzzy Logic Control for Resistive Load. Recent Advances in Environmental Science and Biomedicine.

Subminiature High Power Relay, HK 3FF

Suhaini, S. and Nasrudin, A. R, 2011. Simulation of Integrated SEPIC Converter with Multiplier Cell for Standalone PV Application. IEEE First Conference on Clean Energy and Technology, CET.

Surya, K. J., Babu, C. S., and Babu. A.K.,2012. Design and Analysis of P&O and IP&O MPPT Techniques for Photovoltaic System. International Journal of Modern Engineering Research (IJMER).

Swati. S., Lini. M., and Shimi S.L. 2013. Design and Simulation of Intelligent Control

Taghvaee, M.H., Radzi, M.A.M., Moosavain , S.M., Hashim. H., and Hamiruce, M.M. 2013. A current and future study on non-isolated DC–DC converters for photovoltaic applications. Renewable and Sustainable Energy Reviews 17, 216–227.

Tanaselan ,R., Radzi, M.A.M., Zainuri , M.A.A.M., Wahab, N.I.A., and Rahman R.Z.A. 2015. Dual-Fuzzy Based MPPT for Dual-Load Operation with Photovoltaic SEPIC Converter. Control Conference (ASCC), 2015 10th Asian.

Tey. K.S. and Mekhilef, S. 2015. A Fast-Converging MPPT Technique for Photovoltaic System Under Fast-Varying Solar Irradiation and Load Resistance. IEEE Transactions on Industrial Informatics Volume11, Issue 1.

TMS320F28235, Digital Signal Controllers (DSCs), Data Manual Texas Instrument, 2012.

Voltage transducer LV 25-P/SP2, LEM

Wafa , B., Abdelrahman , O., and Mutasem , N. 2013. An intelligent fuzzy based tracking controller for a dual-axis solar PV system. Automation in Construction.

Yuncong, J., Jaber, A.A.Q., and Mohamed Orabi. 2011. Matlab/Pspice Hybrid Simulation Modeling of Solar PV Cell/Module. Applied Power Electronics Conference and Exposition (APEC).