

INVESTIGATION OF M
ACTIVE COOLING MOI



FUZZY LOGIC CONTROLLER

WORKING (MPPT) FOR
TAIC PANEL USING

NURUL AFIQAH BINTI ZAINAL

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Engineering (Mechatronic)

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

February 2017

P PERPUSTAKAAN UNIVERSITI MALAYSIA PAHANG	
No. Perolehan 117786	No. Panggilan FP
Tarikh 17 APR 2017	- 635 2017 v F155

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENTS	ii
ABSTRAK	iii
ABSTRACT	iv
TABLE OF CONTENT	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF SYMBOLS	xii
LIST OF ABBREVIATIONS	xiii
CHAPTER 1 INTRODUCTION	1
1.1 Project Background	1
1.2 Problem Statement	3
1.3 Project Objectives	4
1.4 Project Scope	4
1.5 Thesis Organization	5
CHAPTER 2 LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Solar As Potential Renewable Energy	8
2.3 Photovoltaic System	11
2.4 PV Panel Efficiency	13

2.4.1	PV Panel Cooling System	14
2.5	DC-DC Boost Converter	17
2.6	Maximum Power Point Tracking (MPPT)	19
2.6.1	Types of MPPT Algorithms	19
2.6.2	Constant Voltage (CV) Algorithm	21
2.6.3	Fuzzy Logic Controller MPPT	22
2.7	Literature Review Gap	25
2.8	Summary	26
CHAPTER 3 METHODOLOGY		27
3.1	Introduction	27
3.2	Develop Model Design	27
3.3	PV System Design	29
3.4	Mathematical Modelling For PV Module	31
3.4.1	Resistive Load Experiment for I-V Characteristics of PV Panel	40
3.5	Cooling System for PV Panel	41
3.5.1	Cooling System Design and Simulation	41
3.5.2	Cooling System Experimental Setup	43
3.6	DC-DC Boost Converter	47
3.6.1	Boost Converter Design and Simulation	47
3.7	Fuzzy Logic Controller	50
3.7.1	Constant Voltage Based Fuzzy Logic Algorithm	50
3.7.2	Fuzzy Logic Controller Circuit Design	54
3.8	Experimental Design	58
3.9	Summary	62

CHAPTER 4 RESULTS AND DISCUSSION	63
4.1 Introduction	63
4.2 PV Panel Mathematical Modelling	63
4.2.1 PV Panel Modelling	64
4.2.2 Load Resistive Experiment on PV Panel Characteristics	69
4.3 Cooling System for PV System	71
4.4 Fuzzy Logic Controller for Maximum Power Point Tracking	74
4.4.1 Experimental on Fuzzy Logic Controller	77
4.4.2 Optocoupler and IR2112 Driver	79
4.5 DC-DC Boost Converter	80
4.6 Summary	83
CHAPTER 5 CONCLUSION	85
5.1 Conclusion and Research Summary	85
5.2 Recommendations	87
REFERENCES	88
APPENDIX A MSR 245W PV Panel Technical Data	95
APPENDIX B Fuzzy logic coding	96
APPENDIX C International Conference on Electrical Power Engineering and Applications, Applied Mechanics and Materials Vol. 793 (2015) pp 378-382	105
APPENDIX D 2nd International Manufacturing Engineering Conference (iMEC), November 2015	106
APPENDIX E 2nd International Manufacturing Engineering Conference (iMEC), November 2015	107

LIST OF TABLES

Table 3.1	Technical data of the MSR 245W PV panel	33
Table 3.2	Boost converter designed parameters	49
Table 3.3	Arduino Uno R3 specification	55
Table 4.1	Load resistive experimental results	69
Table 4.2	PV panel data in two different conditions	73
Table 4.3	Data collected from MATLAB simulation of the fuzzy logic algorithm	76
Table 4.4	Experimental data collected from FL controller	77
Table 4.5	Comparison between simulation and experimental results of FL controller	78
Table 4.6	Experimental data collected from PV system	81

LIST OF FIGURES

Figure 1.1	Annual average daily solar irradiation of Malaysia	2
Figure 1.2	Thesis Organization	7
Figure 2.1	Malaysia annual growth rate on total energy demand	9
Figure 2.2	Global PV installed capacity from 2000 to 2013	10
Figure 2.3	Annual average daily solar irradiation of Malaysia	11
Figure 2.4	PV cell structure	12
Figure 2.5	PV cell equivalent circuit	13
Figure 2.6	PV panel conversion energy	15
Figure 2.7	Schematic diagram of water pumping system for PV panel	16
Figure 2.8	Types of power converter	17
Figure 2.9	Boost converter circuit diagram	18
Figure 2.10	IV and PV characteristics of PV module	19
Figure 2.11	CV method flow chart	22
Figure 2.12	Symmetrical membership function (SMF)	24
Figure 2.13	Asymmetrical membership function (ASMF)	24
Figure 2.14	Fuzzy control system	24
Figure 2.15	Fuzzy controller structure	25
Figure 3.1	Block diagram of the model design	28
Figure 3.2	PV panel temperature characteristics	28
Figure 3.3	Research design flowchart	30
Figure 3.4	Single diode PV cell modeled	31
Figure 3.5	PV modelling using Simulink	34
Figure 3.6	Subsystem 1	35
Figure 3.7	Circuit under subsystem 1	35
Figure 3.8	Subsystem 2 to calculate value of $NskAT$	35
Figure 3.9	Circuit under subsystem 2	35
Figure 3.10	Subsystem 3 to calculate PV photocurrent, I_{ph}	36
Figure 3.11	Circuit under subsystem 3	36
Figure 3.12	Subsystem 4 to obtain the value of PV reverse saturation current	36
Figure 3.13	Circuit under subsystem 4	37
Figure 3.14	Subsystem 5 to obtain PV reverse saturation current, I_{rs}	37
Figure 3.15	Circuit under subsystem 5	38
Figure 3.16	Subsystem 6 indicates the value of PV output current, I_{pv}	38

Figure 3.17	Circuit under the subsystem 6	39
Figure 3.18	Six subsystems connection for PV panel	39
Figure 3.19	Resistive load experiment schematic diagram	40
Figure 3.20	PV cooling system installation diagram	41
Figure 3.21	Block diagram of the cooling system	42
Figure 3.22	Cooling system's circuit diagram	43
Figure 3.23	245W PV panel	44
Figure 3.24	PVC pipe mounted on top of PV panel	44
Figure 3.25	Thin film of water covered the PV panel surface	45
Figure 3.26	AS-2000 Astro liquid filter	45
Figure 3.27	Cooling system experimental installation	46
Figure 3.28	PV temperature monitor	46
Figure 3.29	Boost converter circuit configuration	47
Figure 3.30	Boost converter model design circuit	50
Figure 3.31	Membership function of input variable, Error	52
Figure 3.32	Membership function of input variable, Change of Error	52
Figure 3.33	Membership function of output variable, Duty cycle	53
Figure 3.34	Rule evaluation	53
Figure 3.35	PV system plant with FL controller	54
Figure 3.36	Arduino Uno R3	55
Figure 3.37	Voltage divider design	56
Figure 3.38	Voltage divider experimental circuit	56
Figure 3.39	Optocoupler circuit	57
Figure 3.40	Experimental circuit of optocoupler circuit	57
Figure 3.41	IR2112 driver circuit design	58
Figure 3.42	Experimental circuit of IR2112	58
Figure 3.43	PV system model design	59
Figure 3.44	Sequence of methods	60
Figure 3.45	Controller experimental circuit	62
Figure 3.46	Boost converter experimental circuit	62
Figure 4.1	Irradiation value for PV modelling	64
Figure 4.2	Fixed temperature of 25 °C	65
Figure 4.3	I-V characteristics for difference irradiance value	65
Figure 4.4	P-V characteristics for different irradiance value	66
Figure 4.5	Input of irradiation for fixed irradiation of 1000 W/m ²	67

Figure 4.6	Temperature value for PV modelling	67
Figure 4.7	I-V characteristics for different temperature value	68
Figure 4.8	P-V characteristics for different temperature value	68
Figure 4.9	I-V characteristic comparison based on simulation and experimental result	70
Figure 4.10	P-V characteristic comparison based on simulation and experimental result	70
Figure 4.11	Data collected in a day	71
Figure 4.12	Comparison between voltage inputs (V_{PV}) of PV panel without cooling system versus PV panel with cooling system	72
Figure 4.13	Comparison between temperatures (T_{PV}) of PV panel without cooling system versus PV panel with cooling system	73
Figure 4.14	Percentage change collected from the data of conventional PV panel and PV panel with the cooling system	74
Figure 4.15	Fuzzy logic Simulink simulation in MATLAB	76
Figure 4.16	FL controller PWM signal in steady state from Arduino Uno R3 controller	79
Figure 4.17	PWM signals; a) IR2112 driver (1) and b) Optocoupler 4N25 (2)	80
Figure 4.18	Boost converter simulation	80
Figure 4.19	66.9 V of voltage output (V_{OUT}) from Boost converter	81
Figure 4.20	Voltage oscillating before reached steady state	82
Figure 4.21	PV system's voltage rise time before reaching steady state	82
Figure 4.22	Comparison between voltage outputs (V_{OUT}) of PV system without the cooling system versus PV system with the cooling system by using FL controller	83

LIST OF SYMBOLS

%	Percentage
°C	Degree Celsius
Ω	Ohm
V	Voltage
A	Ampere
W	Watt

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CV	Constant Voltage
DC	Direct Current
ETP	Economic Transformation Programme
FL	Fuzzy Logic
FLC	Fuzzy Logic Controller
GDP	Gross Domestic Product
IncCond	Incremental Conductance
MPP	Maximum Power Point Tracking
MPPT	Maximum Power Point Tracking
OV	Open Voltage
P&O	Perturb and Observe
PV	Photovoltaic
SC	Short-Current
UMP	University Malaysia Pahang

INVESTIGATION OF M
ACTIVE COOLING MOI



FUZZY LOGIC CONTROLLER

WORKING (MPPT) FOR
TAIC PANEL USING

NURUL AFIQAH BINTI ZAINAL

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Engineering (Mechatronic)

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

February 2017

P PERPUSTAKAAN UNIVERSITI MALAYSIA PAHANG	
No. Perolehan 117786	No. Panggilan FP
Tarikh 17 APR 2017	- 635 2017 v F155

ABSTRAK

Projek ini dilaksanakan seiring dengan kepentingan dalam menggalakkan penggunaan tenaga solar bagi melaksanakan sistem fotovoltan (PV) untuk menggantikan penggunaan gas dan arang batu dalam penghasilan tenaga elektrik. Walau bagaimanapun, disebabkan oleh jumlah sinaran suria yg diterima tidak menentu, penghasilan kuasa elektrik daripada panel fotovoltan juga tidak dapat dikawal. Bagi mencapai kuasa titik maksima (MPP) daripada panel PV, logik fuzzy (FL) berdasarkan voltan malar (CV) algoritma digunakan di dalam sistem. Tujuan utama projek ini adalah untuk membangunkan sistem PV yang berdiri sendiri yang cekap dengan sistem penyejukan. Sistem ini dibangunkan melalui simulasi dan eksperimen. Model panel PV direka berdasarkan model PV matematik yang menggunakan model sel diod tunggal. Simulasi ini dilakukan untuk menganalisis ciri-ciri panel PV terutamanya dalam perubahan suhu dan pendedahan kepada sinaran. Ciri-ciri ini digunakan sebagai input dalam membangunkan pengawal logik fuzzy (FL). Untuk mengawal dan mengekalkan suhu panel PV pada tahap optimum, sistem penyejukan dibangunkan ke dalam sistem. Sistem penyejukan membantu meningkatkan output voltan PV serta mengeluarkan kuasa. Dari simulasi, ciri-ciri I-V dan P-V panel PV diperolehi. Secara purata, pelaksanaan sistem penyejukan menunjukkan peningkatan 3.09% dan 1.96% pada bacaan V_{PV} dan V_{out} apabila suhu PV turun sebanyak 17.71%. Ini jelas menunjukkan hasil V_{PV} bergantung kepada suhu PV. Dengan melaksanakan FL algoritma berdasarkan CV kepada kaedah ini, sistem menjadi lebih mantap dan boleh dipercayai dari segi keberkesanan dan kecekapan. Kesimpulannya, sistem PV yang berdiri sendiri berjaya direka dan dianalisis dalam kedua-dua simulasi dan eksperimen bagi menentukan ciri-ciri panel PV dan meningkatkan prestasi sistem. Dengan melaksanakan sistem penyejukan untuk panel PV serta menggunakan pengawal FL dalam mengesan PV MPP prestasi sistem PV dapat dipertingkatkan dan mengurangkan masalah yang memberi kesan kepada penghasilan kuasa dari panel PV.

ABSTRACT

Interest promotion of solar energy to perform an efficient standalone PV system to replace the used of gas and coal as the main demand in producing electricity. Due to the nonlinearity of solar radiation and temperature, it leads to inconsistency in electricity production from the PV panel. To achieve the maximum power point (MPP) of PV panel, fuzzy logic (FL) based constant voltage (CV) algorithm is applied to the system. The aim of this project is to develop an efficient standalone PV system with cooling system. This system is develop in both simulation and experimental. A model of PV panel is designed based PV mathematical modelling by using single cell diode model. The simulation is done to analyze PV panel characteristics especially in variation of temperature and irradianations. These characteristics are used for the inputs in developing the Fuzzy Logic (FL) controller. As to control and maintain the temperature of PV panel on its optimum level, a cooling system is developed into the system. The cooling system helps to increase the PV voltage output as well as the power produce. From the simulation, I-V and P-V characteristics of PV panel are obtained. The implementation of cooling system results in 3.09% and 1.96% of V_{PV} and V_{OUT} percentage change increasing respectively when the PV temperature drop down to 17.71% averagely. This clearly shows the V_{PV} produce depends on the PV temperature. By implementing FL based CV algorithm into this method, it makes the system more robust and reliable in terms of effectiveness and efficiency. In conclusion, a standalone PV system is successfully designed and analyzed in both simulation and experimental set up to determine the PV panel characteristics and increase the system performances. By implementing the cooling system for PV panel as well as using FL controller in tracking PV MPP enhanced the performances of PV system and reduces the problems that affect the power generation from PV panel.

REFERENCES

- Abdelkader, M.R. and Sharaf, F., 2010. A comparative Analysis of the Performance of Monocrystalline and Multi-crystalline PV Cells in Semi-Arid Climate Conditions : The Case of Jordan. *Water*, 4(5): 543–552.
- Abdulkadir, M., Samosir, A.S. and Yatim, A.H.M. 2012. Modeling and simulation based approach of photovoltaic system in Simulink model. *ARPN Journal of Engineering and Applied Sciences*, 7(5): 616–623.
- Aganah, K. And Leedy, A.W. 2011. A constant voltage maximum power point tracking method for solar powered systems. *IEEE 43rd Southeastern Symposium on System Theory (SSST)*, pp.125–130.
- Ahmad, J. 2010. A fractional open circuit voltage based maximum power point tracker for photovoltaic arrays. *Proceedings of the 2nd International Conference on Software Technology and Engineering (ICSTE)*, pp.247–250.
- Alami, A.H. 2014. Effects of evaporative cooling on efficiency of photovoltaic modules. *Energy Conversion and Management*, 77: 668–679.
- Al-Diab, A. and Sourkounis, C. 2010. Variable step size P&O MPPT algorithm for PV systems. *Proceedings of the 12th International Conference on Optimization of Electrical and Electronic Equipment (OPTIM)*, pp.1097–1102.
- Alonso García, M.C. and Balenzategui, J.L. 2004. Estimation of photovoltaic module yearly temperature and performance based on Nominal Operation Cell Temperature calculations. *Renewable Energy*, 29(12), pp.1997–2010.
- Amin, N., Lung, C.W. and Sopian, K. 2009. A practical field study of various solar cells on their performance in Malaysia. *Renewable Energy*, 34(8): 1939–1946.
- Azman, A.Y., Rahman, A.A., Bakar, N.A., Hanaffi, F. and Khamis, A. 2011. Study of Renewable Energy Potential in Malaysia. *Proceedings of the IEEE First Conference on Clean Energy and Technology (CET)*, pp. 170-176.
- Bataineh, K.M. and Hamzeh, A. 2014. Efficient Maximum Power Point Tracking Algorithm for PV Application under Rapid Changing Weather Condition. *ISRN Renewable Energy*, 2014: 1–13.
- Bendib, B., Belmili, H. and Krim, F. 2015. A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic systems. *Renewable and Sustainable Energy Reviews*, 45: 637–648.
- Bendib, B., Krim, F., Belmili, H., Almi, M.F. and Boulouma, S. 2014. Advanced Fuzzy MPPT Controller for a Stand-alone PV System. *Energy Procedia*, 50: 383–392.

- Beriber, D. and Talha, A. 2013. MPPT techniques for PV systems. *Proceedings of the 4th International Conference on Power Engineering, Energy and Electrical Drives*, pp.1437–1442.
- Berrera, M., Dolara, A., Faranda, R. and Leva, S. 2009. Experimental test of seven widely-adopted MPPT algorithms. *Proceedings of the IEEE Bucharest PowerTech: Innovative Ideas Toward the Electrical Grid of the Future*, pp.1–8.
- Bounechba, H., Bouzid, A., Nabti, K. and Benalla, H. 2014. Comparison of Perturb and Observe and Fuzzy Logic in Maximum Power Point Tracker for PV Systems. *Energy Procedia*, 50: 677–684.
- Chouder, A., Guijoan, F. and Silvestre, S. 2008. Simulation of fuzzy-based MPP tracker and performance comparison with perturb & observe method. *Revue des Energies Renouvelables*, 11: 577–586.
- Coelho, R.F., Concer, F.M. and Martins, D.C. 2010. A simplified analysis of DC-DC converters applied as maximum power point tracker in photovoltaic systems. *Proceedings of the 2nd International Symposium on Power Electronics for Distributed Generation Systems*, pp.29–34.
- Dolara, A., Faranda, R. and Leva, S. 2003. Energy Comparison of Seven MPPT Techniques for PV Systems. *Journal of Electromagnetic Analysis and Applications*, 01(03): 152–162.
- Du, Y., Fell, C.J., Duck, B., Chen, D., Liffman, K., Zhang, Y., Gu, M. and Zhu, Y. 2016. Evaluation of photovoltaic panel temperature in realistic scenarios. *Energy Conversion and Management*, 108: 60–67.
- Dubey, S., Sarvaiya, J.N. and Seshadri, B. 2013. Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review. *Energy Procedia*, 33: 311–321.
- Edouard, M. and Njomo, D. 2013. Mathematical Modeling and Digital Simulation of PV Solar Panel using MATLAB Software. *International Journal of Emerging Technology and Advanced Engineering*, 3(9): 24–32.
- Elgendy, M.A., Zahawi, B. and Atkinson, D.J. 2010. Comparison of directly connected and constant voltage controlled photovoltaic pumping systems. *IEEE Transactions on Sustainable Energy*, 1(3): 184–192.
- El-Ghonemy, A.M.K. 2012. Photovoltaic Solar Energy: Review. *International Journal of Scientific and Engineering Research*, 3(11): 1–43.
- Elnozahy, A., Rahman, A.K.A. and Ali, A.H.H. 2015. Performance of a PV module integrated with standalone building in hot arid areas as enhanced by surface cooling and cleaning. *Energy and Buildings*, 88: 100–109.
- Eltawil, M.A. and Zhao, Z. 2013. MPPT techniques for photovoltaic applications. *Renewable and Sustainable Energy Reviews*, 25: 793–813.

- Elyadi, H. and Alhaddad, A. 2014. Maximum Power of PV Cells Using Fuzzy Control. *European Journal of Academic Essays*, 1(5): 52-57.
- Faranda, R., Leva, S. and Maugeri, V. 2008. MPPT techniques for PV systems: Energetic and cost comparison. *Proceedings of the IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century*, pp.1–6.
- Femia, N., Petrone, G., Spagnuolo, G. and Vitelli, M. 2013. *Power electronics and control techniques for maximum energy harvesting in photovoltaic systems*. Taylor & Francis Group.
- Femia, N., Petrone, G., Spagnuolo, G., and Vitelli, M. 2005. Optimization of Perturb and Observe Maximum Power Point Tracking Method. *IEEE Transactions on Power Electronics*, 20(4): 963–973.
- Goh, K.C., Yap, A.B.K., Goh, H.H., Seow, T.W. and Toh, T.C. 2015. Awareness and Initiatives of Building Integrated Photovoltaic (BIPV) implementation in Malaysian Housing Industry. *Procedia Engineering*, 118: 1052–1059.
- Guenounou, O., Dahhou, B. and Chabour, F. 2014. Adaptive fuzzy controller based MPPT for photovoltaic systems. *Energy Conversion and Management*, 78: 843–850.
- Hajighorbani, S., Radzi, M.A.M., Ab Kadir, M.Z.A., Shafie, S., Khanaki, R. and Maghami, M.R. 2014. Evaluation of Fuzzy Logic Subsets Effects on Maximum Power Point Tracking for Photovoltaic System. *International Journal of Photoenergy*, 2014: 1–13.
- Hankins, M. 2010. *Stand-alone solar electric systems*. Earthscan.
- Hart, D.W. 2011. *Power Electronics*. McGraw-Hill.
- Islam, M.R., Saidur, R., Rahim, N.A. and Solangi, K.H. 2009. Renewable Energy Research in Malaysia. *Engineering e-Transaction*, 4(2): 69–72.
- Ismail, A.M., Ramirez-Iniguez, R., Asif, M., Munir, A.B. and Muhammad-Suki, F. 2015. Progress of solar photovoltaic in ASEAN countries: A review. *Renewable and Sustainable Energy Reviews*, 48: 399–412.
- Kamali, S.K. and Mekhilef, S., 2009. Evaluation study on grid-connected PV system at University of Malaya. *Proceedings of the International Conference for Technical Postgraduates (TECHPOS)*, pp.1–7.
- Kardooni, R., Yusoff, S. and Kari, F. 2016. Renewable energy technology acceptance in Peninsular Malaysia. *Energy Policy*, 88: 1–10.
- Khan, F.H., Tolbert, L.M. and Peng, F.Z. 2006. Deriving new topologies of DC-DC converters featuring basic switching cells. *Proceedings of the IEEE Workshop on Computers in Power Electronics*, pp.328–332.

- Kordzadeh, A. 2010. The effects of nominal power of array and system head on the operation of photovoltaic water pumping set with array surface covered by a film of water. *Renewable Energy*, 35(5): 1098–1102.
- Krauter, S., 2004. Increased electrical yield via water flow over the front of photovoltaic panels. *Solar Energy Materials and Solar Cells*, 82(1-2): 131–137
- Leedy, A.W., Guo, L. and Aganah, K.A. 2012. A constant voltage MPPT method for a solar powered boost converter with DC motor load. *Conference Proceedings IEEE Southeastcon*, pp.1-6.
- Locment, F., Sechilariu, M. and Houssamo, I. 2010. Energy efficiency experimental tests comparison of P&O algorithm for PV power system. *Proceedings of the 14th International Power Electronics and Motion Control Conference (EPE-PEMC)*, pp.89–95.
- Lokanadham, M., and Bhaskar, K. 2012. Incremental Conductance based Maximum Power Point Tracking (MPPT) for Photovoltaic System. *International Journal of Engineering Research and Applications (IJERA)*, 2(2): 1420–1424.
- Lyden, S., Haque, M.E., Gargoom, A., Negnevitsky, M. and Mouka, P.I. 2012. Modelling and Parameter Estimation of Photovoltaic Cell. *Proceedings of the Universities Power Engineering Conference (AUPEC)*, pp. 1–6.
- Mahamudul, H., Saad, M. and Henk, I. 2012. A Modified Simulation Method of Photovoltaic Module in Simulink Environment. *Proceedings of the 7th International Conference on Electrical and Computer Engineering*, pp.607–610.
- Mahamudul, H., Saad, M. and Henk, M.I. 2013. Photovoltaic System Modeling with Fuzzy Logic Based Maximum Power Point Tracking Algorithm. *International Journal of Photoenergy*, 2013: 1-10.
- Marnoto, T., Sopian, K., Daud, W.R.W., Algoul, M. and Zaharim, A. 2007. Mathematical model for determining the performance characteristics of multi-crystalline photovoltaic modules. *Proceedings of the 9th WSEAS International Conference on Mathematical and Computational Methods in Science and Engineering*, pp.79–84.
- Mayfield, R. 2012. The Highs and Lows of Photovoltaic System Calculations (online). <http://ecmweb.com/green-building/highs-and-lows-photovoltaic-system-calculations> (23 July 2012)
- Mei, L., Infield, D., Eicker, U. and Loveday, D. 2006. Cooling potential of ventilated PV façade and solar air heaters combined with a desiccant cooling machine. *Renewable Energy*, 31(8): 1265–1278.
- Mekhilef, S., Safari, A., Mustaffa, W.E.S., Saidur, R., Omar, R. and Younis, M.A.A. 2012. Solar energy in Malaysia: Current state and prospects. *Renewable Sustainable Energy Reviews*, 16: 386–396.

- Mohanty, P., Bhuvanewari, G., Balasubramanian, R. and Dhaliwal, N.K. 2014. MATLAB based modeling to study the performance of different MPPT techniques used for solar PV system under various operating conditions. *Renewable and Sustainable Energy Reviews*, 38: 581–593.
- Moharram, K.A., Abd-Elhady, M.S., Kandil, H.A. and El-Sherif, H. 2013. Enhancing the performance of photovoltaic panels by water cooling. *Ain Shams Engineering Journal*, 4(4): 869–877.
- Negnevitsky, M. 2011. *Artificial Intelligence: A Guide to Intelligent Systems*. Pearson Education Limited.
- Oh, T.H., Pang, S.Y. and Chua, S.C., 2010. Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth. *Renewable and Sustainable Energy Reviews*, 14(4): 1241-52.
- Padgavhankar, A.V. and Mohod, S.W., 2014. Experimental Learning of Digital Power Controller for Photovoltaic Module Using Proteus VSM. *Journal of Solar Energy*, 2014: 1-8.
- Rahmani, R. and Seyedmahmoudian, M. 2013. Implementation of Fuzzy Logic Maximum Power Point Tracking Controller for Photovoltaic System. *American Journal of Applied Sciences*, 10(3): 209–218.
- Rekioua, D., Aissou, S. and Panel, A.P. 2013. Photovoltaic Panels Characteristics Methods. *Proceedings of the International Conference on Control, Engineering and Information Technology*, pp.168–174.
- Rezk, H. and Eltamaly, A.M. 2015. A comprehensive comparison of different MPPT techniques for photovoltaic systems. *Solar Energy*, 112: 1–11.
- Saboori, B., Sulaiman, J. and Mohd, S. 2012. Economic growth and CO2 emissions in Malaysia: A cointegration analysis of the Environmental Kuznets Curve. *Energy Policy*, 51: 184–191.
- Sakly, A. and Smida, M.B. 2012. Adequate Fuzzy Inference Method for MPPT Fuzzy Control of Photovoltaic Systems. *International Conference on Future Electrical Power and Energy Systems*, 9: 475-468.
- Salas, V., Olias, E., Barrado, A. and Lazaro, A. 2006. Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems. *Solar Energy Materials and Solar Cells*, 90(11): 1555–1578.
- Salmi, T., Bouzguenda, M., Gastli, A. and Mosmoudi, A. 2012. MATLAB / Simulink Based Modelling of Solar Photovoltaic Cell. *International Journal Of Renewable Energy Research*, 2(2): 213-218.
- Singh, R. and Pandit, M. 2013. Analysis of Photovoltaic Cells With Closed Loop Boost Converter. *International Journal of Advances in Engineering and Technology*, 6(1): 304–315.

- Skoplaki, E. and Palyvos, J.A. 2009. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar Energy*, 83(5): 614–624.
- Sreekumar, S. and Benny, A. 2013. Maximum Power Point Tracking of Photovoltaic System Using Fuzzy Logic Controller Based Boost Converter. *Proceedings of the International Conference on Current Trends in Engineering and Technology*, pp.275-280.
- Teo, H.G., Lee, P.S. and Hawlader, M.N.A. 2012. An active cooling system for photovoltaic modules. *Applied Energy*, 90(1): 309–315.
- Touafek, K., Khelifa, A. and Adouane, M. 2014. Theoretical and experimental study of sheet and tubes hybrid PVT collector. *Energy Conversion and Management*, 80: 71–77.
- Tsai, H., Tu, C. & Su, Y., 2008. Development of Generalized Photovoltaic Model Using MATLAB / SIMULINK. *Proceedings of the World Congress on Engineering and Computer Science*, pp.1-6.
- Verma, D., Nema, S., Shandilya, A.M. and Dash, S.K. 2016. Maximum power point tracking (MPPT) techniques: Recapitulation in solar photovoltaic systems. *Renewable and Sustainable Energy Reviews*, 54: 1018–1034.
- Verma, L.K., Sakhuja, M., Danner, A.J., Yang, H., Zeng, H.C. and Bhatia, C.S. 2011. Self-cleaning and antireflective packaging glass for solar modules. *Renewable Energy*, 36(9): 2489–2493.
- Willoughby, A.A., Omotosho, T.V. and Aizebeokhai, A.P. 2014. A simple resistive load I-V curve tracer for monitoring photovoltaic module characteristics. *International Renewable Energy Congress*, 5(1): 1–6.
- Wong, S.L., Ngadi, N., Abdullah, T.A.T. and Inuwa, I.M. 2015. Recent advances of feed-in tariff in Malaysia. *Renewable and Sustainable Energy Reviews*, 41: 42–52.
- Wu, S. and Xiong, C. 2014. Passive cooling technology for photovoltaic panels for domestic houses. *International Journal of Low-Carbon Technologies*, 9(2), pp.118–126.
- Ya'acob, M.E., Hizam, M., Radzi, M.A.M. and Kadir, M.Z.A.A. 2013. Field Measurement of PV Array Temperature for Tracking and Concentrating 1 kW_p Generators Installed in Malaysia. *International Journal of Photoenergy*, 2013: 1-8.
- Yager, R.R. and Filev, D.P. 1994. *Essentials of Fuzzy Modelling and Control*. John Wiley & Sons, Inc.
- Ying, H. 2000. *Fuzzy Control and Modelling: Analytical Foundations and Applications*. IEEE, Inc.

- Zainuri, M.A.A.M., Radzi, M.A.M., Soh, A.C. and Rahim, N.A. 2014. Development of adaptive perturb and observe-fuzzy control maximum power point tracking for photovoltaic boost dc–dc converter. *IET Renewable Power Generation*, 8(2): 183–194.
- Zaoui, F., Titaouine, A., Becherif, M., Emziane, M. and Aboubou, A. 2015. A Combined Experimental and Simulation Study on the Effects of Irradiance and Temperature on Photovoltaic Modules. *Energy Procedia*, 75: 373–380.