MATHEMATICAL MODELLING AND HYBRID ACO-PSO TECHNIQUE FOR PV PERFORMANCE IMPROVEMENT

ALI MAHMOOD HUMADA

DOCTOR OF PHILOSOPHY (ELECTRICAL AND ELECTRONIC ENGINEERING) UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's full name : ALI MAHMOOD HUMADA

Date of birth : 01 APRIL 1982

Title : MATHEMATICAL MODELING AND HYBRID ACO-PSO TECHNIQUE FOR PV PERFORMANCE IMPROVEMENT

Academic Session : 2015/2016

I declare that this thesis is classified as:

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)

☐ **RESTRICTED** (Contains restricted information as specified by the organization where research was done)

√ **OPEN ACCESS** I agree that my thesis to be published as online open access (Full text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

1. The Thesis is the Property of Universiti Malaysia Pahang.
2. The Library of Universiti Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified By:

(Student's Signature) (Signature of Supervisor)

A4650820
New IC / Passport Number
Date :

Dr. MOJGAN HOJABRI
Name of Supervisor
Date :

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Electrical Engineering.

Signature	:	
Name of Supervisor	:	DR. MOJGAN HOJABRI
Position	:	SENIOR LECTURER
Date	:	AUGUST 2016

Signature	:	
Name of Co-supervisor	:	DR. MOHD. HERWAN BIN SULAIMAN
Position	:	SENIOR LECTURER
Date	:	AUGUST 2016

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

Signature	:	
Name	:	ALI MAHMOOD HUMADA
ID Number	:	PEE13002
Date	:	AUGUST 2016

MATHEMATICAL MODELLING AND HYBRID ACO-PSO TECHNIQUE FOR PV PERFORMANCE IMPROVEMENT

ALI MAHMOOD HUMADA

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy in Electrical Engineering

Faculty of Electrical and Electronic Engineering
UNIVERSITI MALAYSIA PAHANG

AUGUST 2016

TABLE OF CONTENTS

CHAPTER III RESEARCH METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

Symbol	Description
A	PV module area
Eq	the energy gap of solar cell
G	solar irradiance (W/m^2)
G_{STC}	solar irradiance at standard test conditions ($1000W/m^2$)
G▽	the ratio of the generic solar irradiance to the irradiance at STC
I	PV output current
Io	reverse saturation current of the diode (A)
Iph	photogenerated current (A)
$Iph,_{STC}$	photogenerated current at standard rating conditions (A)
I*mpp	coordinates of current at the maximum power point (A)
Isc	short circuit current of the module (A)
$Isc,_{STC}$	short circuit current of the module at standard test condition (A)
I_{mpp}	a current corresponding to the maximum power point (A)
$Io,_{STC}$	reverse saturation current at standard rating conditions (A)
K	Boltzmann constant (1.381E10 – 23 J/K)
MAPE	mean absolute percentage errors
μ_{Isc}	coefficient of the short circuit current (A/1C)
μ_{Voc}	coefficient of the open circuit voltage (V/1C)
N	diode quality factor
$n,_{STC}$	diode quality factor at standard rating conditions
P	power generated by the PV panel (W)
PR	performance ratio
Q	electric charge of an electron (1.602E10 –19 C)

R_s	series resistance (Ω)
R_{so}	reciprocal of the gradient at the open-circuit point
R_{oc}	the inverse of the gradients [(dI/dV)-1] under the open circuit conditions
R_{sh}	shunt resistance (Ω)
R_{sho}	the reciprocal of the gradient at the short-circuit point
R_{sc}	inverse of the gradients [(dI/dV)-1] under the short circuit conditions
SSR	sum of square due to regression
SST	sum of squares due to error
T	PV cell Temperature (K)
T_{STC}	the temperature at standard test conditions (25°C)
$T^{\triangledown}$	the ratio of the generic temperature to the irradiance at STC
V_D	voltage across the diode
V*mpp	coordinates of the voltage at the maximum power point (V)
V_{mpp}	a voltage corresponding to at the maximum power point (V)
Vpv	output volatage of PV panel
Voc	open circuit voltage of the panel
Voc,STC	open circuit voltage of the panel at standard test condition (V)
Va	denotes a random value of the voltage
Vt	thermal voltage value which equal to (q/nKT)

MATHEMATICAL MODELLING AND HYBRID ACO-PSO TECHNIQUE FOR PV PERFORMANCE IMPROVEMENT

ALI MAHMOOD HUMADA

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy in Electrical Engineering

Faculty of Electrical and Electronic Engineering
UNIVERSITI MALAYSIA PAHANG

AUGUST 2016

ABSTRACT

Photovoltaic (PV) solar energy systems have been playing an important role in the field of energy generation for the last few decades. For such systems to attain the maximum efficiency and reliability in power generation, certain factors should be considered to improve the extracted power. For the purpose, this thesis is focused on some of the most important issues, assisting to improve the extracted power status. One of the most important issue for each PV system is the modelling of PV cells and the modules; the accuracy of these models is the main target in building any PV system. Therefore, this study is focused on developing an accurate and reliable PV model, based on five main parameters; the photocurrent, I_{ph}, the reverse diode saturation current, I_o, the ideality factor of diode, n, the series resistance, R_s, and the shunt resistance, R_{sh}. Performance of these five solar cell parameters (I_{ph}, I_o, n, R_S, R_{sh}) and their effect on both the Current–Voltage (I–V) and Power–Voltage (P–V) characteristic curves, were tested and compared with other models, respectively. Firstly, the photocurrent, I_{ph} effect was studied; the results showed that the increase in the I_{ph} leads to an increase in the maximum power point (MPP) in a prominent way. In addition to this increment in MPP, an increase in the values of I_{sc} and V_{oc} were also observed. With an increase in I_o, a regular increasing mode was observed in MPP, the I_{sc} and V_{oc} values in a similar manner. The value of changing n, showed no effect on I_{sc} and V_{oc} values, but increasing n values lead to a decrease in MPP values in the P–V characteristic curve. The increasing R_s values exhibited a decrease in the value of MPP, while not affecting the the I_{sc} and V_{oc} values, in a smiliar pattern with increasing n values. Finally, the effect of R_{sh} value was also tested; showed a barely noticeable effect on MPP, I_{sc} , and V_{oc} values.

Secondly, a hybrid Ant Colony Optimisation-Particle Swarm Optimisation (ACO-PSO) algorithm was proposed to optimally determine the MPPT parameters. To improve the overall performance of the maximum power point (MPPT) system, the efforts of oscillation filtering and noise suppression were taken in this design, as well as the time response and the settling time. The proposed method is employed to track the global MPP under different shadow conditions, based on three different irradiation levels to test the ability and accuracy of the proposed method. The results of tracking MPP by the proposed MPPT technique showed that the improved method tracked the MPP for all the tested cases with a reasonable accuracy and in a very short convergence time as compared to the P&O method.

Thirdly, to develop a new configuration incorporates ACO-PSO and PID to improve the steady state condition after tracking the MPP. The improved PID controller had contributed in attaining the steady state condition and assuring that there is no oscillation around the MPP. In the comparison with the P&O method, it still has a notable oscillation around the MPP, which results in decreasing the efficiency of the extracted power from the PV system. Moreover, in this study, two 5 kWp PV plants from two different PV technologies (mono-crystalline silicon (c-Si) and copper–indium–diselenide (CIS)) were used to validate the PV model performance based on energy generation, energy efficiency, and the performance ratio. Also, two different models from the literature were used to validate the PV model performance. For all of the validation factors, the energy generated, energy efficiency, and performance ratio of the proposed model showed that it is approximately fitting the real results for both of the CIS and c-Si plants with high level of accuracy than the compared models.

ABSTRAK

Sistem tenaga solar fotovoltaik (PV) memainkan peranan penting dalam bidang penjanaan tenaga bagi dekad yang lalu. Bagi memperoleh kecekapan dan keboleh-percayaan yang tinggi, sistem ini telah dibangunkan untuk memenuhi segala keperluan yang memberi kesan dalam proses penjanaan. Untuk tujuan ini, tesis ini memberi tump-uan kepada isu-isu yang paling penting yang dapat membantu meningkatkan kuasa yang diekstrak. salah satu isu yang penting untuk setiap sistem fv adalah model sel dan modul pv serta ketepatan yang boleh menjadi sasaran utama dalam pembinaan sistem PV. Oleh itu, kajian ini memberi tumpuan dan membina model PV yang tepat dan boleh dipercayai yang terdiri daripada lima parameter iaitu arus foto, I_{ph}, arus tepu diod terbalik, I_o, faktor idealiti diod, n, rintangan siri, R_s, dan rintangan pirau, R_{sh}. Prestasi kelima-lima parameter sel solar (I_{ph}, I_o, n, R_s, R_{sh}) dan kesannya ke atas lengkungan ciri arus-voltan (I-V) dan kuasa-voltan (P-V) telah diuji dan dibandingkan dengan model lain. Pertama sekali, kesan arusfoto, I_{ph} telah dicari di mana keputusan menunjukkan bahawa semakin meningkat $I_{ph,}$ peningkatan kepada titik kuasa maksimum, di samping peningkatan dalam i_{ph} membawa kepada peningkatan kedua-dua I_{sc} dan V_{oc}. Untuk menin-gkatkan I_o yang membawa kepada peningkatan titik kuasa maksimum (MPP) dalam mod biasa, disamping ia dipengaruhi kedua-dua I_{sc} dan V_{oc} dan kadar berat yang sama. Selanjutnya, hasil kesan n menunjukkan bahawa ia tidak memberi kesan sama ada kepada I_{sc} dan V_{oc}. Walaubagaimanapun, keputusan untuk meningkatkan R_s menunjukkan bahawa ia membawa kepada mengurangkan nilai MPP, dan juga tidak menjejaskan I_{sc} dan V_{oc}.

Di samping itu, algoritma pengesan titik kuasa maksimum (MPPT) lebih baik menggunakan pengawal PID yang dioptimumkan dilaksanakan dengan merujuk kepada pengeluaran mekanisme algoritma dan tak ciri-ciri linear konvensional P&O fotovolta sebagai input kepada pengawal PID. Untuk meningkatkan prestasi keseluruhan sistem mppt, usaha penapisan ayunan dan penind-asan bunyi telah diambil dalam reka bentuk ini, serta masa tindak balas dan masa menetap. kaedah yang dicadangkan digunakan untuk mengesan mpp global di bawah keadaan bayang-bayang. Dalam maksud ini, tiga syarat bayangan yang berbeza digunakan untuk menguji keupayaan dan ketepatan kaedah yang dicadangkan. Keputusan mengesan MPP dengan teknik mppt yang dicadangkan menunjukkan bahawa kaedah yang lebih baik dikesan mpp untuk semua kes-kes yang diuji dalam ketepatan yang munasabah dan dengan masa pengenapan yang singkat berbanding dengan kaedah P&O.

Di samping itu, ia adalah titik yang lebih penting bahawa kaedah mppt yang digunakan tidak mempunyai apa-apa ayunan sekitar perbandingan mpp dengan P&O kaedah yang masih mempunyai ayunan ketara di sekitar mpp yang menyokong dalam mengurangkan kecekapan kuasa yang dikeluarkan dari sistem pv. Selain itu, dalam kajian ini, dua loji PV 5 kWp daripada dua teknologi PV yang berbeza (silikon mono-kristal (m-Ki) dan tembaga-indium-diselenide (TID)) telah digunakan untuk mengesahkan prestasi model PV berdasarkan penjanaan tenaga, tenaga kecekapan, dan nisbah prestasi. Untuk semua faktor pengesahan, tenaga yang dihasilkan, kecekapan tenaga, dan nisbah prestasi model yang dicadangkan menunjukkan bahawa ia adalah kira-kira yang menepati keputusan sebenar untuk kedua-dua loji TID m-Ki dengan tahap ketepatan yang tinggi daripada model yang dibandingkan.

REFERENCES

Abdelsalam, A.K., Massoud, A.M., Ahmed, S., and Enjeti, P., (2011). High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids. *Power Electronics, IEEE Transactions on, 26*(4), 1010-1021.

Aberle, A., Wenham, S., & Green, M., 1993. *A new method for accurate measurements of the lumped series resistance of solar cells.* Paper presented at the Photovoltaic Specialists Conference, (1993)., Conference Record of the Twenty Third IEEE.

Ahmed, K,(1994). Renewable energy technologies. *A Review of the Status and Costs of.*

Akbaba, M., and Alattawi, M.A., (1995). A new model for I–V characteristic of solar cell generators and its applications. *Solar energy materials and solar cells, 37*(2), 123-132.

Akkaya, R., and Kulaksiz, A., (2004). A microcontroller-based stand-alone photovoltaic power system for residential appliances. *Applied Energy, 78*(4), 419-431.

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.

Araujo, G.L., and Sanchez, E., (1982). A new method for experimental determination of the series resistance of a solar cell. *Electron Devices, IEEE Transactions on, 29*(10), 1511-1513.

Arcipiani, B., (1985). Generalization of the area method for the determination of the parameters of a non-ideal solar cell. *Revue de physique appliquée, 20*(5), 269-272.

Bazzi, A.M., and Krein, P.T., (2011). Concerning “Maximum Power Point Tracking for photovoltaic optimization using ripple-based Extremum Seeking Control”. *Power Electronics, IEEE Transactions on, 26*(6), 1611-1612.

Bazzi, A.M., and Krein, P.T., (2014). Ripple correlation control: an extremum seeking control perspective for real-time optimization. *Power Electronics, IEEE Transactions on, 29*(2), 988-995.

Besheer, A., and Adly, M., (2012). *Ant colony system based PI maximum power point tracking for stand alone photovoltaic system.* Paper presented at the Industrial Technology (ICIT), 2012 IEEE International Conference on.

Bhatnagar, P., and Nema, R., (2013). Maximum power point tracking control techniques: State-of-the-art in photovoltaic applications. *Renewable and Sustainable Energy Reviews, 23*, 224-241.

Bianconi, E., Calvente, J., Giral, R., Mamarelis, E., Petrone, G., Ramos-Paja, C.A., . . . Vitelli, M., (2013). Perturb and observe MPPT algorithm with a current controller based on the sliding mode. *International Journal of Electrical Power and Energy Systems*, *44*(1), 346-356.

Bowden, S., and Rohatgi, A., (2001). Rapid and accurate determination of series resistance and fill factor losses in industrial silicon solar cells.

Brano, V.L., and Ciulla, G., (2013). An efficient analytical approach for obtaining a five parameters model of photovoltaic modules using only reference data. *Applied Energy*, *111*, 894-903.

Brano, V.L., Orioli, A., Ciulla, G., and Di Gangi, A., (2010). An improved five-parameter model for photovoltaic modules. *Solar Energy Materials and Solar Cells*, *94*(8), 1358-1370.

Bratcu, A.I., Munteanu, I., Bacha, S., Picault, D., and Raison, B., (2011). Cascaded dc–dc converter photovoltaic systems: Power optimization issues. *Industrial Electronics, IEEE Transactions on*, *58*(2), 403-411.

Bube, R., (2012). *Fundamentals of solar cells: photovoltaic solar energy conversion*: Elsevier.

Celik, A.N., and Acikgoz, N., (2007). Modelling and experimental verification of the operating current of mono-crystalline photovoltaic modules using four-and five-parameter models. *Applied energy*, *84*(1), 1-15.

Chan, D., Phillips, J., and Phang, J., (1986). A comparative study of extraction methods for solar cell model parameters. *Solid-State Electronics*, *29*(3), 329-337.

Chan, D.S., and Phang, J.C., (1987). Analytical methods for the extraction of solar-cell single-and double-diode model parameters from IV characteristics. *IEEE Transactions on Electron Devices*, 286-293.

Chegaar, M., Azzouzi, G., and Mialhe, P., (2006). Simple parameter extraction method for illuminated solar cells. *Solid-State Electronics*, *50*(7), 1234-1237.

Cibira, G., and Koščová, M., (2014a). Photovoltaic module parameters acquisition model. *Applied Surface Science*.

Cibira, G., and Koščová, M., (2014b). Photovoltaic module parameters acquisition model. *Applied Surface Science*, *312*, 74-80.

Ciulla, G., Brano, V.L., Di Dio, V., and Cipriani, G., (2014). A comparison of different one-diode models for the representation of I–V characteristic of a PV cell. *Renewable and Sustainable Energy Reviews*, *32*, 684-696.

Coelho, R.F., Concer, F., and Martins, D.C., (2009). *A study of the basic DC-DC converters applied in maximum power point tracking.* Paper presented at the Power Electronics Conference, 2009. COBEP'09. Brazilian.

Cotfas, D., Cotfas, P., and Kaplanis, S., (2013). Methods to determine the dc parameters of solar cells: A critical review. *Renewable and Sustainable Energy Reviews, 28,* 588-596.

Cotfas, D., Cotfas, P., Kaplanis, S., and Ursutiu, D., (2008). Results on series and shunt resistances in a c-Si PV cell. Comparison using existing methods and a new one. *Journal of optoelectronics and advanced materials, 10*(11), 3124-3130.

De Blas, M., Torres, J., Prieto, E., and Garcıa, A., (2002). Selecting a suitable model for characterizing photovoltaic devices. *Renewable energy, 25*(3), 371-380.

De Brito, M.A.G., Galotto Jr, L., Sampaio, L.P., de Azevedo e Melo, G., and Canesin, C.A., (2013). Evaluation of the main MPPT techniques for photovoltaic applications. *Industrial Electronics, IEEE Transactions on, 60*(3), 1156-1167.

Dizqah, A.M., Maheri, A., and Busawon, K., (2014). An accurate method for the PV model identification based on a genetic algorithm and the interior-point method. *Renewable Energy, 72,* 212-222.

Dorofte, C., Borup, U., and Blaabjerg, F., (2005). *A combined two-method MPPT control scheme for grid-connected photovoltaic systems.* Paper presented at the Power electronics and applications, 2005 European conference on.

Drigo, M., Maniezzo, V., and Colorni, A., (1996). The ant system: optimization by a colony of cooperation agents. *IEEE Transactions of Systems, Man, and Cybernetics*(Part B), 29-41.

Duffie, J.A., (2006). William A. Beckman Solar Engineering of Thermal Processes: JOHN WILEY and SONS, INC. NY.

El-Adawi, M., and Al-Nuaim, I., (2001). A method to determine the solar cell series resistance from a single I–V. Characteristic curve considering its shunt resistance—new approach. *Vacuum, 64*(1), 33-36.

El-Dein, M.S., Kazerani, M., and Salama, M., (2013). Optimal photovoltaic array reconfiguration to reduce partial shading losses. *Sustainable Energy, IEEE Transactions on, 4*(1), 145-153.

Elgendy, M., Zahawi, B., and Atkinson, D.J., (2012). Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications. *Sustainable Energy, IEEE Transactions on, 3*(1), 21-33.

Esram, T., Kimball, J.W., Krein, P.T., Chapman, P.L., and Midya, P., (2006). Dynamic maximum power point tracking of photovoltaic arrays using ripple correlation control. *Power Electronics, IEEE Transactions on, 21*(5), 1282-1291.

Essah, E.A., Arguelles, A.R., and Glover, N., (2015). Assessing the performance of a building integrated BP c-Si PV system. *Renewable Energy, 73,* 36-45.

Fang, H., Chen, L., and Shen, Z., (2011). Application of an improved PSO algorithm to optimal tuning of PID gains for water turbine governor. *Energy Conversion and Management, 52*(4), 1763-1770.

Garrido-Alzar, C., (1997). Algorithm for extraction of solar cell parameters from I–V curve using double exponential model. *Renewable Energy, 10*(2), 125-128.

Gong, W., and Cai, Z., (2013). Parameter extraction of solar cell models using repaired adaptive differential evolution. *Solar Energy, 94*, 209-220.

Grätzel, M., (2005). Solar energy conversion by dye-sensitized photovoltaic cells. *Inorganic chemistry, 44*(20), 6841-6851.

Haouari-Merbah, M., Belhamel, M., Tobias, I., and Ruiz, J., (2005). Extraction and analysis of solar cell parameters from the illuminated current–voltage curve. *Solar Energy Materials and Solar Cells, 87*(1), 225-233.

Hohm, D., and Ropp, M.E., (2003). Comparative study of maximum power point tracking algorithms. *Progress in photovoltaics: Research and Applications, 11*(1), 47-62.

Humada, A.M., Hojabri, M., Mekhilef, S., and Hamada, H.M., (2016). Solar cell parameters extraction based on single and double-diode models: A review. *Renewable and Sustainable Energy Reviews, 56*, 494-509.

Ishaque, K., and Salam, Z., (2011a). A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model. *Solar Energy, 85*(9), 2217-2227.

Ishaque, K., and Salam, Z., (2011b). An improved modeling method to determine the model parameters of photovoltaic (PV) modules using differential evolution (DE). *Solar Energy, 85*(9), 2349-2359.

Ishaque, K., and Salam, Z., (2013). A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition. *Renewable and Sustainable Energy Reviews, 19*, 475-488.

Ishaque, K., Salam, Z., Amjad, M., and Mekhilef, S., (2012). An improved Particle Swarm Optimization (PSO)–based MPPT for PV with reduced steady-state oscillation. *Power Electronics, IEEE Transactions on, 27*(8), 3627-3638.

Ismail, M., Moghavvemi, M., and Mahlia, T., (2013a). Characterization of PV panel and global optimization of its model parameters using genetic algorithm. *Energy Conversion and Management, 73*, 10-25.

Ismail, M., Moghavvemi, M., and Mahlia, T., (2013b). Design of an optimized photovoltaic and microturbine hybrid power system for a remote small community: case study of Palestine. *Energy Conversion and Management, 75*, 271-281.

Jensen, H., Lalchand, G., and Mak, G., (2006). Compared assessment of selected environmental indicators of photovoltaic electricity in selected OECD cities and Malaysia cities. *Malaysia: Pusat Tenaga Malaysia*.

Ji, Y.-H., Jung, D.-Y., Kim, J.-G., Kim, J.-H., Lee, T.-W., and Won, C.-Y., (2011). A real maximum power point tracking method for mismatching compensation in PV array under partially shaded conditions. *Power Electronics, IEEE Transactions on, 26*(4), 1001-1009.

Jia, Q., Anderson, W.A., Liu, E., and Zhang, S., (1988). A novel approach for evaluating the series resistance of solar cells. *Solar Cells, 25*(3), 311-318.

Jiang, L.L., Maskell, D.L., and Patra, J.C., (2013). A novel ant colony optimization-based maximum power point tracking for photovoltaic systems under partially shaded conditions. *Energy and Buildings, 58*, 227-236.

Jiang, Y., Qahouq, J., and Orabi, M., (2011). *Matlab/Pspice hybrid simulation modeling of solar PV cell/module.* Paper presented at the Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE.

Johari, A., Hafshar, S.S., Ramli, M., and Hashim, H., (2011). *Potential use of solar photovoltaic in Peninsular Malaysia.* Paper presented at the Clean Energy and Technology (CET), 2011 IEEE First Conference on.

Kadri, R., Andrei, H., Gaubert, J.-P., Ivanovici, T., Champenois, G., and Andrei, P., (2012). Modeling of the photovoltaic cell circuit parameters for optimum connection model and real-time emulator with partial shadow conditions. *Energy, 42*(1), 57-67.

Kaminski, A., Marchand, J., and Laugier, A., (1999). I–V methods to extract junction parameters with special emphasis on low series resistance. *Solid-State Electronics, 43*(4), 741-745.

Kaushika, N., Gautam, N.K., and Kaushik, K., (2005). Simulation model for sizing of stand-alone solar PV system with interconnected array. *Solar Energy Materials and Solar Cells, 85*(4), 499-519.

Keogh, W.M., Blakers, A.W., and Cuevas, A., (2004). Constant voltage I–V curve flash tester for solar cells. *Solar Energy Materials and Solar Cells, 81*(2), 183-196.

Khan, B., (2006). *Non-conventional energy resources*: Tata McGraw-Hill Education.

Khan, F., Baek, S.-H., and Kim, J.H., (2014). Intensity dependency of photovoltaic cell parameters under high illumination conditions: An analysis. *Applied Energy, 133*, 356-362.

Khan, F., Singh, S., and Husain, M., (2010). Effect of illumination intensity on cell parameters of a silicon solar cell. *Solar Energy Materials and Solar Cells, 94*(9), 1473-1476.

Khatib, T., Sopian, K., and Kazem, H.A., (2013). Actual performance and characteristic of a grid connected photovoltaic power system in the tropics: A short term evaluation. *Energy Conversion and Management, 71*, 115-119.

Khezzar, R., Zereg, M., and Khezzar, A., (2014). Modeling improvement of the four parameter model for photovoltaic modules. *Solar Energy, 110*, 452-462.

Khouzam, K., and Hoffman, K., (1996). Real-time simulation of photovoltaic modules. *Solar Energy, 56*(6), 521-526.

Kim, W., and Choi, W., (2010). A novel parameter extraction method for the one-diode solar cell model. *Solar Energy, 84*(6), 1008-1019.

Kimball, J.W., and Krein, P.T., (2008). Discrete-time ripple correlation control for maximum power point tracking. *Power Electronics, IEEE Transactions on, 23*(5), 2353-2362.

Kiran, E., and İnan, D., (1999). Technical note An approximation to solar cell equation for determination of solar cell parameters. *Renewable energy, 17*(2), 235-241.

Kou, Q., Klein, S., and Beckman, W., (1998). A method for estimating the long-term performance of direct-coupled PV pumping systems. *Solar Energy, 64*(1), 33-40.

Kymakis, E., Kalykakis, S., and Papazoglou, T.M., (2009). Performance analysis of a grid connected photovoltaic park on the island of Crete. *Energy Conversion and Management, 50*(3), 433-438.

Lal, M., and Singh, S., (2007). A new method of determination of series and shunt resistances of silicon solar cells. *Solar Energy Materials and Solar Cells, 91*(2), 137-142.

Lasdon, L.S., Waren, A.D., Jain, A., and Ratner, M., (1978). Design and testing of a generalized reduced gradient code for nonlinear programming. *ACM Transactions on Mathematical Software (TOMS), 4*(1), 34-50.

Laudani, A., and Fulginei, F.R., (2014). Comments on "An efficient analytical approach for obtaining a five parameters model of photovoltaic modules using only reference data"(Appl. Energy 111 (2013) 894–903). *Applied Energy*.

Lee, K.S., (2014). Maximum power point tracking method: Google Patents.

Leyva, R., Alonso, C., Queinnec, I., Cid-Pastor, A., Lagrange, D., and Martinez-Salamero, L., (2006). MPPT of photovoltaic systems using extremum-seeking control. *Aerospace and Electronic Systems, IEEE Transactions on, 42*(1), 249-258.

Lin, C.-H., Huang, C.-H., Du, Y.-C., and Chen, J.-L., (2011). Maximum photovoltaic power tracking for the PV array using the fractional-order incremental conductance method. *Applied Energy, 88*(12), 4840-4847.

Lotsch, H., Goetzberger, A., and U. Hoffmann, V., (2005). Efficiency and Performance of PV Systems. *Photovoltaic Solar Energy Generation*, 147-161.

Luo, F.L., and Ye, H., (2007). Small signal analysis of energy factor and mathematical modeling for power dc–dc converters. *Power Electronics, IEEE Transactions on, 22*(1), 69-79.

Macabebe, E.Q.B., Sheppard, C.J., and van Dyk, E.E., (2011). Parameter extraction from I–V characteristics of PV devices. *Solar Energy, 85*(1), 12-18.

Matsuo, H., Shigemizu, T., Kurokawa, F., and Watanabe, N., (1993). *Characteristics of the multiple-input DC-DC converter.* Paper presented at the Power Electronics Specialists Conference, 1993. PESC'93 Record., 24th Annual IEEE.

McEvoy, A., Markvart, T., Castañer, L., Markvart, T., and Castaner, L., (2003). *Practical handbook of photovoltaics: fundamentals and applications*: Elsevier.

Navabi, R., Abedi, S., Hosseinian, S.H., and Pal, R., (2015). On the fast convergence modeling and accurate calculation of PV output energy for operation and planning studies. *Energy Conversion and Management, 89*, 497-506.

Nedumgatt, J.J., Jayakrishnan, K., Umashankar, S., Vijayakumar, D., and Kothari, D., (2011). *Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation.* Paper presented at the India Conference (INDICON), 2011 Annual IEEE.

Ng, K.M., Adam, N.M., Inayatullah, O., and Kadir, M.Z.A.A., (2014). Assessment of solar radiation on diversely oriented surfaces and optimum tilts for solar absorbers in Malaysian tropical latitude. *International Journal of Energy and Environmental Engineering, 5*(1), 1-13.

Nguyen, D.D., and Lehman, B., (2006). *Modeling and simulation of solar PV arrays under changing illumination conditions.* Paper presented at the Computers in Power Electronics, 2006. COMPEL'06. IEEE Workshops on.

Orioli, A., and Di Gangi, A., (2013). A procedure to calculate the five-parameter model of crystalline silicon photovoltaic modules on the basis of the tabular performance data. *Applied Energy, 102*, 1160-1177.

Ortiz-Conde, A., Sánchez, F.J.G., and Muci, J., (2006). New method to extract the model parameters of solar cells from the explicit analytic solutions of their illuminated I–V characteristics. *Solar Energy Materials and Solar Cells, 90*(3), 352-361.

Ortiz-Rivera, E., and Peng, F.Z., (2005). *Analytical model for a photovoltaic module using the electrical characteristics provided by the manufacturer data sheet.* Paper presented at the Power Electronics Specialists Conference, 2005. PESC'05. IEEE 36th.

Ouennoughi, Z., and Chegaar, M., (1999). A simpler method for extracting solar cell parameters using the conductance method. *Solid-State Electronics*, *43*(11), 1985-1988.

Patel, M.R., (2005). *Wind and solar power systems: design, analysis, and operation*: CRC press.

Polman, A., Van Sark, W., Sinke, W., and Saris, F., (1986). A new method for the evaluation of solar cell parameters. *Solar cells, 17*(2), 241-251.

Rajasekar, N., Krishna Kumar, N., and Venugopalan, R., (2013). Bacterial Foraging Algorithm based solar PV parameter estimation. *Solar Energy, 97*, 255-265.

Reisi, A.R., Moradi, M.H., and Jamasb, S., (2013). Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review. *Renewable and Sustainable Energy Reviews, 19*, 433-443.

Rosell, J., and Ibanez, M., (2006). Modelling power output in photovoltaic modules for outdoor operating conditions. *Energy Conversion and Management, 47*(15), 2424-2430.

Safari, A., and Mekhilef, S., (2011). Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter. *Industrial Electronics, IEEE Transactions on, 58*(4), 1154-1161.

Salam, Z., Ahmed, J., and Merugu, B.S., (2013). The application of soft computing methods for MPPT of PV system: A technological and status review. *Applied Energy, 107*, 135-148.

Sera, D., Mathe, L., Kerekes, T., Spataru, S.V., and Teodorescu, R., (2013). On the perturb-and-observe and incremental conductance MPPT methods for PV systems. *Photovoltaics, IEEE Journal of, 3*(3), 1070-1078.

Shi, J., Dong, J., Lv, S., Xu, Y., Zhu, L., Xiao, J., . . . Luo, Y., (2014). Hole-conductor-free perovskite organic lead iodide heterojunction thin-film solar cells: High efficiency and junction property. *Applied Physics Letters, 104*(6), 063901.

Shockley, W., 1953. Electrons and holes in semiconductors.

Shockley, W., and Queisser, H.J., (1961). Detailed balance limit of efficiency of p-n junction solar cells. *Journal of applied physics, 32*(3), 510-519.

Solangi, K., Islam, M., Saidur, R., Rahim, N., and Fayaz, H., (2011). A review on global solar energy policy. *Renewable and sustainable energy reviews, 15*(4), 2149-2163.

Spiazzi, G., Buso, S., and Mattavelli, P., (2009). *Analysis of MPPT algorithms for photovoltaic panels based on ripple correlation techniques in presence of parasitic components.* Paper presented at the Power Electronics Conference, 2009. COBEP'09. Brazilian.

Suryavanshi, R., Joshi, D.R., and Jangamshetti, S.H., (2012). *PSO and PandO based MPPT technique for SPV panel under varying atmospheric conditions.* Paper presented at the Power, Signals, Controls and Computation (EPSCICON), 2012 International Conference on.

Tafticht, T., Agbossou, K., Doumbia, M., and Chériti, A., (2008). An improved maximum power point tracking method for photovoltaic systems. *Renewable energy, 33*(7), 1508-1516.

Tang, J., and Sargent, E.H., (2011). Infrared colloidal quantum dots for photovoltaics: fundamentals and recent progress. *Advanced materials, 23*(1), 12-29.

Tey, K.S., and Mekhilef, S., (2014). Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast-changing solar irradiation level. *Solar Energy, 101*, 333-342.

Tivanov, M., Patryn, A., Drozdov, N., Fedotov, A., and Mazanik, A., (2005). Determination of solar cell parameters from its current–voltage and spectral characteristics. *Solar energy materials and solar cells, 87*(1), 457-465.

Villalva, M.G., and Gazoli, J.R., (2009). Comprehensive approach to modeling and simulation of photovoltaic arrays. *Power Electronics, IEEE Transactions on, 24*(5), 1198-1208.

Wolf, M., and Rauschenbach, H., (1963). Series resistance effects on solar cell measurements. *Advanced energy conversion, 3*(2), 455-479.

Xuesong, Z., Daichun, S., Youjie, M., and Deshu, C., (2010). *The simulation and design for MPPT of PV system Based on Incremental Conductance Method.* Paper presented at the information engineering (ICIE), 2010 WASE international conference on.