

Modeling of Buck Converter Models in MPPT using PID and FLC

Chandani Sharma*, Anamika Jain

Department of Electronics and Communication Engineering, Graphic Era University, Bell Road, Clement Town, Dehradun, India

*Corresponding author, e-mail: chandani19nov@gmail.com

Abstract

PV has become universal for power utility applications in comparison to conventional technologies when it comes to economic competitiveness. As the efficiency of solar PV panel is low, it becomes mandatory to extract maximum power from the PV panel at any given period of time. Maximum Power and efficiency in Photovoltaics can be improved by Maximum Power Point tracking even under distributed temperature and irradiance functions. The paper attempts to compare two different Buck converter models based on predictive control. The two converter models using State space differential equation and direct component in MATLAB/SIMULINK are optimized through PID and FLC to obtain increased gain and desired converter output. A PV system connected with Buck converter using an intelligent controller (FLC) for extracting maximum power at different environmental conditions is proposed and the results are compared with conventional PID controller.

Keywords: PV, Maximum Power Point tracking, Buck converter, MATLAB/SIMULINK, PID, FLC

Copyright © 2015 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

Energy is the foundation stone of human development. Global awareness on saving energy and efficient use of available sources has brought concerns to achieve sustainability. Solar PV energy maintains all life on earth and is an excellent alternative to generate electricity. It is abundant, renewable, free, clean, green and requires less maintenance. Solar Renewable Energy Technology (SRET) has explored immense possibilities towards power grid and process control applications [1]. The sustainability offered by solar powered systems gain importance due to shortage of conventional fuels. Moreover, the environmental and economic impact of conventional fuels is also taken into consideration. Globally more than 1.5 billion people have no access to electricity. Dynamic Control Systems can be made to contribute a large number of electricity generations and by adopting PV technology it can be made more innovative [2].

A large number of PV modules have been employed in standalone and grid electricity generation and distribution systems. A photovoltaic array consisting number of solar cells has non linear voltage-current VI characteristics. This non linearity is converged by determining an operating point or Maximum Power Point (MPP) obtained at Standard Test Conditions (STC) to deliver maximum output from panel. STC locates temperature 25°C and an irradiance of 1000 W/m² on surface of panel. The performance of most promising PV technology needs to be regulated in accordance with MPP. The PV system output is affected by temperature, irradiance and partial shaded conditions. These changes in environmental conditions, limit the efficiency and power output from panel. If the measured output of panel is deviated from desired set point, Maximum Power Point Tracker (MPPT) estimates and monitors MPP.

The design of MPPT system to achieve regulated output is done using voltage converters and controllers for converging MPP even under distributed conditions. By the principle of Maximum power transfer theorem, maximum power is transmitted from source to load when source and load impedance are matched. This impedance mismatch is corrected using an interface termed Voltage Converter. To achieve fast and reliable MPP, Controllers keep a record of converter behavior irrespective of environmental fluctuations. Different types of converters and controllers are available for optimizing PV panel efficiency using MPPT.

Various types of commercially available converters include Buck converter (to reduce or step down panel voltage), Boost converter (to increase or step up voltage across load), Buck-Boost converter (to step up and step down panel output), Cuk Converter (to step up and step down panel output by reversing polarity of voltage), and SEPIC (Single-ended primary-inductor converter) that causes load voltage at output to be higher than, less than, or equal to panel voltage without inversion. Buck converter is a linear regulator and has certain advantages over the above mentioned converters. It is cheap, less complex and easy to implement. It gives higher efficiency and prevents current transient observed as ripples thereby generating less oscillatory output. In the present work, the solar PV model is implemented using Buck converter.

There are various controlling techniques employed in MPP trackers using different controllers. These are classified into Offline or Indirect techniques (based on previous experimented datasets), Direct Sampling and Modulation techniques (operating on real time systems direct samples), Intelligent and Hybrid techniques (based on expert knowledge). From the present work it can be seen that the Fuzzy logic system based intelligent controller gives superior performance over conventional controllers with fast response and no overshoot. Therefore by the help of this developed model, the converter output can be made very close to desired output voltage required for MPP. This model can be used to track the maximum power and thus the efficiency of the system can be increased.

2. PV Panel and Converter Subsystem

PV comprises of solar cells that works on photoelectric effect to convert sunlight into electricity. Solar arrays comprise of large number of solar modules built by solar cells. Solar panel equations [3] are used for PV panel modeling in SIMULINK-MATLAB, these include:

Thermal Voltage Equation	$V_T = k_B T_{OPT} / q$	(1)
Diode Current Equation	$I_D = N_p I_S [e^{(V/N_s) + (I_{RS}/N_s)/N V_T C} - 1]$	(2)
Load Current Equation	$I_L = I_{PH} N_p - I_D - I_{SH}$	(3)
Photocurrent Equation	$I_{PH} = [k_i (T_{OPT} - T_{REF}) + I_{SC}] I_{RR}$	(4)
Shunt Current Equation	$I_{SH} = (I_{RS} + V) / R_{SH}$	(5)
Reverse Saturation Current	$I_S = [I_{RS} (T_{OPT} / T_{REF})^{3 + q^2 E_g / N k_B} * e^{(1/T_{OPT} - 1/T_{REF})}]$	(6)
Reverse Current Equation	$I_{RS} = I_{SC} / [e^{(q V_{OC} / N k_B T_{OPT})} - 1]$	(7)
Output Power	$P = VI$	(8)

The terms used above are given below in Table 1.

Table 1: Different terms used in equations,

V_T	Thermal Voltage	R_{SH}	Shunt Resistance
V	Operating Voltage	R_S	Series Resistance
V_{OC}	Open Circuit Voltage	N	Ideality Factor
I_{PH}	Photocurrent	k_B	Boltzmann constant
I_S	Diode Reverse Saturation Current	k_i	Current Proportionality constant
I_{SC}	Short Circuit Current	q	Electron charge
I	Cell Output Current	N_s	Cells in series
T_{REF}	Reference Operating Temperature	N_p	Cells in parallel.
T_{OPT}	Operating Temperature	G	Irradiance
E_g	Energy Band Gap	C	Cells in Module

The complete solar panel subsystem is shown in Figure 1 [4].

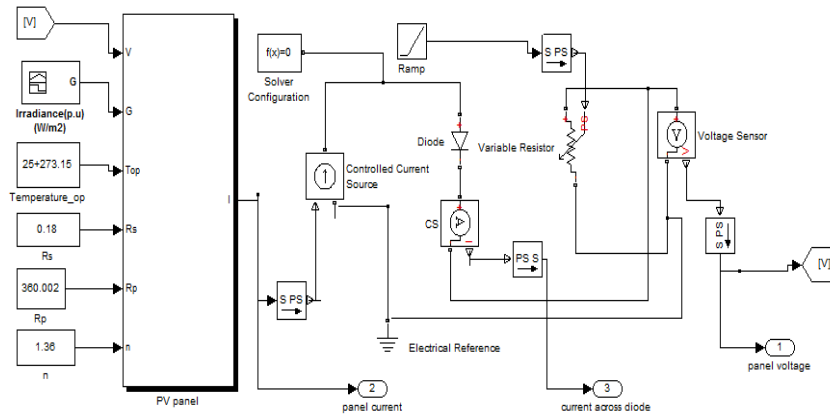


Figure 1 Solar Panel Subsystem

Certain specifications of model are required for installation of panel [5]. These include,

- P_{MPP} : Power at MPP
- I_{MPP} : Current at MPP
- V_{OC} : Open Circuit Voltage
- V_{MPP} : Voltage at MPP
- I_{SC} : Short Circuit Current

Simulation results of subsystem for STC are given in Table 2.

Table 2: Specifications of model,
Characteristics at STC
($G=1KW/m^2$ and $T=25^{\circ}C$)

P_{MPP}	59.39 W
V_{MPP}	16.64 V
I_{MPP}	3.567 A
I_{SC}	3.7981 A
V_{OC}	21.07 V

Due to the change in environment, the temperature changes [6]. The simulation results for varying temperature keeping the irradiance constant $1000W/m^2$ are shown in Table 3.

Table 3: Simout variables for changing Temperature,

T °C	V_{OC}	I_{SC}	V_{MPP}	I_{MPP}	P_{MPP}
5	21.31	3.754	18.06	3.317	59.92
10	21.25	3.765	16.69	3.578	59.75
15	21.19	3.776	16.68	3.575	59.65
20	21.13	3.787	16.66	3.571	59.53
25	21.07	3.798	16.64	3.567	59.39
30	21.01	3.809	16.62	3.563	59.23
35	20.95	3.82	16.6	3.557	59.06
40	20.89	3.831	16.57	3.552	58.87
45	20.83	3.842	16.54	3.545	58.67

As the temperature increases, Open Circuit Voltage (V_{OC}) decreases, whereas the Short Circuit Current (I_{SC}) increases. Moreover, the effect of change in temperature on V_{OC} is more significant in comparison to that on I_{SC} . The model is again simulated using different values of irradiance whereas keeping the temperature constant $25^{\circ}C$ (according to STC).

The simulation results for different irradiance functions (constant, trapezoidal, step) are shown below in Table 4.

Table 4: Simout variable for changing Irradiance,

Irradiance	V_{OC}	I_{SC}	V_{MPP}	I_{MPP}	P_{MPP}
Step	20.41	2.278	16.4	2.109	34.61
Constant (1000W/m ²)	21.07	3.798	16.64	3.567	59.39
Trapezoidal	20.78	3.038	17.12	2.752	47.12

It can be seen from Table 4 that more output is obtained for V_{OC} when the irradiance is constant. But as the irradiance pattern changes i.e. trapezoidal, step, the output decreases.

From the above simulation results (Table 3, Table 4), it is observed that reading of Open circuit voltage V_{OC} and Short circuit current I_{SC} are more sensitive to irradiance variations as compared to temperature. For STC, estimating minimum deflection and maximum efficiency the MPP is obtained at 16.64V. The change observed is given by Dynamic Impedance [3] of source given by expression (9),

$$\frac{dV}{dI} = -\frac{V}{I} \quad (9)$$

To monitor MPP in distributed conditions, a tracker is required that permanently adjusts MPP even under variable temperature and irradiance [7]. However, application specific systems require impedance matching and output voltage to be modified accordingly, for which a Converter is inserted as an interface. Figure 2 shows block diagram of MPPT circuit [8].

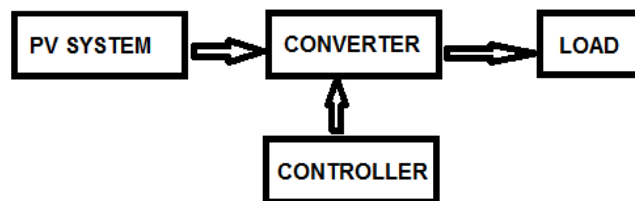


Figure 2 MPPT Tracker circuit

A converter is a power electronic device used to convert one form of voltage to other. Different converters are available [9]-[16] such as,

Buck converter	:	Step down voltage
Boost converter	:	Step up voltage
Buck Boost converter	:	Step up-down voltage
Cuk converter	:	Step up-down with reverse polarity
SEPIC	:	Step up-down or output equal to input

In the present work, Buck converter (shown in Figure 3) is used to decrease the voltage at the output to the desired level.

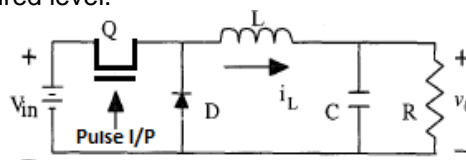


Figure 3 Basic circuit of Buck converter

Buck Converters provide advantages of inrush current and short circuit protection. Moreover, they are easier to design and implement as compared to other converters. Buck converter uses diode, inductor, capacitor, load resistor and MOSFET that acts as a switch. Its ON-OFF switching operation is controlled by controller. The control system monitors the desired

output voltage to be delivered across the load. The set point of the controller is fixed according to the specific application and thus the output of converter is obtained accordingly. If the triggering by controller on gate terminal of MOSFET gives positive threshold voltage, MOSFET is turned ON and results in drain current flow, else it appears in cut-off state.

The above model is tested with and without controller. When the controller is not used the output is not appropriate, as the MOSFET is not triggered and works as an open switch. When the controller is used (either PID or FLC) the gate of the MOSFET receives a positive threshold voltage and is turned ON. In the present work, two different models are developed using controller, one using PID and the other using FLC. These models can be operated using state space differential equation or direct available components in Simulink.

State space model is developed using equations (10) and (11) followed by diagram in Figure 4.

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}(V_{in} - v_o) \\ \frac{dv_o}{dt} = \frac{1}{C}(i_L - \frac{v_o}{R}) \end{cases}, \quad 0 < t < dT, \quad Q: ON \tag{10}$$

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}(-v_o) \\ \frac{dv_o}{dt} = \frac{1}{C}(i_L - \frac{v_o}{R}) \end{cases}, \quad dT < t < T, \quad Q: OFF \tag{11}$$

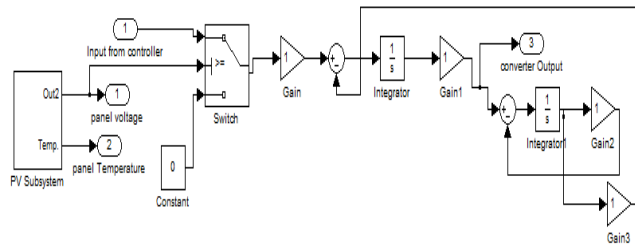


Figure 4 Buck Converter using state space variables

The results so obtained are compared with direct component model. The direct component model shown in Figure 5 was simulated for different values of R, L and C and the optimum values of three components were selected. The values are taken as L=20mH, C=0.3µF and R_L=50Ω.

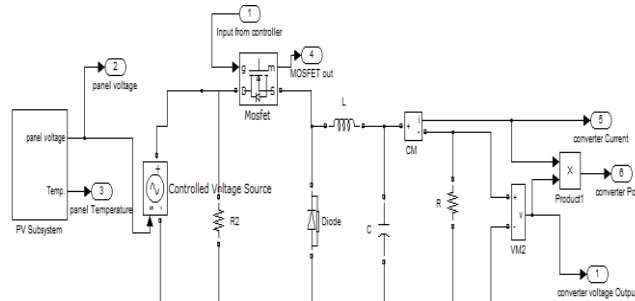


Figure 5 Buck Converter using direct components

When the above models are simulated without controller, the results were not satisfactory since the condition maintained is similar to OFF state. Thus a controller is required in circuit so that control signal from controller turns the circuit ON. A comparison of these two

models (State space model and direct component model) is presented using conventional (PID) and intelligent (FLC) controllers.

3. PID Controller

PID (Proportional Integral Derivative) Controller is earliest controller used to evaluate error based on P (present), I (past) and D (future) rates of output [17].

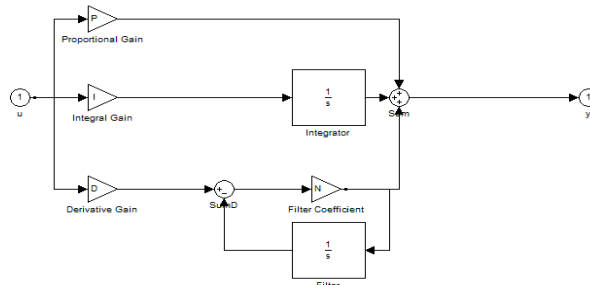


Figure 6 PID Controller

$$U(t) = K_P \cdot e(t) + K_I \int e(t) dt + K_D \dot{e}(t) \quad (12)$$

Where, $U(t)$: Control signal, $e(t)$: tracking error, K_P : Proportional gain, K_I : Integral gain, K_D Derivative gain.

Figure 7 shows the Block diagram of PID control system for Buck converter.

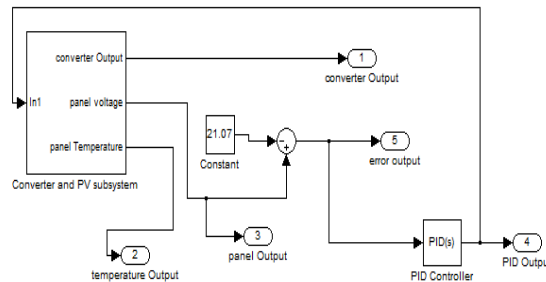


Figure 7 PID control system for Buck converter

This controller is simulated for State space model as well as direct component model using Figure 5 and Figure 6 respectively. The simulation results for the same using PID controller and without controller are shown in Table 5.

Table 5: PID simulation for two models at different temperatures,

T °C	V _{oc} desired	Without controller		With PID	
		converter output	State space equations	Direct components	
5	21.31	0.01065	0.8738	3.928	
10	21.25	0.01062	0.8738	7.628	
15	21.19	0.01059	0.8738	9.329	
20	21.13	0.01056	0.8738	12.66	
25	21.07	0.01053	0.8738	17.42	
30	21.01	0.0105	0.8738	21.15	
35	20.95	0.01047	0.8738	0.01063	
40	20.89	0.01044	0.8738	0.01073	
45	20.83	0.01041	0.8738	0.01083	

From Table 5, it is clear that the output of direct component is closer to the desired output in comparison to the other two outputs. Moreover, direct components model gives better response over state space model therefore we used direct components model.

4. FUZZY LOGIC CONTROLLER

Contrary to conventional, intelligent controllers use artificial intelligence. Intelligent systems emulate characteristics of human intelligence being adaptive, planning uncertainty and dynamic controlling [18]. A fuzzy controller is a fuzzy system, which is used to control a target system using supervisory control. The fuzzy controller has a linguistic interpretation which can be expressed with the help of fuzzy sets, membership functions, and fuzzy rules. Design of the fuzzy controller means selection of fuzzy rule base structure, including the number of fuzzy sets for each input and output [19]-[28].

A two-input single-output fuzzy logic controller is designed with the input variables error (E) and change in error (ΔE) equation (13) and (14) scaled for output voltage with changing parameters temperature and irradiance. The output variable Duty Cycle (D) of the converter is given by equation (15).

$$E(n) = \frac{P(n) - P(n-1)}{I(n) - I(n-1)} \tag{13}$$

$$\Delta E(n) = E(n) - E(n-1) \tag{14}$$

$$D = \frac{V_{out}}{V_{in}} \tag{15}$$

It is certain that Duty cycle must be minimum for Buck converter as it steps down the output. Duty cycle obtained for FLC is 0.978 as compared to PID which gave 0.998. Table 6 describes the formulated rules.

Table 6: Fuzzy Rules,

ΔE \ E	NB	NS	Z	PS	PB
NB	Z	Z	NB	NB	NB
NS	Z	Z	NS	NS	NS
Z	NS	Z	Z	Z	PS
PS	PS	PS	PS	Z	Z
PB	PB	PB	PB	Z	Z

For different rules, Defuzzification method gives a quantitative summary. The Defuzzification method used is the centroid method given by equation (16).

$$D = \frac{\sum_{j=1}^n \mu(D_j) \cdot D_j}{\sum_{j=1}^n \mu(D_j)} \tag{16}$$

Where D is the defuzzified value, Union of the membership functions is found by the MAX aggregation method and μ (Dj) is the degree of the membership function. The block diagram of FLC control system with Buck converter is shown in Figure 8.

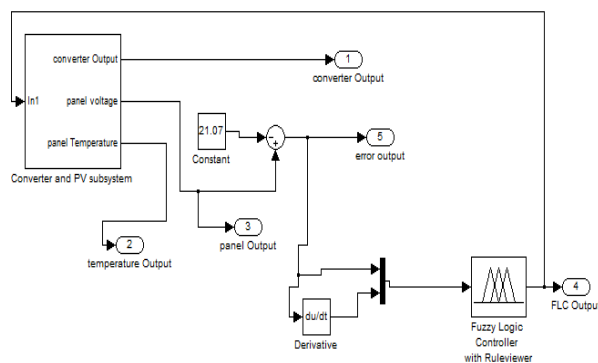


Figure 8 FLC control system for Buck converter

Similar to PID, above model is tested using state space and direct component Buck converter models. The various parameters of FLC system are given below,

Error input : [-0.24, +0.06]
 Change in error : [-0.5, +0.5]
 Output Duty cycle : [21, 21.4]

The entire process of Implication, Aggregation and Defuzzification [29]-[30] of the system is shown in the Rule viewer (Figure 9) and Surface viewer (Figure 10) windows of Fuzzy Logic Toolbox.

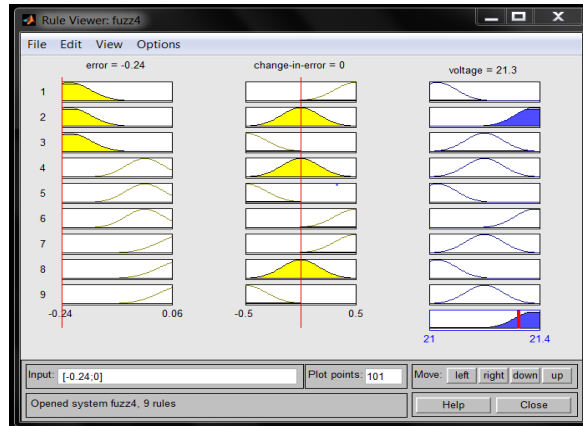


Figure 9 Fuzzy Rule viewer

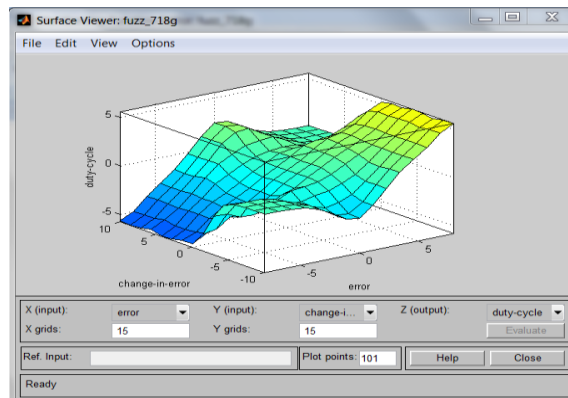


Figure 10 Fuzzy Surface viewer

Table 7 shows simulation results for FLC model for various values of temperature.

Table 7: Results for FLC model,

T °C	V _{oc}	Without controller			With FLC	
		desired	converter output	State space equations	Direct components	
5	21.31		0.01065	7.243		21.27
10	21.25		0.01062	7.223		21.25
15	21.19		0.01059	7.204		21.2
20	21.13		0.01056	7.184		21.14
25	21.07		0.01053	7.164		21.08
30	21.01		0.0105	7.143		21.02
35	20.95		0.01047	7.122		20.96
40	20.89		0.01044	7.101		20.9
45	20.83		0.01041	7.08		20.83

Again it can be seen from Table 7 that direct component model gives a superior output in comparison to state space model. Hence, direct component model is better.

If we compare the results of direct component model for PID and FLC (as shown in Table 8) it clearly indicates that FLC output is much closer to the desired output in comparison to the PID controller output.

Table 8: PID and FLC comparative study for fixed component Buck converter model at different temperatures

T °C	V _{oc} desired	With Controller Direct components model	
		PID	FLC
5	21.31	3.928	21.27
10	21.25	7.628	21.25
15	21.19	9.329	21.20
20	21.13	12.66	21.14
25	21.07	17.42	21.06
30	21.01	21.15	21.02
35	20.95	0.01063	20.96
40	20.89	0.01073	20.9
45	20.83	0.01083	20.83

Therefore it can be concluded that an FLC system can efficiently track the MPP irrespective of the environmental fluctuations [31]-[34].

5. Results and Analysis

The system has been simulated for two converter subsystems using state space and direct components model. An analysis is carried out using open loop (without controller) and closed loop based on variable parameters i.e. temperature and irradiance using PID and FLC.

The simulation results obtained after implementing Fuzzy Logic Controller gives optimized results for chosen membership functions. The oscillatory behavior observed at the output of the converter for varying temperature conditions is stabilized using FLC while in case of PID the oscillations are minimized but the desired output is not achieved. The similar type of work was done by S. Sathyamoorthi [29]. The experiment results were obtained using FLC only and desired results came out 19.3V over 20V set point for 100W solar panel. In the present paper, the results of FLC and PID models are compared for varying environmental conditions. A large steady state error is observed in case of PID 3.65 at STC (21.07-17.42) while the steady state error is reduced to 0.01 at STC (21.07-21.06) when it is implemented using FLC. Thus, it can be concluded that the intelligent system gives superior performance in comparison to conventional PID controller and hence it can be implemented for various snapshots of PV utilization marked by vast research potential for big projects in electricity generation and distribution.

References

- [1] Technology Roadmap: Solar Photovoltaic Energy Report International Energy Agency, 2014.
- [2] Energy Statistics Report, Central Statistics Office, National Statistical Organization, Ministry of Statistics and Programme Implementation, Government Of India, March 2014.
- [3] Chandani Sharma and Anamika Jain, "Solar Panel Mathematical Modelling using Simulink" in International Journal of Engineering Research and Applications, May 2014, Vol. 4, Issue 5, version 4, pp 67-72.

- [4] Chandani Sharma and Anamika Jain, "Simulink based Multivariable Solar Panel Modelling" in *Telkominika Indonesian Journal of Electrical Engineering*, August 2014, Vol. 12, Issue 8, pp 5784-5792.
- [5] Tarak Salmi, Mounir Bouzguenda, Adel Gastli and Ahmed Masmoudi, "MATLAB/Simulink Based Modelling Of Solar Photovoltaic Cell", *International Journal of Renewable Energy Research*, February 2012, Vol.2, Issue 2.
- [6] Huiying Zheng, Shuhui Li, Rajab Chaloo and Julio Proano, "Shading and bypass diode impacts to energy extraction of PV arrays under different converter configurations", *Renewable Energy*, August 2014, Vol. 68, pp. 58-66.
- [7] V. Salas, E. Oli's, A. Barrado and A. Lazaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems," *Solar Energy Materials & Solar Cells*, 2006, Vol. 90, pp 1555-1578.
- [8] N. Pongratananukul, "Analysis and Simulation Tools for Solar Array Power Systems," Ph.D. dissertation, Dept. Electrical and Computer Engineering, Univ. Central Florida, Orlando, 2005.
- [9] Mummadi Veerachary, Tomonobu Senjyu and Katsumi Uezato, "Neural-Network-Based Maximum-Power-Point Tracking of Coupled-Inductor Interleaved-Boost-Converter-Supplied PV System Using Fuzzy Controller" *IEEE Transactions on Industrial Electronics*, August 2003, Vol. 50, no. 4.
- [10] C. Hua and C. Shen, "Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system", in *Proceedings of Power Electronics Specialist Conference, Japan*, May 17–22, 1998.
- [11] T. T. N. Khatib, A. Mohamed, N. Amin and K. Sopian, "An efficient maximum power point tracking controller for photovoltaic systems using new boost converter design and improved control algorithm," *WSEAS Transactions on. Power Systems*, April 2010, Vol. 5, no. 2, pp. 53–63.
- [12] Li. Shuhui, Haskew, Li Dawen and Fei Hu, "Integrating photovoltaic and power converter characteristics for energy extraction study of solar PV systems" *Renewable Energy*, Dec 2011, Vol. 36, Issue 12, pp. 3238-3245.
- [13] Swathy C.S., C Agees Kumar and R. Manju, "Maximum Power Point Tracking of Photovoltaic system using Intelligent Controller" *International Journal of Engineering and Technology*, Vol. 5, No. 2, Apr-May 2013.
- [14] Rosa. A Mastromauro, Marco Liserre and Antonio Dell Aquila, "Control Issues in Single-Stage Photovoltaic Systems MPPT, Current and Voltage Control" *IEEE Transactions on Industrial Informatics*, May 2012, Vol. 8, no. 2.
- [15] M. A. S. Masoum, H. Dehbonei and E. F. Fuchs, "Theoretical and experimental analyses of photovoltaic systems with voltage and current based maximum power point tracking," *IEEE Transactions on Energy Conversion*, December 2012, Vol. 17, no. 4, pp. 514–522.
- [16] B. Subudhi and R. Pradhan, "Characteristics evaluation and parameter extraction of a solar array based on experimental analysis," *Proceedings of 9th IEEE Power Electronics and Drives Systems*, Singapore, December 5–8, 2011.
- [17] Anastasios I. Dounis, Panagiotis Kofinas, Constantine Alafodimos, Dimitrios Tseles "Adaptive fuzzy gain scheduling PID controller for maximum power point tracking of photovoltaic system" *Renewable Energy*, December 2013, Volume 60, Pages 202–214.
- [18] Zadeh. L.A, *Fuzzy sets, Information and Control*, Vol. 8, pp. 338-353. 1965.
- [19] M. A. Usta, O. Akyaszi and I.H. Atlas, "Design and performance of solar tracking system with fuzzy logic Controller", *Sixth International Advanced Technologies Symposium (IATS'11)*, Elazig, Turkey, May16-18, 2011.
- [20] A. Louchene, A. Benmakhlouf and A. Chaghi, " A. Benmakhlouf and A. Chaghi "Solar Tracking system with fuzzy reasoning applied to crisp sets" *Revue des Energies Reneouvelables*, June 2007, Vol. 10 no. 2, pp. 231-240.
- [21] A. Mathew and A. I. Selvakumar, "New MPPT for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive network," *IEEE Transactions on Energy Conversion*, September 2006, Vol. 21, no. 3, pp. 793–803.
- [22] Y. Chen, K. Smedley, F. Vacher and J. Brouwer, "A new maximum power point tracking controller", *Proceedings of 18th Annual IEEE Conference on Applied Power Electronics*, Florida, February 2003.
- [23] C. Liu, B.Wu and R. Cheung, "Advanced algorithm for MPPT control of photovoltaic systems", *Proceedings of Canadian Solar Buildings Conference*, Montreal, Canada, August 20–24, 2004.
- [24] Balasubramanian and S. Singaravelu, "Fuzzy logic controller for the maximum power point tracking in photovoltaic system," *International Journal of Computer Applications*, March 2012, Vol. 41, no.12.
- [25] Yeong-Chau Kuo, Tseng-Jun Liang, and Jiang-Fuh Chen, "Novel Maximum-Power-Point-Tracking Controller for Photovoltaic Energy Conversion System," *IEEE Transactions on Industrial Electronics*, June 2001, Vol. 48, No. 3.

- [26] Wang Fei, "The Research and Application of MPPT Technology Based on Combination of Incremental Conductance and Fuzzy Control," *International Journal of Control and Automation* Vol.8, No.5, 2015, pp: 91-98.
- [27] Jaw-Kuen Shiau, Yu-Chen Wei and Min-Yi Lee, "Fuzzy Controller for a Voltage-Regulated Solar-Powered MPPT System for Hybrid Power System Applications," *Energies*, Vol.8, No. 5, 2015, pp: 3292-3312.
- [28] Ravi Bathula, D. Bala Gangi Reddy and P. Nageswara Rao, "Power Quality Improvement by Mppt Photovoltaic System Using Fuzzy Logic Technique Based APF," *International Journal of Advanced Technology and Innovative Research*, Vol. 7, No. 6, 2015, pp: 906-911.
- [29] Mamdani E. H, Application of fuzzy algorithms for the control of a dynamic plant, *Proceedings of IEEE*, 1974, Vol 121, pp. 1585-1588.
- [30] Mounir Derri, Mostafa Bouzi, Ismail Lagrat and Youssef Babaet, "Maximum Power Point Tracking using Fuzzy Logic Controller for stand-alone photovoltaic system," *International Journal of Engineering Research and Technology*, November 2014, Vol. 3, Issue 11.
- [31] R. Arulmurugan, N. Suthanthira Vanitha, "Fuzzy Logic Controller with Maximum Power Point Tracking using Creative Design of DC to DC Buck Converter for Photovoltaic Power System," *Proceedings of International Conference on Advances in Control System and Electricals Engineering*, 2013.
- [32] S. Sathyamoorthi, Rolga Roy, "Implementation of MPPT Tracking Dc-Dc Converter Using PSO With Fuzzy for the Control of Inverter Fed Induction Motor," *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 3, Issue 4, April 2014.
- [33] Chandani Sharma, Anamika Jain, "Performance Comparison of PID and Fuzzy Controllers in Distributed MPPT," *International Journal of Power Electronics and Drive Systems*, Vol. 6, Issue 3, September 2015.
- [34] Chandani Sharma, Anamika Jain, "Distributed MPP Tracking of PV through Buck Converter Using Fuzzy," *Telkominika Indonesian Journal of Electrical Engineering*, Vol. 15, Issue 2, August 2015, pp: 197-208.