ISSN: 2456-6616 (Online)

Dynamic Modeling and Control of PV Panel using Buck Converter Models

Chandani Sharma[1], Anamika Jain[2]
[1]Assistant Professor, Dept. of ECE, Graphic Era University, Dehradun, Uttrakhand, India
[2]Professor, Dept. of ECE, Graphic Era University, Dehradun, Uttrakhand, India
[1]chandani19nov@gmail.com, [2]anamikajain2829@gmail.com

Abstract:
In this paper, the method to increase PV power output and obtain improved MPP (Maximum Power Point) with changing temperature and irradiance have been mapped and discussed. In order to achieve this, the components and subsystems have been analyzed and validated. The validated models are then used to maximize the power output of the conversion system. Solarex MS-60W panel is modeled using solar cell equations in MATLAB/SIMULINK environment. To obtain stable voltage output, two different models of DC/DC Converters are supplemented. Closed loop buck converter using state space nonlinear differential equations and MATLAB/SIMULINK direct component model are compared to reveal best results. A comparison is formulated for models and advantages of Fuzzy Logic Controller showing better performance and optimization in MPP determination using chosen membership functions is highlighted.

Keywords: Photovoltaics, Sustainability, Buck converter, Solarex MS-60W, MATLAB/SIMULINK Fuzzy Logic Controller.

1. Introduction

Solar is an upcoming futuristic sustainable technology that has expanded tremendously and appears to be largest contributor in Green technology applications nowadays. With thrust on implementing solar power systems in recent years, Maximum Power Point Tracking systems are being designed and implemented. MPPT systems deliver maximum power output under all varying conditions of temperature and irradiance. It corresponds to a well-tuned system that maintains STC (standard test conditions). STC include temperature of 25 °C (298.15K) and an irradiance of 1000 W/m^2. However, by fluctuations in temperature and irradiance due to environment changes output is distorted. Thus, to effectively monitor process control applications, balanced output using STC are framed through a controller.

Succeeding session describes PV model as per datasheet of Solarex MS-60W developed in Matlab using Simulink. Further it is simulated for constant as well varying temperature and irradiance conditions. The output against connected load delivers maximum output at STC but direct connection of load with panel load makes system expensive. It appears to be highly non adaptive for instant changes and time consuming. Thus, Converter specifically Buck converter is used in between panel and load as it is easy to design. The nonlinear characteristic output from solar cell requires a controller to work appropriately for fluctuating conditions. For this, Fuzzy Logic Controller is supplemented to give robust output and fixed set point as per STC.

2. Solar Cell Panel Modeling

Fig.1 gives dc equivalent model of solar cell. It is designed in MATLAB (Simulink) by modeling solar cell equations. The simulated model appears as Fig. 2.

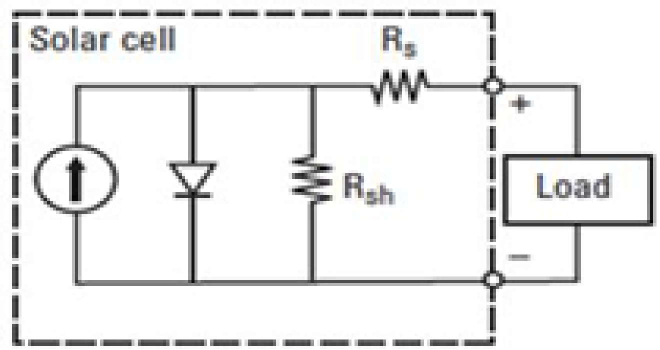

Fig. 1. Solar Cell DC equivalent model

Solar panel modeled is designed in accordance with specifications of Solarex MS-60W available. Table 1 gives a comparison of datasheet and modeled panel.

Table 1: Specifications compared for Solarex and model

Characteristic	**Specifications for G=1KW/m^2 25°C**	
	Solarex MS-60W	*Our Model*
PMPP	60 W	59.39 W
VMP	17.1 V	16.64 V
IMP	3.5 A	3.567 A
ISC	3.8 A	3.7981 A
VOC	21.1 V	21.07 V

Fig. 2 subsystem shown is simulated and results for modeled structure of Solarex MS-60W appears as indicated in Table 2 and 3.

ISSN: 2456-6616 (Online)

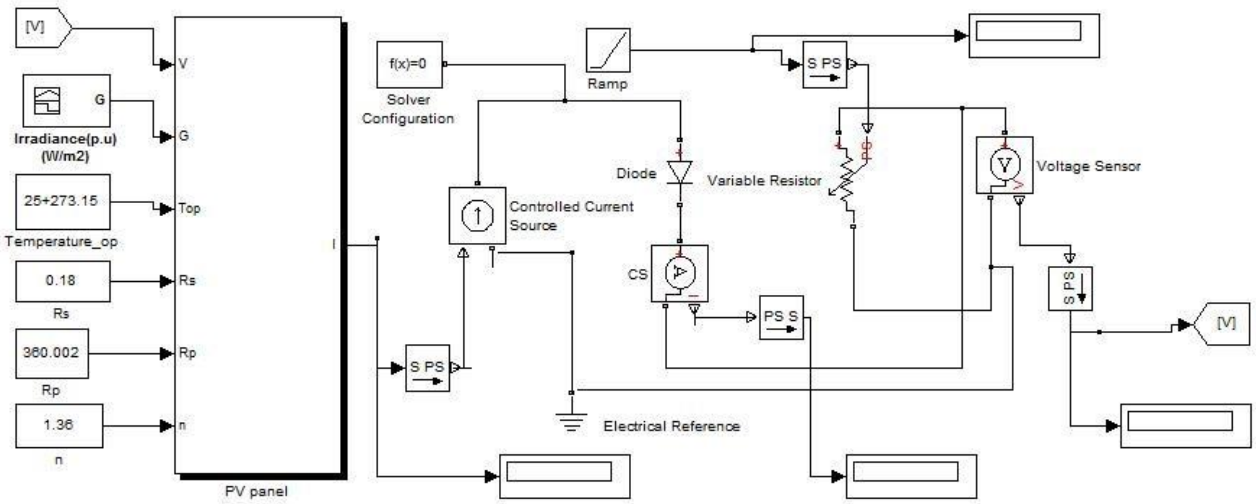

Fig. 2. Solar Panel Subsystem

Table 2: Simout variables for Solarex MS-60W panel

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

Table 3: Simout variable G for Solarex MS-60W panel

G	VOC	ISC	VMPP	IMPP	PMPP
Step	20.4	2.28	16.4	2.109	34.61
Constant	21.1	3.8	16.64	3.567	59.39
Trapezoidal	20.8	3.04	17.12	2.752	47.12

The experiment summarizes that irradiance cause higher change in I-V and P-V Characteristics in comparison to variable temperature. The two parameters of solar cell i.e. Open circuit voltage V_{OC} and Short circuit current I_{SC} effect MPP which can be seen from results in Table 2 and 3. V_{OC} decreases sharply with increase in I_{SC} with increase in temperature thereby resulting decrease in power output. Similar results are observed for change in irradiance also. Thus, to maintain STC at all points MPP needs to be tracked and output voltage required at STC needs to be converted for all conditions.

3. Maximum Power Point Determination using Buck Converter

The converter outputs can be monitored for STC through MPP Tracker circuit. The block diagram of same is given in Fig. 3.

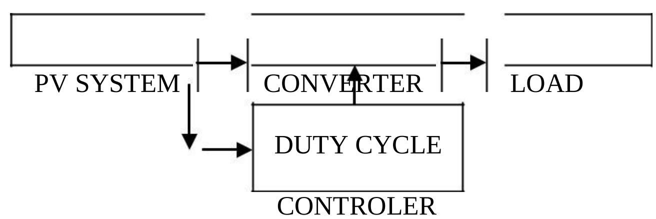

Fig. 3. Blocks used in MPP Tracker circuit

As concerns the different blocks used in tracker, PV output power gets reduced with changes in temperature and irradiance. The compensation of same is made by use of Converters. Buck converter being simplest in design and providing prevention of sudden short circuit is used to “buck up” or “decrease” output from PV panel.

It utilizes four main components including BJT (operating as a switch), diode, inductor and filter capacitor at output followed by Load. Pulse input is applied at gate of BJT to switch Converter ON and OFF. On the basis of switching Duty cycle, converter operating frequency is determined, and output voltage is stabilized. Buck converter is shown in Fig. 4.

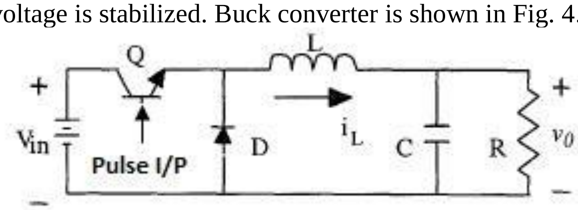

Fig. 4. Basic circuit of Buck converter

Two different Buck converter models are simulated, and experiments are performed for variable temperature and irradiance. These are mentioned below.

Model-A

Model A is designed using State space equations. Instead of applying KCL for circuit simplification, ON or OFF condition is considered taking ideal semiconductor devices. This means zero ON voltages, zero OFF currents and zero switching times. However, for total simulation time T, Duty cycle D is calculated. D refers to ratio of time for which circuit operates in ON condition to total time.

State space equations use binary values of inductor and capacitor. MOSFET is categorized as ON and OFF based on operational input pulse at gate given by Controller or a Frequency Generator. MOSFET in ON condition gives inductor current $i_L(t)$ and the capacitor voltage $v_C(t)$ as,

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

and in OFF condition appears as,

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}(-v_o) \\ \frac{dv_o}{dt} = \frac{1}{C}(i_L - \frac{v_o}{R}) \end{cases}, \quad dT < t < T, \; Q: OFF \quad (2)$$

Above equations in Simulink are modeled as in Fig. 5.

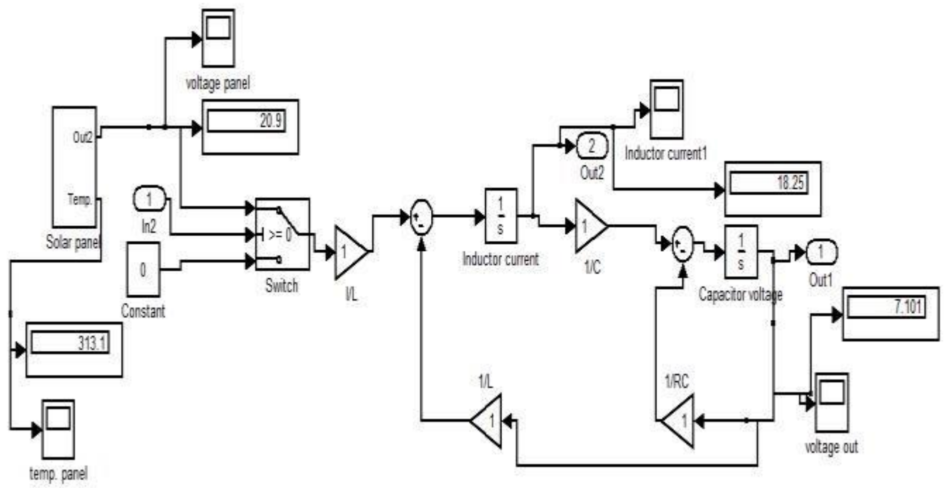

Fig. 5. Buck Converter using state space variables

Model-B

Model B uses direct components to determine output instead of ON and OFF variables. SIMULINK components are directly used with trigger pulses at Gate input of MOSFET. Fig. 6 shows uncontrolled Pulse Generator or frequency generator at Gate input.

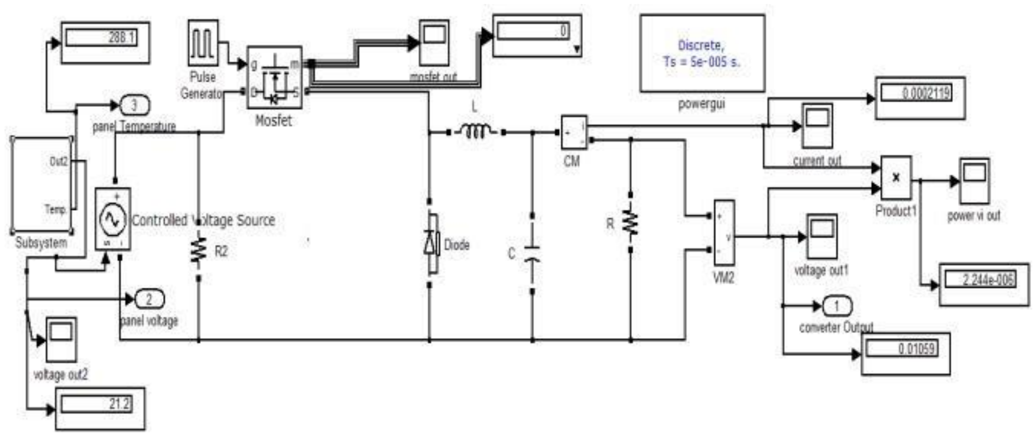

Fig. 6. Buck Converter using Pulse Generator

Experiments highlight that uncontrolled pulse Generator does not initiate current in inductor and output across load. Thus, Controller needs to be introduced in circuit to obtain appropriate output.

Comparison of Model-A and Model-B

Based on models discussed above, comparison is framed prior to outputs obtained across Converter A and B for uncontrolled pulse generator trigger at Gate. Table 4 summarizes the outputs for changeable temperature at constant irradiance.

Table 4: Converter outputs for variable Temperature

T °C	VOC STC	V CONVA	V CONVB
5	21.31	.01065	.01079
10	21.25	.01062	.01076
15	21.19	.01059	.01073
20	21.13	.01056	.01070
25	21.07	.01053	.01067
30	21.01	.01050	.01064
35	20.95	.01047	.01060
40	20.89	.01044	.01056
45	20.83	.01041	.01051

Since the outputs are too small to be used as outputs across load, an ordinary pulse generator cannot be used as an input pulse to converter. A comparison was directed for different irradiance functions changing to Step and Trapezoidal. No change was observed with outputs mentioned in Table 5.

Table 5: Converter outputs for variable Irradiance

Panel	V CONVA		V CONVB	
T °C	Step	Trapezoidal	Step	Trapezoidal
5	0.01061	0.01063	0.01075	0.01077
10	0.01058	0.01060	0.01076	0.01078
15	0.01055	0.01057	0.01078	0.0108
20	0.01052	0.01054	0.01082	0.01084
25	0.01049	0.01051	0.01088	0.0109
30	0.01046	0.01048	0.01094	0.01096
35	0.01143	0.01145	0.01100	0.01102
40	0.0114	0.01142	0.01106	0.01108
45	0.01137	0.01139	0.01112	0.01114

.

It is analyzed from readings that pulse input to converter needs to be controlled through Controller to generate desired outputs.

4. Fuzzy Logic Controller for Stabilization

Controller establishes set of control functions required to make appropriate adjustments in voltage output across panel using Converter. Conventional controllers being inaccurate and linear are replaced by Fuzzy Logic Controllers. The Fuzzy logic controller designed here, is used to adjust the converter output voltage by adjusting duty cycle through variation of the gate voltage. Practically, panel sensors are incorporated at the end to measure the online variations in temperature and irradiance. The basic block diagram using Controller, PV and Converter subsystem is given in Fig. 7.

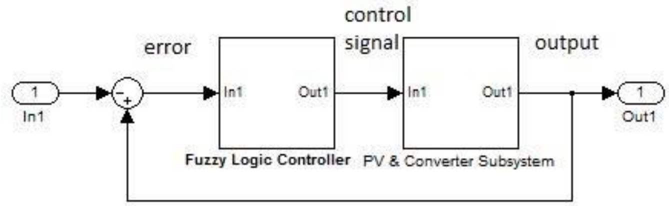

Fig. 7. Block diagram of Controller with PV and converter subsystem

A fuzzy system is a knowledge-based system which utilizes fuzzy if-then rules and fuzzy logic in order to obtain the output of the system. There are certain advantages of using Fuzzy controllers. They give better output, faster response by monitoring variations and easy tuning. The different processes in obtaining controlled outputs from FLC are represented in Fig. 8.

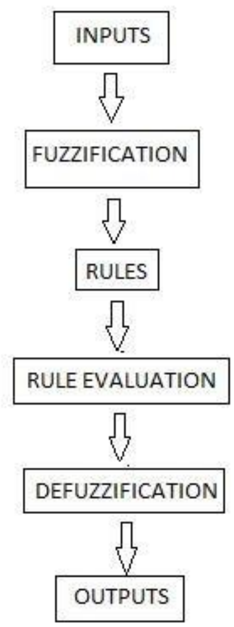

Fig. 8. Processes used in FLC

Presently a two-input single-output fuzzy logic controller is designed with the input variables as: the error (E) and change in error (CE) given by equations 3 and 4.

$$E(n) = \frac{P(n) - P(n-1)}{I(n) - I(n-1)} \quad (3)$$

$$CE(n) = E(n) - E(n-1) \quad (4)$$

The output variable is Duty Cycle of the converter (D) which specifies a ratio for input and output voltage.

$$D = V_{OUT}/V_{IN} \quad (5)$$

The input variables in a fuzzy control system are mapped into sets of membership functions termed "fuzzy sets". The process, of converting a crisp input value to a fuzzy value, is called "fuzzification". The input-output variables used, are shown in Fig. 9.

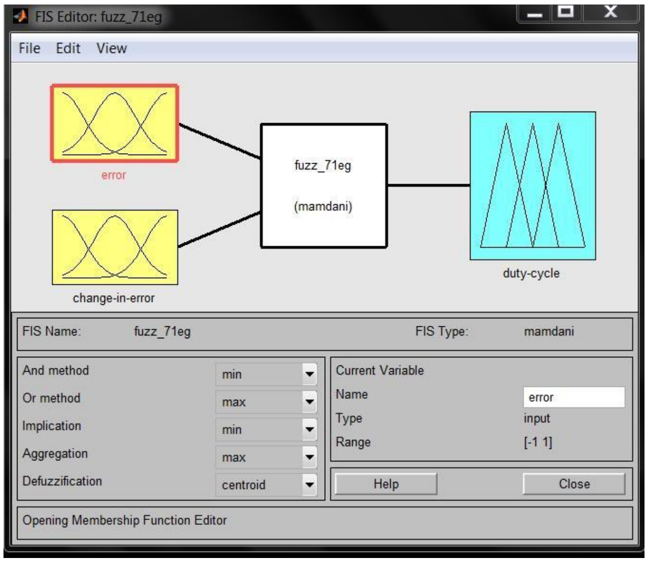

Fig. 9 Fuzzy Logic Controller with membership functions

Gaussian membership functions with 50% overlapping shown in Fig. 10 are taken as membership functions.

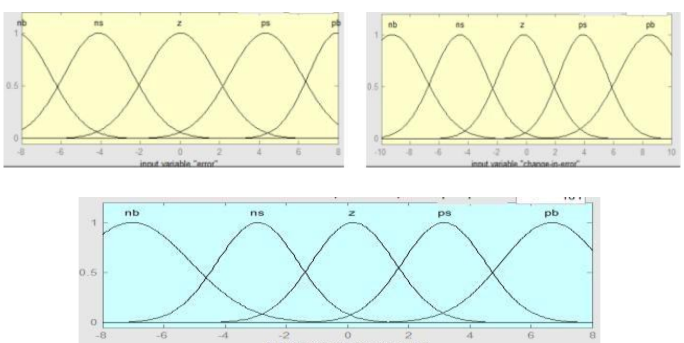

Fig. 10. Fuzzy Membership Functions

The Fuzzy Logic is a rule-based systems and deals with situations using set of rules. A Fuzzy IF-THEN rule is a knowledge representation scheme for capturing knowledge (typically human knowledge) that is imprecise and inexact in nature. This can be achieved by using linguistic variables to describe elastic conditions (i.e. conditions that can be satisfied to a degree) in the IF part of Fuzzy rule. The Knowledge Base is structured in frames, which represent the operator knowledge about the plant in the form of geometrical structure, process representations and control sequences. The fuzzy logic can be derived into a 5□5-rule matrix that consists of 25 rules. Table 6 shows the fuzzy logic rules formulated.

Table 6: Fuzzy Logic Rule Matrix

E	CE	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

where,
B: Negative Big, NS: Negative Small, PS: Positive Small, PB: Positive Big, Z: Zero

The 5 x 5-rule matrix may be redefined in 25 rules as for instance, If E (n) is NB and ΔE (n) NB, then D is Z, If E (n) is NB and ΔE (n) NS, then D is Z and so on….

On the basis of these rules developed, the system works, and the implication method is applied. After the implication method, the output for each rule is aggregated and the defuzzification is done to find the crisp output.

Defuzzification method gives a quantitative summary, i.e. given the possibility distribution of the fuzzy output. The Defuzzification method used for the present case is the centroid method as this is the most prevalent and physically appealing of all the defuzzification methods.

Experiments were conducted by selecting different ranges of membership functions. It was found that most appropriate value for universe of discourse for error input is taken [-8, +8] and change in error is chosen [-10, +10] for the panel voltage set point. The output variable duty cycle is chosen to be as [-8, 8]. Simulink model Fig. 11 shows MPP tracking using FLC.

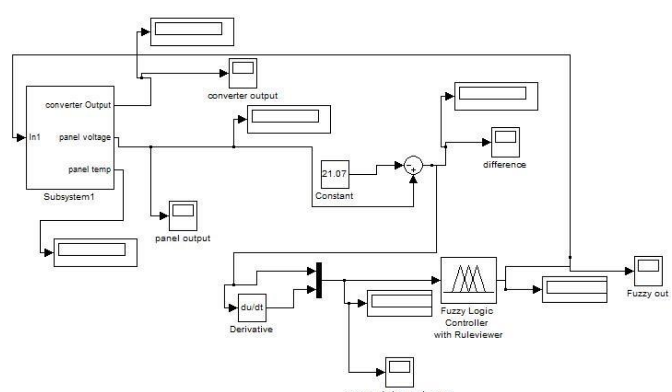

Fig. 11. Fuzzy Logic Controller

The simulation results for FLC based on two models of Buck Converter are tabulated in Table 6 for variable temperature and irradiance followed by outputs in Fig. 12.

Table 6: Converter outputs using Controller for variable temperature and irradiance

T °C	VOC	VCONV A	V CONVB
5	21.31	7.243	21.27
10	21.25	7.223	21.25
15	21.19	7.204	21.2
20	21.13	7.184	21.14
25	21.07	7.164	21.08
30	21.01	7.143	21.02
35	20.95	7.122	20.96
40	20.89	7.101	20.9
45	20.83	7.08	20.83

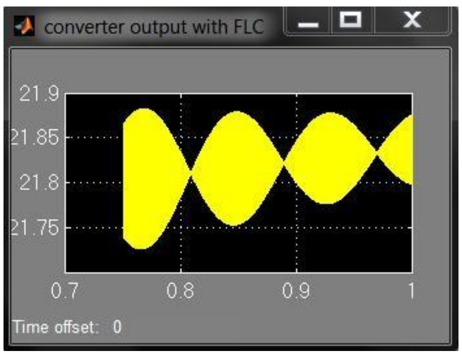

Fig. 12. Converter output using FLC

5. Conclusions

The performance of two different Buck converter models is studied. The system has been simulated for open loop without using controller and thereafter by FLC. The effect of closed loop has been analyzed on both variable parameter's temperature and irradiance. Simulation for open and closed loops and their affects on each other are also discussed.

The effect of the interaction between the two variable parameters has been analyzed using the Fuzzy control system. From the various tests performed, it can be concluded that the performance of the system was closer to MPP at STC, while using the FLC in Model B for selected values of components. The simulation obtained after implementing Fuzzy Logic Controller give optimized results for chosen membership functions. The oscillatory behavior observed for converter for varying temperature conditions is stabilized using FLC.

REFERENCES

[1] [1] G. Balasubramanian, S. Singaravelu, "Fuzzy logic controller for the maximum power point tracking in photovoltaic system," International Journal of

[2] [2] Computer Applications (0975 – 8887) Volume 41– No.12, March 2012.

[3] [3] Chandani Sharma, Anamika Jain, "Entrepreneurship through Start-ups in hill areas using photovoltaic systems" *Bulletin of Electrical Engineering and Informatics*, Vol. 6, Issue 2, pp. 105-121, June 2017.

[4] [4] Chandani Sharma, Anamika Jain, "Basis Weight Gain Tuning Using Different Types of Conventional Controllers" *Bulletin of Electrical Engineering and Informatics*, Vol. 5, Issue 1, pp. 62-71, March 2016.

[5] [5] Chandani Sharma, Anamika Jain; "Modeling of Buck Converter Models in MPPT using PID and FLC", *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, Vol. 13, Issue 4, pp. 1270-1280, December 2015.

[6] [6] 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, pp. 625-635, September 2015.

[7] [7] Chandani Sharma, Anamika Jain; "Distributed MPP Tracking of PV through Buck Converter Using Fuzzy" Telkominika *Indonesian Journal of Electrical Engineering*, Vol. 15, Issue 2, pp. 197-208, August 2015.

[8] [8] Chandani Sharma, Anamika Jain; "Simulink based Multivariable Solar Panel Modeling" *Telkominika Indonesian Journal of Electrical Engineering*, Vol. 12, Issue 8, pp. 5784-5792, August 2014.

[9] [9] Chandani Sharma, Anamika Jain; "Maximum Power Point Tracking Techniques-A Review" *International Journal of Recent Research in Electrical and Electronics Engineering*, ISSN 2349-7815, Vol. 1, Issue 1, pp. 25-33, April-June 2014.

[10] [10] M.A. Islam, N. Mohammad, P.K.S. Khan, "Modeling and performance analysis of a generalized photovoltaic array in Matlab", Joint International Conference on Power Electronics, Drives and Energy Systems by IEEE, Dec 2010.

[11] [11] 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, Vol. 48, No. 3, June 2001.

[12] [12] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed

[13] Masmoudi "MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell", International Journal of Renewable Energy Research, Vol.2, Issue 2, Feb 2012.

[14] [13] S. Lalouni, D. Rekioua, T. Rekioua and E. Matagne, "Fuzzy logic control of stand-alone photovoltaic system with battery storage," Journal of Power Sources 193 (2009) 899–907.

[15] [14] Dr.P.Sangameswar Raju, Mr. G. Venkateswarlu, "Simscape Model of Photovoltaic cell", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 5, May 2013.

[16] [15] 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 90 (2006) 1555–1578.