Adaptive Fuzzy Logic based Perturb and Observe (P&O) Maximum Power Point Tracker (MPPT) for PV Array Under Partial Shading Condition

Abdulkarim Mayere
Centre for Renewable Energy Research
Bayero University Kano
Kano, Nigeria

Aminu Momoh
Department of Electrical Engineering
Bayero University Kano
Kano, Nigeria

***Abstract*—Partial shading on PV cells causes power loss, hotspots and reduces the reliability of the photovoltaic generation system. Conventional MPPT techniques under this condition often fail to give optimum MPP. Focusing on the afore mentioned problem attempts has been made to improve the most commonly used MPPT (P&O) for its simplicity and ease of implementation. However, intelligent controllers such as Artificial Neural Network and particle swarm optimization often cause complexity in the system. To maintain simplicity, the purpose of this paper is to improve the performance of P&O MPPT using Fuzzy Logic Controller for PV array under partial shading condition. The Fuzzy Logic has variable step size and is used to vary the fixed step size of the P&O MPPT. The new algorithm was modeled for KC200GT PV array and was tested on TP240 PV module for validation. The result obtained shows that the FLBP&O MPPT has fast convergence at MPP and extract more power under partial shading condition.**

Keywords:- Component; formatting; style; styling; insert (key words)

I. INTRODUCTION

As per technical report of European Photovoltaic Industry Association (EPIA), capacity of photovoltaic (PV) energy was increases to 84 GW by 2017 according to the aggressive projections [17], and going by this trend in year 2020 the PV installation capacity will even be far more. Photovoltaic (PV) is a method of generating electrical power by converting solar irradiation into direct current electricity using semiconductors which exhibit Photovoltaic effects. PV generating system at its low cost still faces two major problems. One is low conversion efficiency of solar energy into electrical power and the other is the nonlinear characteristics of PV array which makes the electrical power generated vary with temperature and solar irradiation [3], [4]. Unlike solar thermal system, PV system will fail to perform well if they face shading effects [5]. Shading drastically reduces the solar collector's efficiency "η" by reducing cell power, and altering the short circuit-current "Isc", the open-circuit voltage "Voc", and the fill factor "FF" [6]. Thus it becomes difficult to extract the maximum available power from the PV system at all time. To overcome these challenges a Maximum Power Point Tracker (MPPT) is used.

Among all MPPT methods existing, perturb and observe (P&O) is the most commonly used for its simplicity and ease of implementation; however, it presents drawbacks such as slow response speed, oscillation around the MPP in steady state, and even tracking in wrong way under rapidly changing atmospheric conditions (Partial Shading) [7].The Partial Shading introduces local peaks together with global peak MPP in the PV system and therefore necessitated the use of an improved (intelligent control) or hybridized MPPT algorithm to achieve better PV output performance.

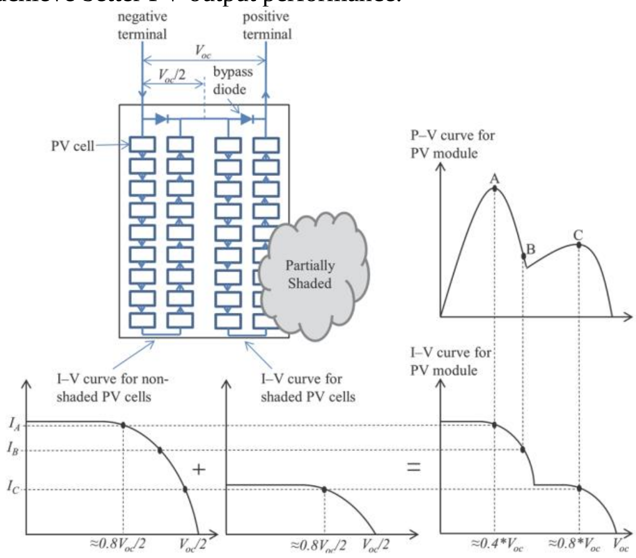

Figure 2: Shading effect on PV module [insert ref]

Proportional-Integral-Derivative (PID) based P&O MPPT algorithm is an improved control algorithm, but because its real time controller has a saturation region, and this region added to the integral effect of the PID produces a phenomenon called reset-windup which result in overshoot in the time response and can even destabilize the system [8]. This problem still affects the tracking operation time. In other to control the effect that partial shading introduced to P&O algorithm for MPPT and reduce the complexity of the system, this paper presents a Fuzzy Logic Controller (FLC) concept to improve P&O algorithm. The Fuzzy Logic Control (FLC) based P&O MPPT technique implementing Mamdani fuzzy inference system (FIS) modified the P&O algorithm as proposed. It can not only increase MPP under shading condition, but can also improve the time of tracking under such condition.

II. LITERAURE REVIEW

A. PV Generator and Boost Converter

The block diagram is shown in figure 3 below:

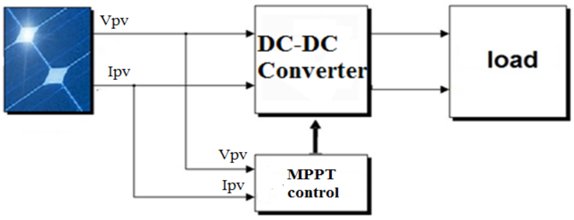

Fig. 3 Proposed block diagram.

It comprises of the PV array, DC-DC boost Converter, FLB P&O MPPT. The relationship between output voltage and power of the PV at varying irradiance and temperatures is non-linear. For this paper, the characteristic of KC200GT PV module as adopted in [9] is shown in table I below. The PV array consists of three (3) modules connected in series.

TABLE I. PARAMETERS OF THE KC200GT SOLAR ARRAY AT 25°C

Parameter	*Value*	*Unit*
Imp	7.61	A
Vmp	26.3	V
Pmax,e	200.143	W
Isc	8.21	A
Voc	32.9	V
KV	-0.1230	V/K
KI	0.0032	A/K
Ns	36	

The design of a solar energy system is concerned with obtaining maximum efficiency at minimum cost. In normal operation, a small deviation of 1% from the optimum power transfer condition can cause a loss of output power [18]. For increasing efficiency of PV, we need to track MPP.

A proposed Maximum Power Point Tracking (MPPT) scheme obtained by varying the duty ratio for DC/DC boost converter has been successful [12, 16].

The Boost converters are extremely used in Photovoltaic in order to keep voltage at a value that has maximum power [11].

B. *Boost Converter Model*

The parameters for the boost converter can be calculated from the input output equations written as:

$$V_o = \frac{V_{in}}{(1-D)} \quad (1)$$

Where Vo is the output voltage of the converter, Vin is the input voltage and D is the duty cycle.

The relationship between the input and output current is:

$$I_o = (1-D)I_{in} \quad (2)$$

The capacitance C of a boost converter is given by:

$$C = \frac{D}{f \times R_o \times \left[\frac{\Delta V_o}{V_o}\right]} \quad (3)$$

The inductance L is:

$$L = \frac{V_{in} \times D}{f \times \Delta I_o} \quad (4)$$

According to [15] the steady-state equation of boost converter under ideal condition in terms of load resistance and internal resistance can be expressed as:

$$R_{in} = \frac{V_{in}}{I_{in}} = (1-D)^2 R_o \quad (5)$$

Since the range of duty ratio is from 0 to 1, therefore,

$$R_o \geq R_{in} \quad (6)$$

According to IEC harmonics standard, current and voltage ripple percentages (CRP) and (CVP) should be bounded within 40% and 2% respectively. Base on equations (1)-(5) the parameters of the boost converter are:

Vo = 236.7V, Vin = 78.9V, L = 0.0053H, C = 0.0353Mf, f = 20KHZ.

The topology of the boost converter interface with PV array is shown in figure 4 below:

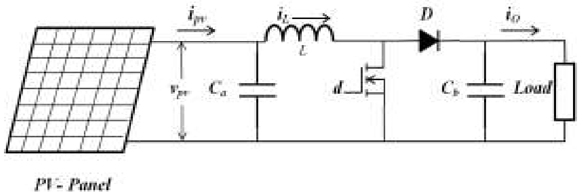

Figure 4 PV array and Boost Converter

C. *Maximum Power Point Tracker*

Maximum Power Point Tracking, frequently referred to as MPPT, operates Solar PV modules in a manner that allows the modules to produce all the power they are capable of generating. MPPT is not a mechanical tracking system but it works on a particular tracking algorithm and it based on a control system. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different. MPPT algorithms are used to obtain the maximum power from the solar array based on the variation in the irradiation and temperature. The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature [11].

Among all techniques, the Perturb and Observe (P&O) method and the Incremental Conductance (InCond) algorithms are the most commonly applied algorithms. Other techniques based on different principles include fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc [26]. Both P&O and InCond algorithms are based on the "hill-climbing" principle, which consists of moving the operation point of the PV array in the direction in which the power increases. Hill-climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant. The advantages of both methods are simplicity and requirement of low computational power. The drawbacks are: oscillations occur around the MPP and they get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions or even locate the local MPP during a big change in atmospheric condition. In this paper P&O MPPT is selected for improvement under these shading conditions using Mamdani FLC (Fuzzy Logic Controller).

D. *Perturb and Observe MPPT*

The P&O algorithm adopted for the [10] is shown in the figure 5 below.

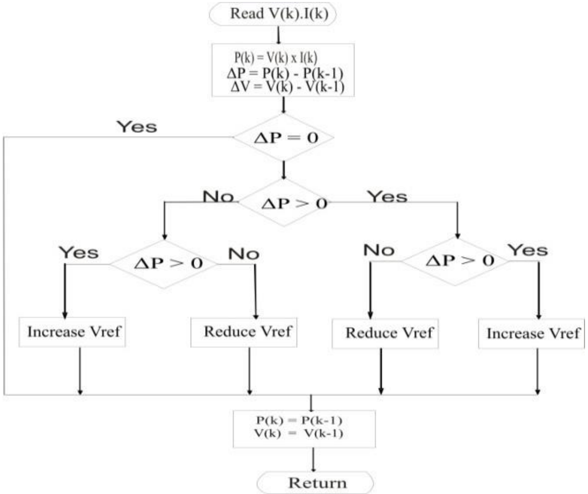

Fig. 5 P&O MPPT algorithms

There are total of four possible cases which will influence the direction of the MPP tracking in regions 1 and 3 of figure 6 below.

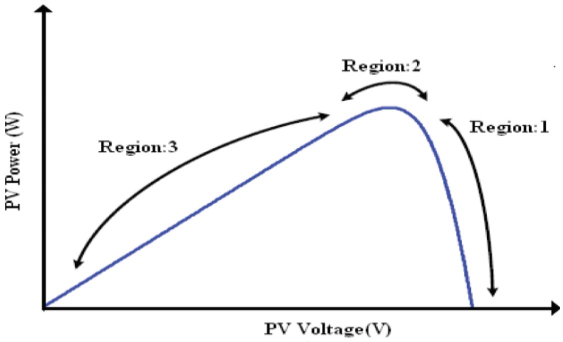

Fig. 6 Operation of P&O MPPT

Case I where Pk>Pk-1 and Vk>Vk-1 are described as region 3 in Fig. 6. Increasing the module operating voltage will lead to an increasing of PV power. Therefore, P&O MPPT will apply increment of perturbed voltage ΔV to the present PV operating voltage. Subsequently the module power is monitored.

Case II where Pk>Pk-1 and Vk<Vk-1 are illustrated as region 1 in Fig. 6. It is noticed that the decreasing of module operating voltage will cause an increased of PV power. Thus, P&O MPPT should take action to have a reduction of ΔV to the module operating voltage. If the condition is unchanged, the decrement of ΔV should be continued until the MPP is successfully spotted.

Case III is described as Pk<Pk-1 and Vk>Vk-1. This case is represented by region 1 in Fig. 6. If the PV operating voltage is increased, the PV power will be decreased. Thus, the module operating voltage should be reduced by ΔV.

Case IV where Pk<Pk-1 and Vk<Vk-1 are described as region 3 in Fig. 6. It can be observed that the power is decreased when the PV operating voltage is reduced. Thus, the P&O MPPT should apply an increment of ΔV to the module operating voltage to reach the MPP voltage point.

E. Fuzzy Logic Controller

Fuzzy Logic Controller is one of the most successful applications of fuzzy set theory, introduced by Zadeh in 1965 [6]. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Fuzzy logic control generally consists of three stages: fuzzification, rule base table lookup, and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function similar to Fig. 7 below. In this case, five fuzzy levels are used: NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), and PB (Positive Big).

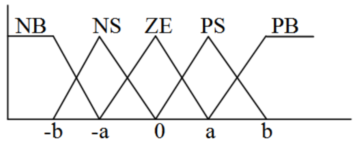

Figure 7 Membership function for input and output of fuzzy logic controller.

In some cases seven fuzzy levels are also used probably for more accuracy. In Fig. 7, a and b are based on the range of values of the numerical variable. The membership function is sometimes made less symmetric to give more importance to specific fuzzy levels. The inputs to a MPPT fuzzy logic controller are usually an error E and a change in error ΔE. The user has the flexibility of choosing how to compute E and ΔE. Since dP/dV or dP/dI vanishes at the MPP, approximation can be applied as follows,

$$\mathrm{Error}, E = \frac{P(t) - P(t-1)}{Ipv(t) - Ipv(t-1)} \tag{7}$$

$$\text{Change in error}, \Delta E = E(t) - E(t-1) \tag{8}$$

Once E and ΔE are calculated and converted to the linguistic variables, the fuzzy logic controller output, which is typically a change in duty ratio ΔD of the power converter, can be looked up in a rule base table such as Table 2 below. The linguistic variables assigned to ΔD for the different combinations of E and ΔE is based on the power converter being used and also on the knowledge of the user. The rule base is shown in Table II for the boost converter. If for example, the operating point is far to the left of the MPP, that is E is PB, and ΔE is ZE, then we want to increase the duty ratio largely, that is ΔD should be PB to reach the MPP. In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function. This provides an analog signal that will control the power converter to the MPP.

TABLE II. FUZZY RULE BASE

ΔE / E	***NB***	***NS***	***ZE***	***PS***	***PB***	***NB***
NB	ZE	ZE	NB	NB	NB	NB
NS	ZE	ZE	NS	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS	ZE
PS	PS	PS	PS	ZE	ZE	PS
PB	PB	PB	PB	ZE	ZE	PB

III. THE PROPOSED SCHEME

The main difference between Fuzzy Logic Controller and Adaptive Fuzzy Logic Controller is that the Sugeno output membership functions are either linear or constant. A typical rule in a Sugeno fuzzy model has the form: If Input 1 is x and Input 2 is y, then Output is z = ax + by + c. For a zero-order Sugeno model, the output level z is a constant (a = b = 0) in

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 02, February-2019

[14]. Fuzzy Logic Controller (FLC) of the proposed scheme comprises of components as illustrated in figure 8.

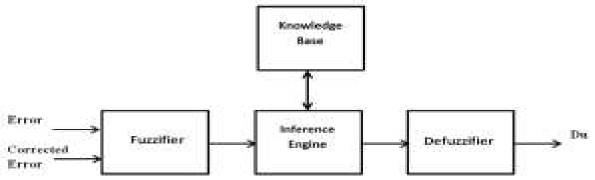

Figure 8 Structure of fuzzy logic controller

Fuzzification interface, where predefined fuzzy subsets determine the input crisp values.

Fuzzy rule base, which provides the set of “if then” statements to define the controller behavior.

Inference engine, which processes output from input set of fuzzy values using the fuzzy rule base.

Defuzzification interface is where crisp values of output fuzzy set are obtained. The output of FLC is a change in the duty cycle of the DC-DC converter. The process of defuzzification converts linguistic value of output into a crisp output value. The input to defuzzification process is an aggregated output fuzzy set and the output is a single number. Many defuzzification techniques have been proposed in the literature. The most commonly used method is the Center of Gravity (COG) or centroid defuzzification method. In this method, the defuzzifier determines the center of gravity (centroid) and uses that value as the output of FLC. For a continuous aggregated fuzzy set, the centroid is given by:

$$U_f = \frac{\sum_{i=1}^{n} w_i V_{fi}}{\sum_{i=1}^{n} w_i} \quad (9)$$

For the purpose of this paper the output duty cycle UF of the FLC is use to further increase the next perturbation step size voltage output of P&O before feeding it to control the converter duty cycle, D. The output of the FLBP&O MPPT is given by:

$$V_{FLBP\&O} = \frac{\sum_{i=1}^{n} w_i V_{fi}}{\sum_{i=1}^{n} w_i} + V_{P\&O} \quad (10)$$

The flowchart of the proposed Fuzzy Logic controller Based P&O MPPT is shown in the figure 12 below.

The scale factors K1, K2 and K3 are adjusted base on [18].

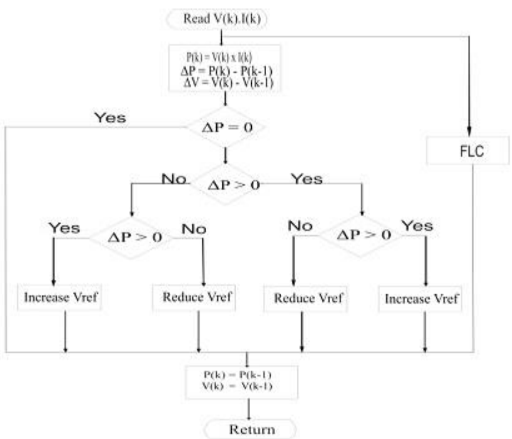

Fig. 12 The FLBP&O MPPT algorithms

IV. SIMULATION RESULTS AND DISCUSSION

The PV module is interface with boost converter without MPPT and with MPPT and results are shown below:

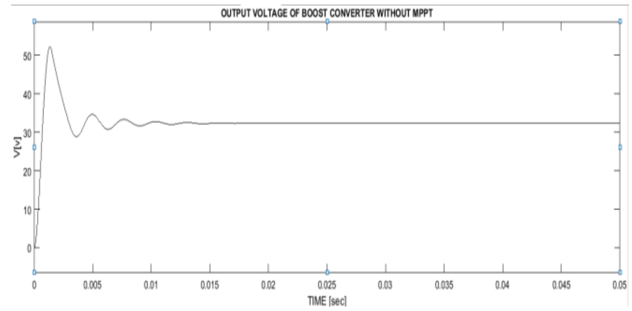

Fig. 13 Voltage out versus time of the converter interface with PV module without MPPT

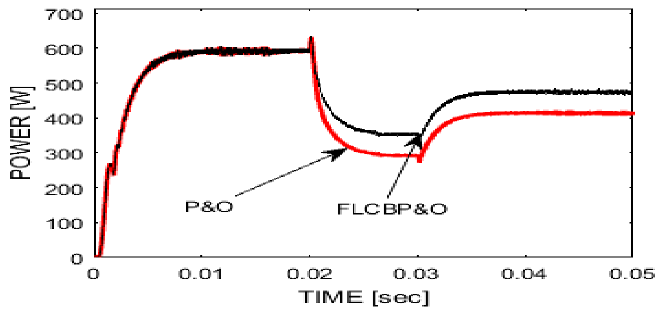

Fig. 14 Output Power versus time of the converter interface with PV array for P&O MPPT and FLBP&O MPPT at irradiance variation from 1000 W/m2, 500 W/m2 and 700 W/m2 respectively.

From the results obtained the FLBP&O MPPT improved the output power of P&O MPPT from 300Watt to 360Watt and from 420Watt to 480Watt for irradiance changing from 1000 W/m2, 500 W/m2 and 700 W/m2 respectively (Partial Shading). This is summarized in the table III shown below:

TABLE III. COMPARISON BETWEEN P&O AND FLBP&O MPPT OUTPUT POWER OF KC200GT PV ARRAY

Case No.	*Irradiance Level (W/m²)*	*Output Power (W) P&O*	*Output Power (W) FLBP&O*	*% Increase*
1	1000	598	600	0.34
2	700	420	482	14.76
3	500	300	358	19.33

In terms of time the FLBP&O MPPT shows fast convergence time as it reaches MPP in 0.008sec compare to 0.012sec for P&O MPPT.

For validation of the FLBP&O MPPT on TP240 PV module at irradiance variation from 1000 W/m2 to 600 W/m2 and 400 W/m2, at time 15000sec and 25000secs respectively, the parameters are entered on the code and encrypt in subsystem. The result of the original model from Rahul T. (2016) is shown in figure 15(a) below:

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 02, February-2019

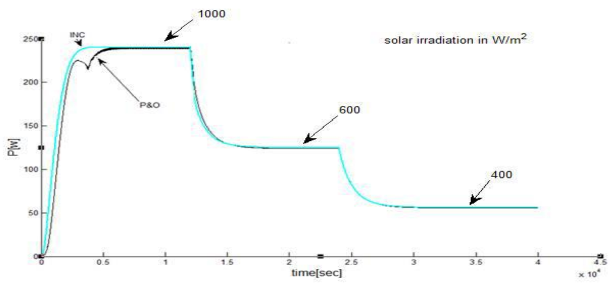

Figure 15(a) Output Power with time for TP240 using P&O MPPT and INC MPPT under shading condition.

Figure 15(b) shows the simulation of TP240 module under the same pattern of shading using the proposed FLBP&O MPPT. The tracker still presents some oscillation due to manual setting of the PI of the Fuzzy Logic Controller for K1, K2 and K3. These optimize the membership function of Fuzzy and can better be done using any of the intelligent algorithms such as Particle Swamp Optimization (PSO) or Artificial Intelligent Controller.

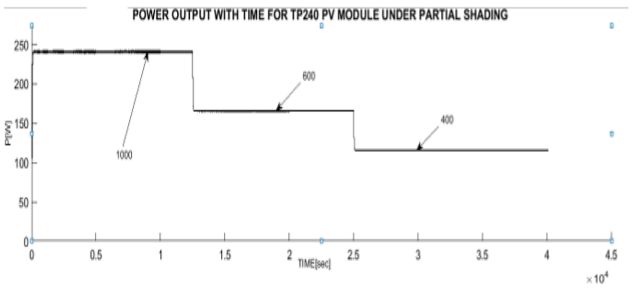

Figure 15(b) Output Power with time for TP240 using FLBP&O MPPT under shading condition.

The result is summarized in table IV below:

TABLE IV. COMPARISON BETWEEN P&O AND FLBP&O MPPT OUTPUT POWER OF TP240 PV ARRAY

Case No.	*Irradiance Level (W/m²)*	*Output Power (W) P&O*	*Output Power (W) FLBP&O*	*% Increase*
1	1000	239	240	0.42
2	600	130	152	16.92
3	400	70	100	42.85

V. CONCLUSION

The Fuzzy Logic Based P&O MPPT has been implemented in Matlab/Simulink. In this dissertation the result of P&O MPPT and FLCBP&O MPPT are checked under partial shading for simulation using simulink for KC200GT PV array and TP240 PV module. The output of FLBP&O MPPT performs better than the conventional P&O MPPT in time response and Power extraction. There is need for further work to use neuro-fuzzy to optimize P&O MPPT and also Use PSO to optimize the membership function of the Fuzzy Logic Based P&O MPPT.

REFERENCES

[1] T. Esram and P.L. Chapman, Comparism of Photovoltaic Array Maximum Power Poin Tracker Techniques, IEEE Trans. Energy Conversion, Volume 22, no 2, pp 439-449, 2007.
[2] S. Kumar et al, Solar PV Performance Issues and Challenges, International Jornal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineer Volume 2 Pages 2168-2172, 2014.
[3] M. Lissere et al, Future Energy System: Integrating Renewable Energy Sources into the Smart Power Grid through Industrial Electronics, IEEE Ind. Electr. Power Application, Vol. 4, no. 1, pp 18-37, March 2010.
[4] S. Jain and V. Agarwal, Comparison of the Performance of Maximum Power Point Tracking Scheme as Applied to Single-Stage Grid Connected Photovoltaic System, IET Elctr. Power Appl., Vol. 1, no. 5, pp 753-762, Sept. 2007
[5] David A. J, Compensation for differential energy balances across a building Incorporating solar energy systems. Energy Build. 43: Page(s): 1105-1112, 2011.
[6] Partain and Fraas, Effect of Shading on Solar Cells, Solar Cells and Their Application Page No. 1- 10, 2007.
[7] B. Amrouche, Artificial intelligence based P&O MPPT method for photovoltaic systems Development Centre of Renewable Energy, P.O. Box 62, Bouzareah, Algiers, Algeria2 Institute of Electronic, University of Blida, Algeria,pp 11-20, 2007.
[8] Emmanuel Kwaku Anto et.al, PID-based P&O MPPT Controller for Offgrid Solar PV Systems Using Ziegler-Nichols Tuning Method to Step, Ramp and Impulse Input, Jornal of Multidiscplinary Engineering Science Studies,Department of Electrical & Electronics Engineering, KNUST,Kumasi, Ghana,pp 669-680, 2016
[9] Marcelo Gradella Villalva et.al, Comprehensive Approach to Modeling and Simulation of Research, Department of EEE, SOA University, Bhubaneswar , India, pp 1252-1263.
[10] Moacyr A. G. de Brito et.al, Evaluation of MPPT Technique for Photovoltail Applications, Sao Paulo University, UNESP, Power Electronic Labouratory, Electrical Department,pp 1039-1044, 2011.
[11] Yuen-Haw Chang et.al, A Maximum Power Point Tracking of PV System by Adaptive Fuzzy Logic Control, Proceedings of the International Multiconference of Engineers and Computer Scientist, Hong Kong, pp 1-6, 2011.
[12] Vidhya Fulmali et.al, Modeling and Simulation of Boost converter for Solar-PV Energy System to enhance its Output, IEEE International Conference on Computer, Communication and Control (IC4-2015), IES IPS Academy Indore, India, pp 1-4, 2015.
[13] Sumathi, S et al., Application of MATLAB/SIMULIN in Solar PV Systems, Solar PV and Wind Energy Conversion Systems, Green Energy and Technology, Springer International Published Switzerland, pp 59-85, 2015.
[14] Sugeno M, Industrial applications of fuzzy control, Elsevier Science Pub. Co. pp1-20, 1985.
[15] Salas, V. et.al, Review of the maximum power point tracking algorithms for stand- alone photovoltaic systems, Solar Energy Materials and Solar cells, Universidad Carlos III de Madrid, Avda. de la Universidad, 30-28911 Legane´s, Madrid, Spain, pp1555-1578, 2005.
[16] Muhammad H. Rashid, "Power Electronics Circuits, Devices and Applications", Third Edition
[17] Gaëtan, M., Marie, L., Manoël, R., 'Theologitis IT, Myrto P. Global Market Outlook For Photovoltaics 2013-2017', In:Proceedings of the European Photovoltaic Industry Association, Belgium; 2013.p.1–60.
[18] Li Zheng, A Practical Guide to Tune of Proportional and Integral (PI) Like Fuzzy Controllers, pp 622- 640, 1987.