TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 8, August 2014, pp. 5861 ~ 5868
DOI: 10.11591/telkomnika.v12i8.5911

Grid-connected Photovoltaic Power Systems and Power Quality Improvement Based on Active Power Filter

Brahim Berbaoui*[1], Samira Dib[2], Rachid Dehini[2]
[1]Unité de recherche en Energie Renouvelables en milieu saharien, URERMS, Centre de Développement des Energies Renouvelables, CDER, 01000, Adrar, Algeria
[2]Department of Electrical Engineering, Bechar University, Algeria
*Corresponding author, email: berbaoui.brahim@gmail.com

Abstract

This paper presents a Parallel Active Power Filter (PAPF) using Photovoltaic cells Energy to feed linear or nonlinear loads with current perturbations compensation and the excess of the energy is injected into the mains. As a result of using instantaneous p-q theory as a control scheme, the multi-function operation such as harmonic elimination, reactive power control and uninterruptible power supply will be achieved. The system consisting of Photovoltaic cells, connected to a diode rectifier feeding a parallel active power filter is simulated in MATLAB/SIMULINK environment. The simulation results prove the efficiency of using the proposed method for Photovoltaic cells energy injection and power quality improvement in the grid power system.

Keywords: *photovoltaic cells energy, MPPT, PAPF, current harmonics, p-q theory*

1. Introduction

Continuously, fossil fuel time is getting missing. Energy and fuel exigency is exponentially increasing with time. Simultaneously energy cost is also continuously rising. In order to surpass these problems we can use renewable resources at our disposal from which energy can be tapped; Photovoltaic cells converts solar energy to direct electric energy [1].

The system of Photovoltaic power generation is a principal efficient technique of using solar energy, which can convert sunlight radiation directly into electricity through the photovoltaic effect, and has broad prospects for development with a series of advantages such as clean and pollution-free, noise-free, and renewable [2].

Non-linear devices produce distorted current waveforms in the power system. The injected harmonics have several impacts on the utilities grid and loads connected to system. To overcome these power quality problems, harmonic active filters are widely used in the system. [3-4]. In this paper, the analysis are focused on the system configuration with a direct coupling between the Photovoltaic cells and the shunt active power filter employed to inject the solar power into the utility grid under fixed Photovoltaic power conditions. The proposed design is not only able of delivering the solar power to the grid, but will also act as a parallel active power filter (PAPF) to mitigate the current harmonics and regulate reactive power injected by the non-linear loads. In order to investigate and mitigate the harmonic capabilities of the proposed system; a 1MW Photovoltaic power with shunt active power filter connected to a three-phase power grid feeding non-linear load was simulated in MATLAB / SIMULINK environment.

2. Parallel Active Power Filter

Parallel active power filter is a power converter utilized in order to compensate current disturbances (harmonics, reactive power and unbalance). In order to meet quality enhancement constraints proper control of its power switches is needed. Several topologies and configuration have been introduced in the literature and in commercial implementations for this filter that highlight different aspects of its compensation tasks [11]. The most common topology of the shunt active power filter is shown in Figure 1. Its main components are voltage source inverter,

Received March 3, 2014; Revised April 23, 2014; Accepted May 10, 2014

DC bus (in our situation is a capacitor), output passive filter and a control system. The most important objective of the PAPF is to compensate the current harmonics generated by non linear loads [12]. The reference currents consists of the harmonic components of the load currents which the active filter must supply [5]. These reference currents are fed through a controller to generate switching signals for the power switching devices of the voltage source inverter (VSI). Finally, the AC supply will only need to provide the fundamental component for the non linear load.

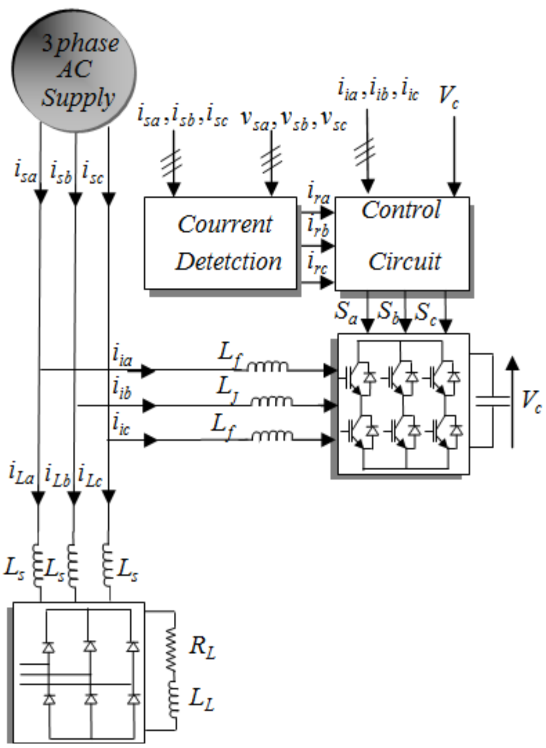


Figure 1. General Structure of Parallel Active Power Filter

3. Photovaltaic Generator Modeling

Electrical energy needs are still increasing over these last years but production constraints like pollution [6] and global warming lead to development of renewable energy sources, particularly photovoltaic energy. Due to very limited conversion efficiency, it is necessary to optimize all the conversion chain and specifically DC-DC converters by use to maximum power point tracking strategies [13] which is shown in (Figure 2).

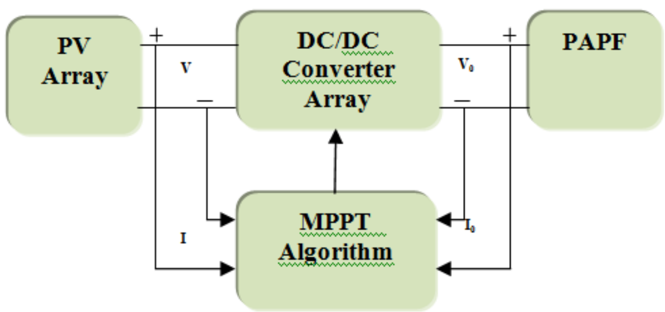


Figure 2. Block diagram of typical MPPT system

Photovoltaic generators consist usually of several modules interconnected in series and parallel for a given operating voltage an output power. Photovoltaic generators modeling can then be deduced from those of solar cells; many studies have been already proposed using one diode or more precise two diodes models. In this paper we use the conventional single diode model presented on (Figure 3).

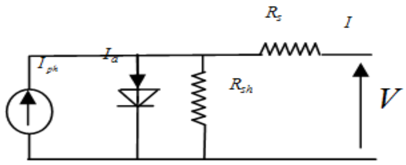


Figure 3. Conventional Single Diode Model

Iph is the photo generated current related to the illumination level, Id the diode current, Rsh and Rs are respectively the shunt and series resistances. Based on (Figure 3), the output voltage and current dependence can be written in the form:

$$I = I_{ph} - I_0\left(e^{\frac{V+R_s I}{V_t}} - 1\right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

a) Vt is the thermal voltage written as:
$V_t = (A * K * T)/q$ where A is the ideality factor, K the Boltzmann constant, T the temperature of the cell and q the elementary charge.

b) I_0 is the dark current. Compared to the measured photocurrent Iph_ref at standard tests conditions (STC: Gref =1000W/m², Tref =25°C), the photocurrent at another operating conditions can be expressed as:

$$I_{ph} = \frac{G}{G_{REF}}\left[I_{PH,REF} + \alpha(T - T_{REF})\right] \quad (2)$$

G is thesolar irradiance, α is the short circuit current temperature coefficient. Iph_ref can be taken to be the short current at STC (Icc_ref),Icc_ref and α are generally given by solar module manufacturer [14]. In the case where the cell temperature Tamb not is determined directly by a temperature sensor, it can be deduced from the following relation:

$$T = T_{amb} + \left[\frac{N_{oct} - 20}{800}\right]G \quad (3)$$

Tamb is the ambient temperature, Noct is the normal operating cell temperature given in most cases by the manufacturer. For the dark current I_0 and we can write:

$$I_0 = I_{0,REF}\left(\frac{T}{T_{REF}}\right)^{3/A} \exp\left[\frac{qE_g}{AK}\left(\frac{1}{T_{REF}} - \frac{1}{T}\right)\right] \quad (4)$$

I_0,ref is the dark current at STC and Eg is the forbidden band energy. In the single diode model, we assumed Rsh to be infinite; the series resistance can be derived in the form [7]:

$$R_s = -\frac{dV}{dI_{(VOC)}} - \frac{AKT/q}{I_0 \exp\left(\frac{qV_{oc}}{AKT}\right)} \quad (5)$$

Equation (1) can be solved by numerical method like Newton Raphsons.

$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)} \quad (6)$$

The VSI is controlled in such a way that it can be used to inject sinusoidal current into the grid for energy extraction from the Photovoltaic cells during linear or non-linear load conditions. During non-linear load conditions, VSI can be used also as PAPF for harmonic and reactive compensation. To control the performance and the effectiveness of the Photovoltaic cells, the VSI is operated based on the concept of p-q theory. The control input is a current error signal which in this application, is the difference between the actual current injected by VSI and the desired or reference current waveform.

4. Reference Currents Generation

The reference currents for the control of the PAPF are calculated using the active and reactive power analysis in a stationary αβ frame (p-q theory). Load currents and phase voltages of the three-phase system expressed in αβ frame are given by:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (8)$$

Where ia, ib, ic are the load currents and ea, eb, ec are the three-phase grid voltages. The instantaneous real power and the instantaneous imaginary power absorbed by the load are, respectively, defined as follows:

$$p_l(t) = e_\alpha(t) i_\alpha(t) + e_\beta(t) i_\beta(t) \quad (9)$$

$$q_l(t) = e_\alpha(t) i_\beta(t) - e_\beta(t) i_\alpha(t) \quad (10)$$

P_l and q_l are made up of a DC and an AC component, so that they may be expressed by:

$$p_l = \overline{p_l} + \tilde{p}_l \quad (11)$$

$$q_l = \overline{q}_l + \tilde{q}_l \quad (12)$$

Where $\overline{p}_1$ and $\overline{q}_1$ are DC components due to fundamental currents while $\tilde{p}_1$ and $\tilde{q}_1$ are AC components due to harmonic currents. In order to generate the reference currents, a balance between instantaneous powers supplied by the grid and the PAPF and drained by the load is to be computed. If pg and q_g are the real and imaginary instantaneous powers supplied by the main, while p_f and q_f are the real and imaginary instantaneous powers supplied by the PAPF, in order to compensate reactive power and eliminate harmonic currents, the grid should supply $p_g = \overline{p}_1$ and q_g=0.

The oscillatory component of pl is to be fed by PAPF, while ql must be fully fed by the PAPF because it is also possible in this way to achieve reactive power compensation[9]. The oscillatory part of pl is due to harmonic components[10] , so if it is fed to the load by the PAPF, grid current remains sinusoidal, while the load keeps on receiving the same amount of harmonic and fundamental current. Power balance yields:

$$\begin{aligned} p_g &= \overline{p_l} \\ p_g &= 0 \\ p_f &= p_l - p_g = p_l - \overline{p_l} = \tilde{p}_l \\ q_f &= q_l - q_g = q_l \end{aligned} \tag{13}$$

Previous equations need to be modified in order to consider proper operation of the capacitor on the DC side of the inverter. The capacitor stores energy which is utilized as a power supply for the normal operation of the PAPF. More in detail, in normal operating conditions the PAPF does not feed active power because it should be able to supply $p_f = \tilde{p}_l$ and $q_f = q_l$ and so only reactive power is fed. For this reason, capacitor voltage level is constant during the steady state. In order to regulate DC voltage level, it is necessary to control active power balance among the grid, load and PAPF. When the load absorbs a precise quantity of power $\overline{p_l}$ and if $p_g \succ \overline{p_l}$ excess power is drawn by the PAPF, which increases the DC side voltage. If $p_g \prec \overline{p_l}$, since the load needs a precise amount of power, the PAPF feeds the remaining part in order to have $\overline{p_g} + \overline{p_f} = \overline{p_l}$ and hence the DC voltage level decreases. To control the proper amount of active power fed or drawn by the PAPF, it is necessary to introduce a gain factor k [8].

$$k = \frac{\overline{p_g}}{\overline{p_l}} \tag{14}$$

In normal conditions this gain is quite near unity, because the losses in PAPF components are negligible. When DC capacitor charging is needed, the gain factor is above unity because grid must supply an additional amount of active power to the PAPF. When DC voltage level is too high, gain factor is regulated to values below unity, so a power less than $\overline{p_l}$ is required to the grid and the remaining part of $\overline{p_l}$ is fed to the load by the PAPF.

Hence the instantaneous reference powers for the PAPF are:

$$\begin{aligned} p_f^* &= \tilde{p}_l + (1-k)\overline{p_l} \\ q_f^* &= q_l \end{aligned} \tag{15}$$

A transformation from instantaneous powers to currents allows generating proper reference for currents control according to the following equation:

$$\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_f \\ q_f \end{bmatrix} \tag{16}$$

5. Simulation Results and Discussion

The proposed Photovoltaic cells are not only capable of supplying extracted solar power to the power system, but it also can significantly mitigate harmonic currents which are drawn by non-linear loads. In order to demonstrate the validity of the concepts discussed previously a simulation using MATLAB/SIMULINK environment is done as it is shown in Figure 4. The parameters of the system are shown in Table 1.

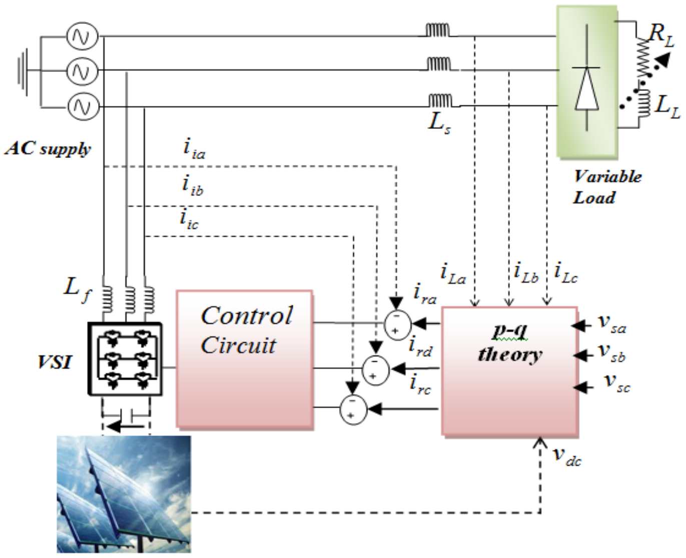
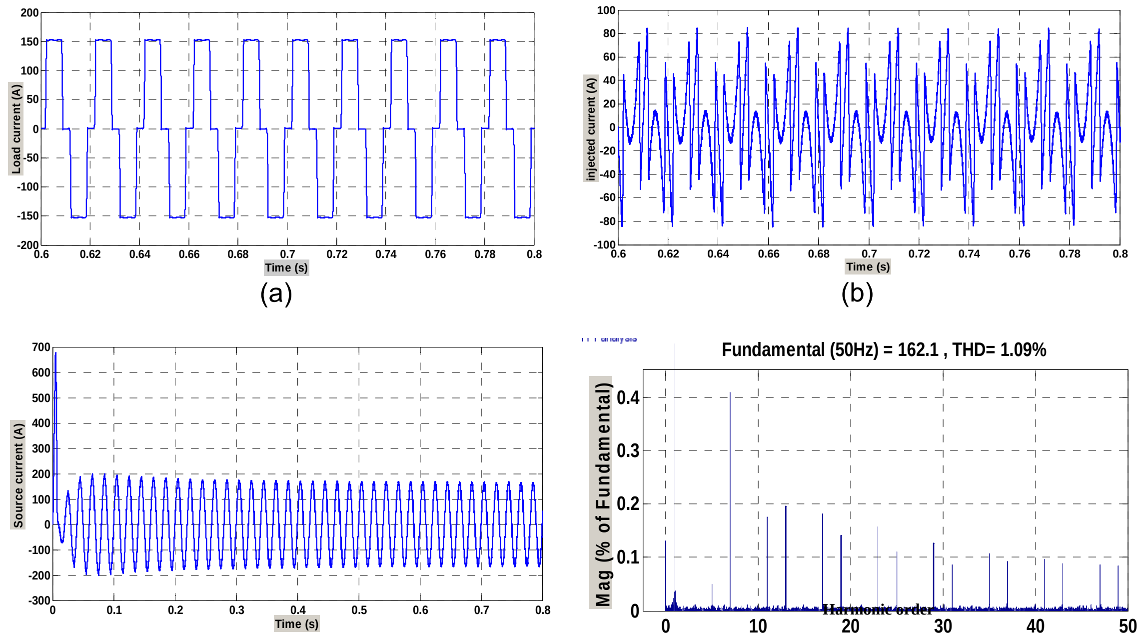


Figure 4. SIMULINK Implementation of PAPF with PV

Table 1. System Parameters

GRID	
Source Voltage V_s	220 V
Load Power P_L	80 kVA
Frequency f_s	50 Hz
PHOTOVOLTAIC CELLS	
Nominal Power P_T	24 KW
cells Voltage V_T	850 V
PAPF	
Switching Frequency	12 kHz
Output Filter	1 mH
DC Link Capacitor	8.8 mF
Capacitor DC Voltage	2600 V
reference current	p-q Method
VSI control	PWM + PI

The simulation results of the proposed PAPF with PV are shown in the Figure 5. PV cells produces less than 600W at 600 Volts, so cells are connected in series and parallel to produce enough power. At 0.2 second the photovoltaic power is increasing what makes the absorbed current from the source by the non linear load decreases. At approximately 0.6 second the photovoltaic cells produces 3% of the power needed by the non linear load and the current of the source decreases to 162.1 A (RMS), the current supply decrease (Figure 5) means that the active power is injected by PAPF to release the excess power in the DC bus condenser, so as to stabilize its voltage (Figure 6).We can say that the photovoltaic cells starts delivering power to the grid after it has finished feeding the PAPF by all the power it needs. Finally, it is clear that the PAPF injects appropriate amount of current to mitigate harmonics generated by the non linear load and at the same time deliver the excess active power to the grid.



(a) (b) (c) (d)

Figure 5. (a) Phase-a load current, (b) Phase-a reference current, (c) Phase-a the supply current, (d) Harmonic spectrum of supply current Phase ‘a’, with (PV).

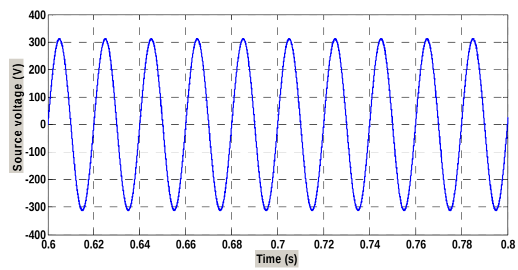


Figure 6. Phase-a the Supply Voltage Waveforms, with a (PV)

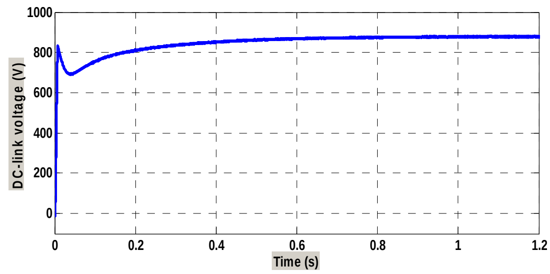
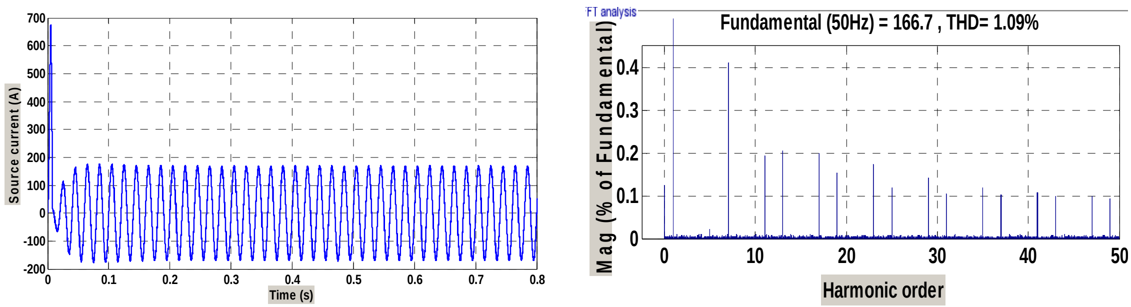


Figure 7. DC-link Voltage



(a) (b)

Figure. 8 (a) phase-a the supply current, (b) Harmonic spectrum of supply current Phase ‘a’, without a (PV).

6. Conclusion

Photovoltaic power seems to be the favorable clean energy source of the future. So, to optimize its use we have proposed a direct coupling of Photovoltaic cells with parallel active power filter (PAPF). From the results obtained, it is proven that by using the proposed system, Photovoltaic power can be efficiently extracted by solar cells and injected into the grid by PAPF which has two functions; the first is feeding the linear or non linear load with harmonic current mitigation capability and second injecting the surplus power into the mains. Finally and according to the obtained results we can consider the proposed system to be efficient solution to the growing demand of power at the present and in the future.

References

[1] CM Chovatia, NP Gupta, PN Gupta. Power Quality Improvement in a PV Panel connected Grid System using Shunt Active Filter. *International Journal of Computer Technology and Electronics Engineering (IJCTEE)*. 2012; 2(4).
[2] V Busa, KK Narsingoju, GV Kumar. Simulation Analyis of Maximum Power Control of Photo Voltaic Power System. *International Journal on Advanced Electrical and Electronics Engineering (IJAEEE).* ISSN (Print): 2278-8948. 2012; 1(1).
[3] GY Jeong, TJ Park, BH Kwon. *Line-voltage sensorless active power filter for reactive power compensation*. Electric Power Applications, IEE Proceedings. 2000; 1(47): 385-390.
[4] Tumbelaka, CV Nayar, K Tan, LJ Borle. *Active filtering applied to a line-commutated inverter fed permanent magnet wind generator*. Presented at International Power Engineering Conference IPEC2003, Singapore. 2003.
[5] Wada, H Fujita, H Akagi. *Considerations of a Shunt Active Filter Based on on Voltage Detection for Installation on a Long Distribution Feeder'*. in Proc. Conf. IEEE-IAS Ann. Meeting. 2001: 157-163.
[6] Yahfdhou, A Mahmoud, I Youm. Modeling and Optimization of a Photovoltaic Generator with Matlab/Simulink. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)* ISSN: 2278-3075. 2013; 3(4).
[7] H Tumbelaka. A Grid Current Controlled Shunt Active Power Filter Using Polarized Ramptime Current Controlled. Electrical and computer Engineering Perth Curtin University of Technology. 2006.
[8] eEll'Aquila A, Lecci A, Zanchetta P, Liserre M. Fuzzy active filter performance in transient conditions. EPE 2001.
[9] M Izhar, CM Hadzer, M Syafrudin, S Taib, S Idris. Performance for passive and active power filter in reducing harmonics in the distribution system. 2004.
[10] G Dawei, L Qingchun, S Xlaorui. Design and performance of an active power filter for unbalanced loads. 2002.
[11] HH Tumbelaka, LJ Borle. *Application of a Shunt Active Power Filter to Compensate Multiple Non-linear Loads.* Presented at Australasian Universities Power Engineering Conference (AUPEC). Melbourne, Australia. 2002.
[12] Zhang Chao, Ren Zi-Hui, Zhang Yi-Jun, Ma Xiao-Ping. Shunt Active Power Filter System Design for Inter-harmonic. *International Journal of Power Electronics and Drive Systems* DOI: 10.11591/ijpeds.v3i4.4442
[13] Rajendra Aparnathi, Ved Vyas Dwivedi. A Voltage Controller in Photo-Voltaic System with Battery Storage and Applications. *International Journal of Power Electronics and Drive Systems* DOI: 10.11591/ijpeds.v3i4.4549
[14] Nur Mohammad, Md Asiful Islam, Tarequl Karim, Quazi Delwar Hossain. Improved Solar Photovoltaic Array Model with FLC Based Maximum Power Point Tracking. *International Journal of Electrical and Computer Engineering (IJECE)* DOI: 10.11591/ijece.v2i6.1328