The Journal of CPRI,
Vol. 10, No. 1, March 2014 pp. 137-146

Studies and Analysis of Effects of Shading on the Performance of a Solar-Photovoltaic System

Neha Adhikari* and Vikas Pratap Singh**

This paper presents the studies on the solar photovoltaic system in the partial shading conditions. The standalone solar photovoltaic system for residential application of 2 kW power rating is considered in the system analysis. The proposed system is using a set of batteries for energy storage with a flyback dc-dc converter and a single phase voltage source inverter is designed with the controller to regulate the power quality at the consumer end. The studies are carried out as case studies on the different conditions of the shading and results are presented to analyze the PV output power and evaluate the overall system performance. Based on the results obtained few measures are suggested to keep the check on the performance in such conditions.

Keywords: *Solar photovoltaic, MPPT controller, Inverter, Partial shading, Standalone energy system*

1.0 INTRODUCTION

The use of solar photovoltaic for energy generation is being widely popular nowadays due to advantages associated with such systems as widely availability, environmental friendly etc. The solar-PV systems in residential applications are still in the emerging state due to many factors such as installation cost, efficiency etc. The partial shading conditions in such systems can be taken care of while designing such systems [1-3]. After the installation probability of such conditions needs to be analyzed in terms of effects on the performance of the overall system performance.

In this study the partial conditions are considered including all the condition where, the operating conditions of cells are not identical due to variations in the solar radiation. In case of the partial shading condition current of shaded part will be less than the non-shaded part thus it creates mismatch and it can lead to excess heating in the shaded cell hot-spot situation creates[4-8]. To avoid such cases it is needed to analyze the partial shading in the solar-PV systems.

The standalone solar-PV system using 2kW solar array with a battery backup for feeding the average consumer load upto 8hrs is designed with a voltage source inverter. In this study efforts are made to evaluate the system under different cases of shading such as series shading, parallel shading, multi string shading and single unit shading and results are presented for the performance of the system under such cases. This provides an overview of the effects of shading on the PV output power and performance of the system.

2.0 SYSTEM CONFIGURATION

The proposed system is designed for 2 kW rated power and 250 W panels are connected in series parallel to realize the combination. The isolated

*Engineering Officer Grade-3, Energy Efficiency and Renewable Energy Division, CPRI, Bangalore-560080, India. E-mail: nehaadhikari@cpri.in
**Energy Efficiency and Renewable Energy Division, Central Power Research Institute, Bangalore-560080. India. Mobile : 9458207770,
Email: vikasforsmile@iitj.ac.in

flyback converter is connected with the array for optimum battery charging application. The battery is charging using the control algorithm based on CC-CV-CC charging method. The output voltage and current of the designed array at maximum power point under STC and the open circuit voltage and short circuit current under the STC conditions are different for different modules. However, battery is charged at constant 260V and connected to a single phase VSI to feed the ac consumer loads. Figure 1 shows the proposed system configuration.

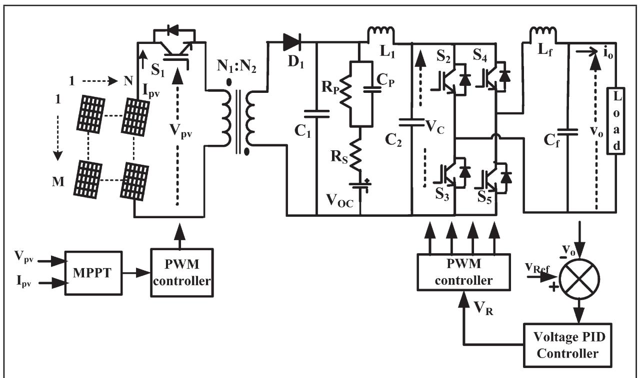

FIG. 1 PROPOSED SYSTEM CONFIGURATION OF SOLAR-PV SYSTEM

The case studies are considered as shading on a single panel of series/ parallel connected cells and shading on multiple panels. The MPPT controller is designed using analgorithm based on the conventional perturb and observation method. The proposed method is designed to determine the value of perturb in each cycle.

3.0 DESIGN AND MODELING

The solar panel is modeled using a single diode model considering the number of cells in series and parallel. Two models of panel (panel-A and panel-B) are modeled for series and parallel connected cells and the system design includes a designing of a flyback converter, MPPT controller, PWM controller for VSI and an output filter. The detail design is presented as follows.

3.1 Modelling of PV Array

The solar cell is having non-linear power characteristics with environmental conditions. The solar-PV array is modeled using a conventional single diode model [9-10]. The panel of 250W is having numbers of cells connected together to append up to 250W power. Two panels are modeled with different cell arrangements for studying the effects of shading. The output current of solar cell can be shown as,

$$I_{PV} = I_{pvt} - I_d \left\{ \exp\left(\frac{V_{PV} + R_a}{V_t N} \right) - 1 \right\} \quad ....(1)$$

Where, I_{PV} = output current of PV, V_{PV} =output voltage of PV, $V_t = N_s KT/q$ = thermal voltage of array, Ns number of cells connected in series, q = electron charge (1.60 e^{-19} C), k = the Boltzmann constant (1.380 e^{-23}J K^{-1}),T = temperature of the p-n junction (K), K and N =the diode ideality constant.

Here I_{pvt} is current produced by a photovoltaic cell, it is function of solar irradiance and temperature. The diode saturation current, I_d is function of temperature, which is expressed in equation (12) and equation (13) as.

$$I_{pvt} = (I_{pv} + K_a \Delta T)\frac{G_1}{G_2} \quad ....(2)$$

$$I_d = \frac{I_{sc} + K_a \Delta T}{\exp\left(\frac{V_{oc} + K_b \Delta T}{N V_t} \right) - 1} \quad ....(3)$$

where, I_{pvt} is the light generated current at the nominal condition which are 25°C and 1000 W /m^2, $\Delta T = T_1 - T_2$, T_1 and T_2 = actual and nominal temperature in Kelvin, G_1 (W/ m^2) =value of solar irradiation by the PV surface and G_2 =the nominal value of solar irradiation, K_a = short-circuit current/temperature coefficient, K_b open-circuit voltage/temperature coefficient, I_{SC}short-circuit current, V_{OC} open-circuit voltage under the nominal condition.

The N_P is number of cells in series and N_S is number of cells in parallel. For 250W panel total no. of cells is 60, panel-A is modeled considering as 6 series cell and 10 parallel cells and second case panel-B, when 10 series cells and 6 parallel cells.Figure 2 shows the characteristics obtained from the panel-A and Figure 3 shows the characteristics of the second panel. Under STC i.e. 1000 W/m^2 solar radiations and 25°C of cell temperature the characteristics obtained from the model for the 2 kW solar array (4X2) are shown in Table 1.

TABLE 1

PARAMETERS OF SOLAR-PV ARRAY WITH DIFFERENT MODULES

S.No.	Parameter	Array using module-I	Array using module-II
1	V_{mp}	122	73.2
2	V_{oc}	150	90.2
3	I_{mp}	16.4	27.2
4	I_{oc}	17.2	28.6

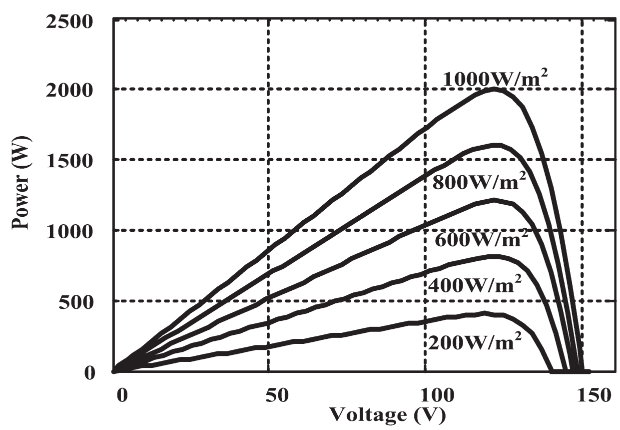

FIG. 2 (A) POWER-VOLTAGE CHARACTERISTICS OBTAINED FROM THE PANEL-A

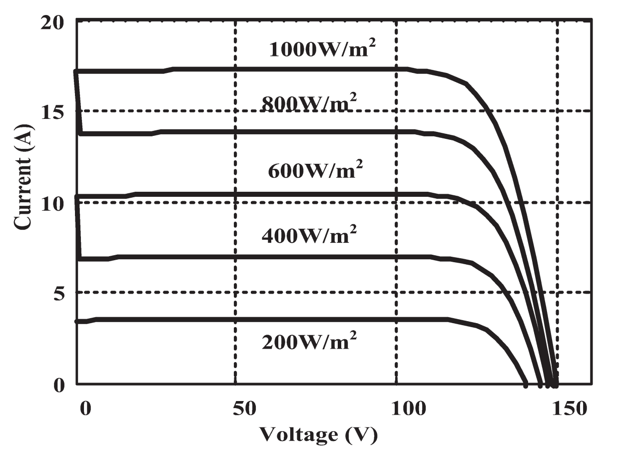

FIG. 2 (B) CURRENT-VOLTAGE CHARACTERISTICS OBTAINED FROM THE PANEL-A

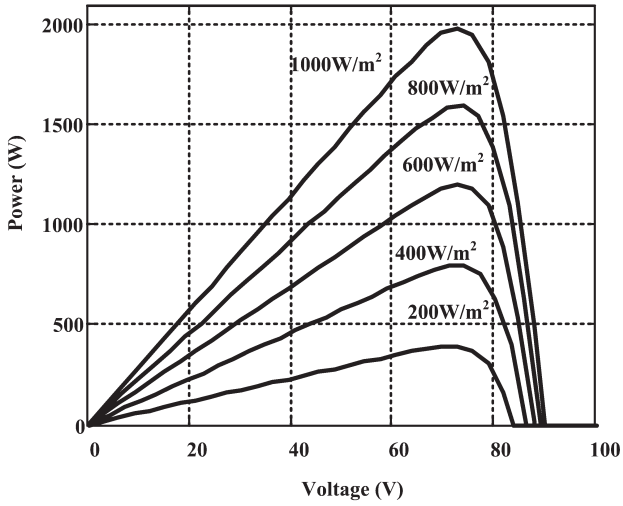

FIG. 3 (A) POWER-VOLTAGE CHARACTERISTICS OBTAINED FROM THE PANEL-A

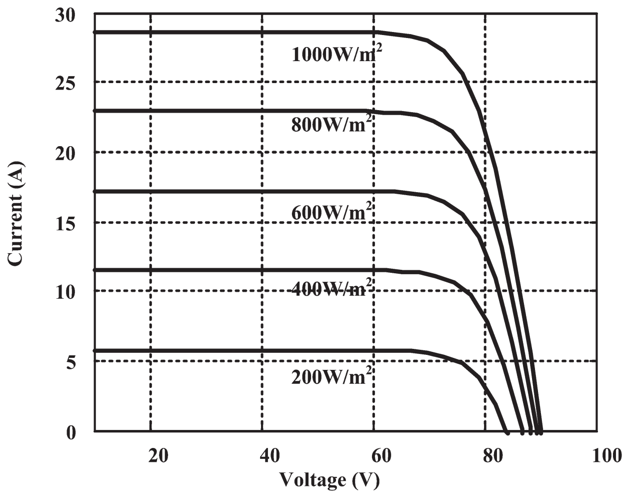

FIG. 3 (B) CURRENT-VOLTAGE CHARACTERISTICS OBTAINED FROM THE PANEL-B

Characteristics of solar array, considering both the panels under different solar radiations are shown in Figure 2 and Figure 3. The rated power of both arrays is 2 kW but the voltage and current characteristics are different due to different cell arrangements. The output voltage of array-A is in the range of 120-150V and in case of array-B is 80-100V.

3.2 Design of DC-DC Converter

The isolated flyback converter is used for the MPPT control and battery charging application. Isolated flyback dc-dc converter is derived form of a buck-boost converter, where the inductor is replaced by a transformer and the primary to secondary winding ratio is determined for desired output voltages [11]. It also provides an advantage as it does not require an output inductor, the voltage regulation in this case is achieved through a MPPT controller combining with PWM control for generation of switching signals [12]. The flyback converter is designed considering the input voltage (60-140V), output voltage (240V), switching frequency (10kHz)and rated power as 2kW. Eq. (4) - (6) are used to design the parameters for the flyback converter as,

$$V_{oc} = V_{in} \cdot \left\{ \frac{d_1}{1-d_1} \right\} \cdot \frac{N_2}{N_1} \quad ....(4)$$

$$L_m = \frac{V_{in.} d_1}{f_{s1} . \Delta i_{Lm}} \quad ....(5)$$

$$C_1 = \frac{V_{OC.} d_1}{f_{s1} . R . \Delta C_1} \quad ....(6)$$

Where, f_{s1} (Switching Frequency)=10kHz, L_m (magnetizing Inductance), V_{OC}(output voltage)=240V, V_{in}(Input voltage), C_1 (output capacitance, n (Turns ratio for flyback transformer), P_{omax}(maximum output power)=2000W, d_1(duty cycle for operation in DCM)=0.5. The design values obtained for turns ratio as 1:4, magnetizing inductance as 0.7mH, output capacitor as 100μF, considering the ripple current in the inductor as 20% of the rated current and ripple voltage at the output side as 2% of rated output voltage.

3.3 MPPT Control Algorithm

For modelling of MPPT controller the conventional perturbation and observation method is used with the generation of the step in each cycle. For a given perturbation on the voltage of the panel leads to an increase (decrease) the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. As a consequence of the P&O algorithm, when the MPP is reached, the system may oscillate around it and this problem can be overcome by reducing the perturbation step size [13-14] . The step value is calculated by the ratio of change in power to the change in the voltage. Figure 4 shows the operating flowchart of P&O algorithm, where V_{pv} and I_{pv} are output voltage and current of PV array and k is the value of variation in voltage to compute next perturbation. Here for modeling of this algorithm in Matlab, the s-function method is used, and the perturbation direction is decided by comparing the PV output power on three points of the characteristics curve. Figure 4 shows the flowchart for the proposed algorithm.

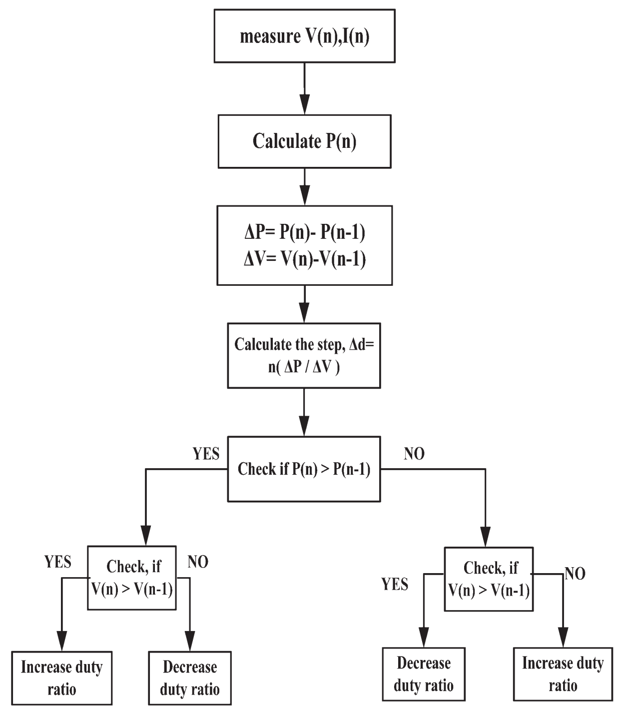

FIG. 4 MPPT ALGORITHM

3.4 Design of VSI and Filter

A single phase voltage source inverter (VSI) is selected as dc-ac converter. After selecting the VSI topology, the next step is to select its device ratings. To calculate the rating of VSI switches a rated load condition as well as non-linear operating conditions of the load is considered. An average load of the system is considered as 1kW. Thus the VSI is designed to withstand at this load as well as non-linear loads [15], the voltage and current of the switch is calculated as 600V, 32A. A closed loop control is also applied for changing the duty cycle of the VSI switches for maintaining the output voltage of the system under varying load conditions using reference sine wave voltage and a PID voltage controller [16]. The LC filter is designed to filter the higher order harmonics and supply the consumer load at 50Hz. The value of filter inductor and capacitor is calculated using Eq. (7-8) as,

$$L_f = \frac{V_{dc-}V_o}{I_{L_f}} f_{s2}.d_2 \quad \text{....(7)}$$

$$f_c = \frac{1}{2\pi\sqrt{L_f C_f}} \quad \text{....(8)}$$

The filter inductance is calculated as 1.2 mH and the value of capacitance is calculated as 14.7μF, considering the resonance frequency at 3kHz.

3.5 Output Voltage Regulator

A PID voltage controller is used for regulation the voltage under load variation. Ziegler-Nichols method is used for tuning of PID controller. Ziegler and Nichols have suggested that the value of K_p (proportional gain), K_i (integral gain) and K_d (derivative gain) can be found by set the controller in the proportional mode and increasing the gain until an oscillation takes place [17]. The period of oscillation (P_c) is measured when the amplitude of oscillation is quite small and the crossover frequency (ω_c), the critical gain (G_c) is obtained from the Nyquist and root locus plot. The response of the system has been measuren in the matlab, using model tuning tools. After obtaining all these values, Ziegler Nichols has suggested [16], that one can set the values of the parameters K_p, K_i and K_d according to the equation (9-11) as,

$$K_p = 0.2G_c \quad \text{....(9)}$$

$$K_i = 0.5\,K_P/P_c \quad \text{....(10)}$$

$$K_i = K_P P_c / 3 \quad \text{....(11)}$$

where K_p, and K_i, are the proportional and integral gains respectively. G_c is critical gain of the system. P_c is period of oscillation. G_{PI} is gain of PI controller. It is observed that for optimum performance of the controller to guarantee intersections between the triangular and the error signal, it is necessary to set the proportional gain K_p, to unity and the integral gain K_i, equal to the frequency of the triangular waveform. Here they are determined and set accordingly, K_p is set to 2.1 and K_i is 0.005 and K_d is 0.3.

4.0 CASE STUDIES AND RESULTS

The performance of proposed system is analyzed in different shading conditions considering both types of panels and results are presented as follows.

4.1 Partial Shading Case-1

This case study is based on the shading on a single panel, under this study the shading is considered in east-west direction and the amount of shading is taken as 50% of the panel area, considering the radiation of 1000W/m^2 at remaining panel area. The results obtained from both the panels under the same situation are presented in Figure 5 and Figure 6.

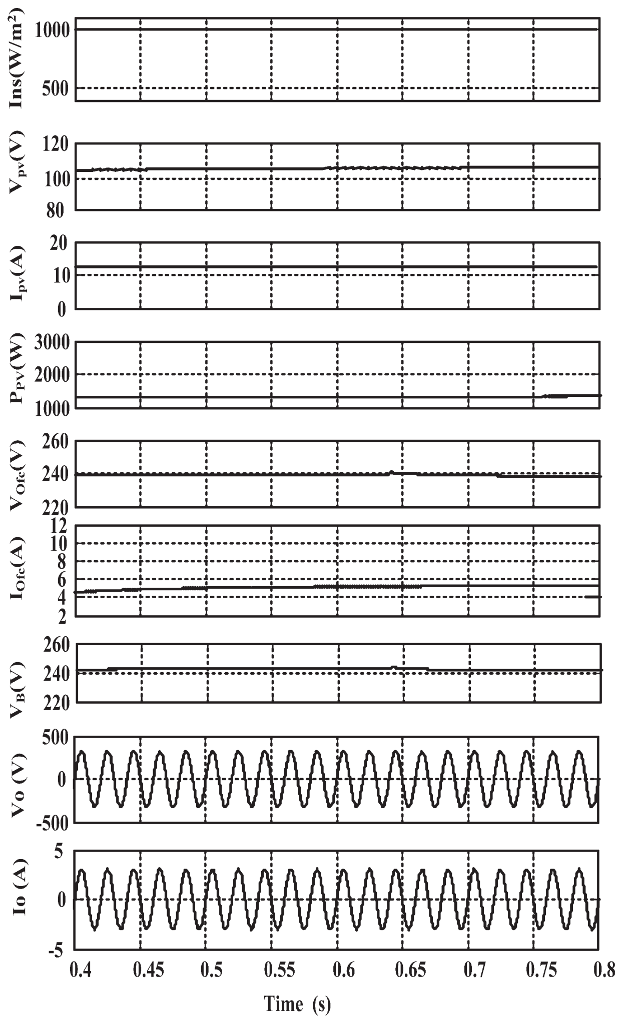

FIG. 5 PERFORMANCE OF THE SYSTEM CONSIDERING PANEL-A

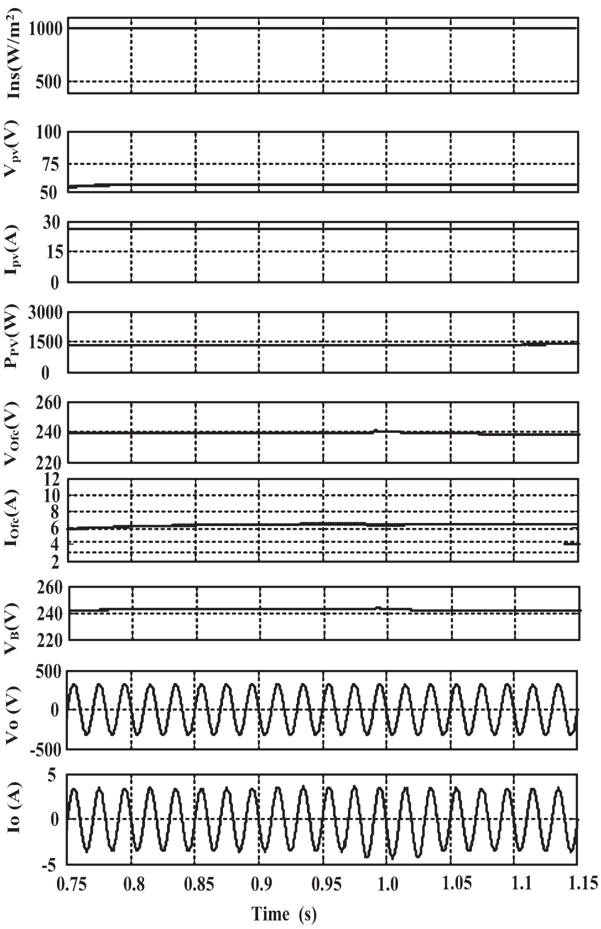

FIG. 6 PERFORMANCE OF THE SYSTEM CONSIDERING PANEL-B

From Figure 5 and Figure 6 it can be observed that the output power of the system is reduced to the 1374W, due to shading while the power output of the system using panel-B is still on the higher side. The output voltage and current of PV array (V_{pv} and I_{pv}) is varying due to variation in the output voltages of both the panels. While the output voltage from dc-dc converter is same, thus it verifies the voltage regulation by the designed controller. The battery is charged at this voltage and the output voltage and current of VSI is observed as sinusoidal. Under this case the performance of panel-A based system is better that the panel-B based system

4.2 Partial Shading Case-2

This case study is further extended under shading on a single panel but in different direction, under this study the shading is considered in north-west direction and the amount of shading is taken as 50% of the total panel area. The results obtained from both the panels under the same situation are presented in Figure 7 and Figure 8.

From Figure 7 and Figure 8 the performance of the system considering both the panels in case of north-south shading can be observed. Under this case it can be seen that the power output from the panel-A based system is on the higher side that the panel-B based system. The performance of both the panels is now reversed from the previous case study. In the Figure 7 there is variation the output current is observed that is due to load variation and under the varying load condition the output voltage remains same, thus the PID based output controller performance is verified.

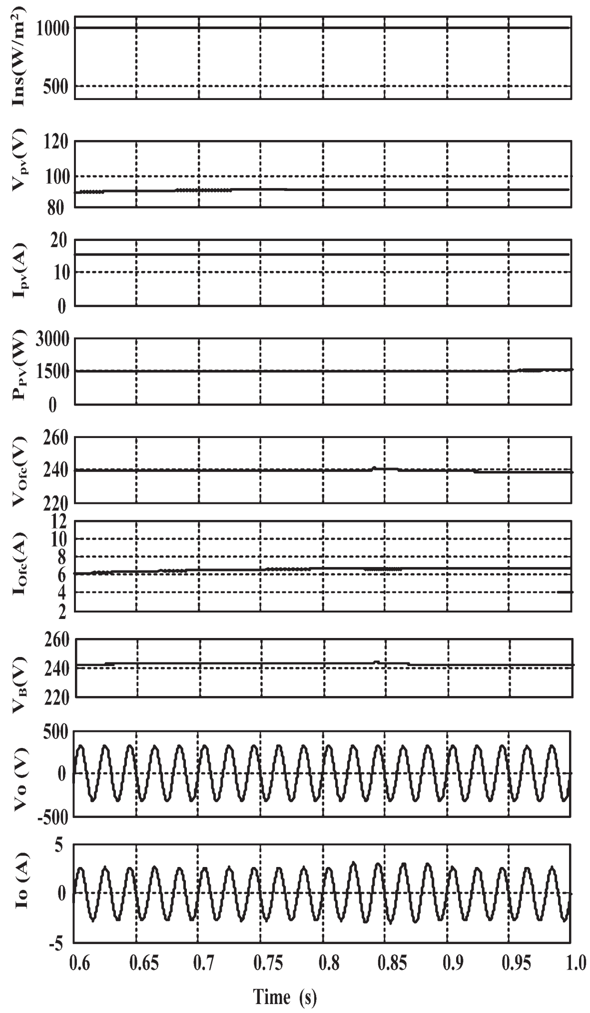

FIG. 7 SHOWS THE RESULTS FROM PANEL-A

4.3 String Shading Case-1

Now the studies have been carried out for the shading in the whole string, this case study is presenting the effects of shading on multiple panels, under this study the shading is considered in east-west direction and the amount of shading is taken same as 50%. The results obtained from both the panels under this case are presented in Figure 9 and Figure 10.

Under this case again the panel-B based system performance is better as it has higher output power generation under same radiation and same case of shading. The output power of the panel-A based system can be seen at 750 W, while the panel-B based system is generating the 1059 W power. The load variation in the output current of VSI can be observed, with the steady output voltage.

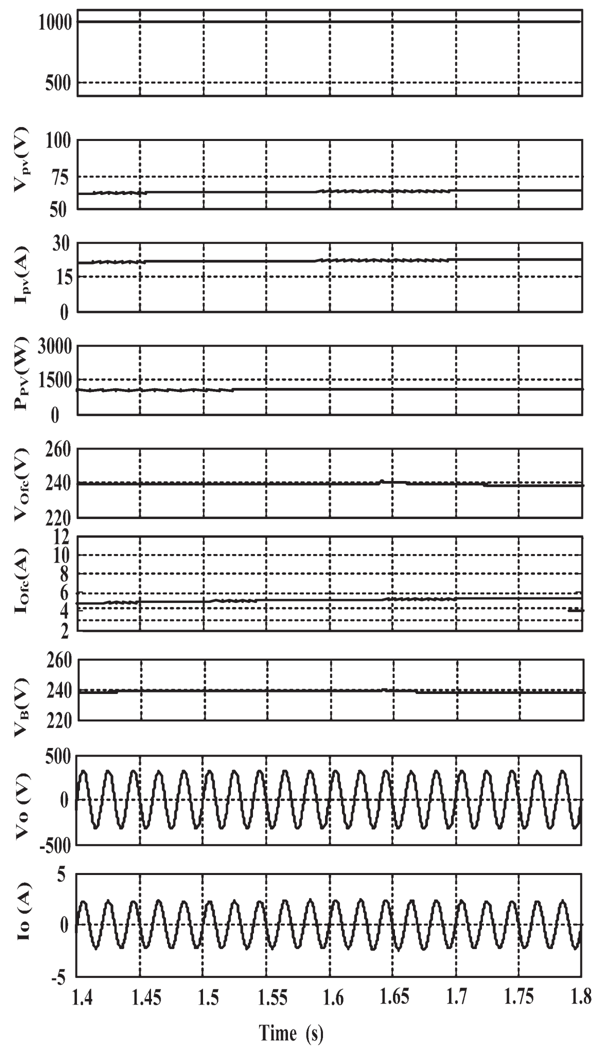

FIG. 8 SHOWS THE RESULTS FROM PANEL-B

4.4 String Shading Case-2

The effects of shading on multiple panels are further carried out in north-south direction considering both the panels, under this study the shading is considered as 50%. The results obtained from both the panels under the same situation are presented in Figure 11 and Figure 12

From Figure 11 and Figure 12 it can be observed that under this case of shading panel-A based system performs better that the other one. As the power output from the panel-A based array is 1489 W while the panle-B based system generates only 878 W.

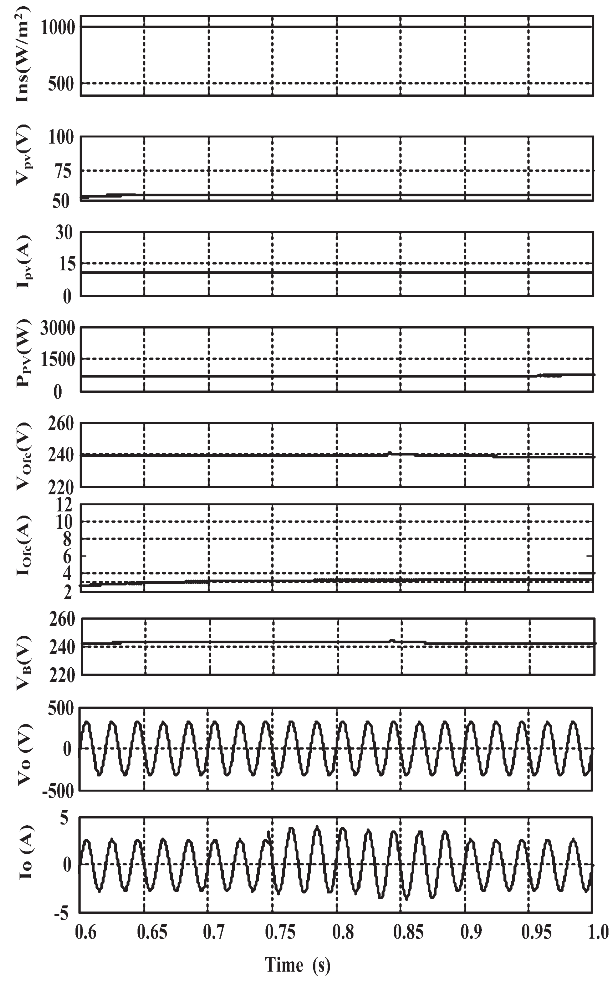

FIG. 9 SHOWS THE RESULTS FROM PANEL-A

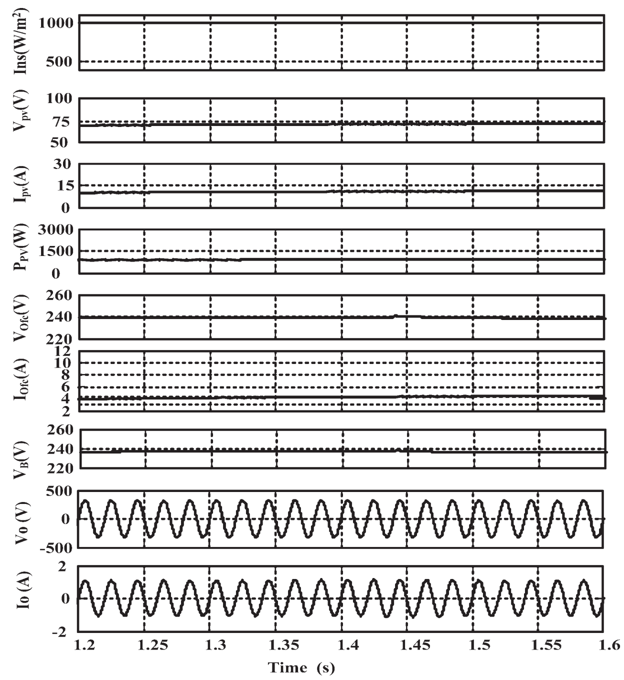

FIG. 10 SHOWS THE RESULTS FROM PANEL-B

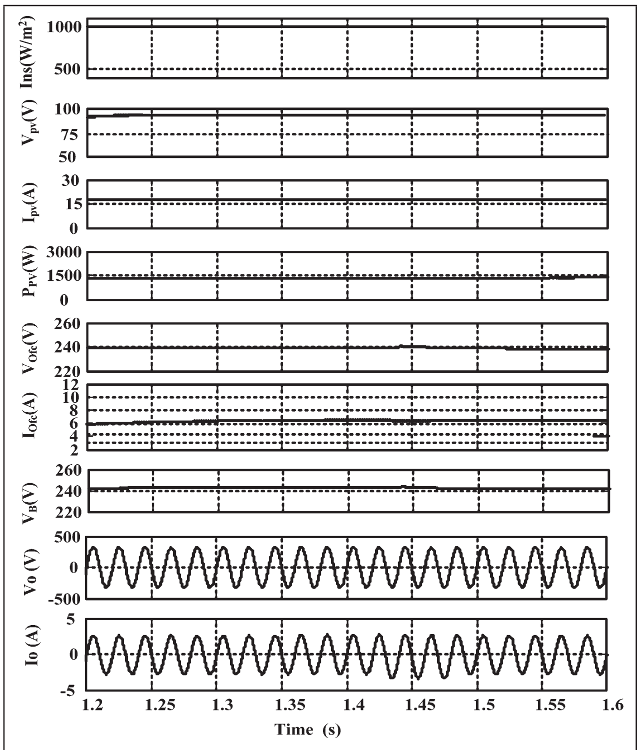

FIG. 11 SHOWS THE RESULTS FROM PANEL-A

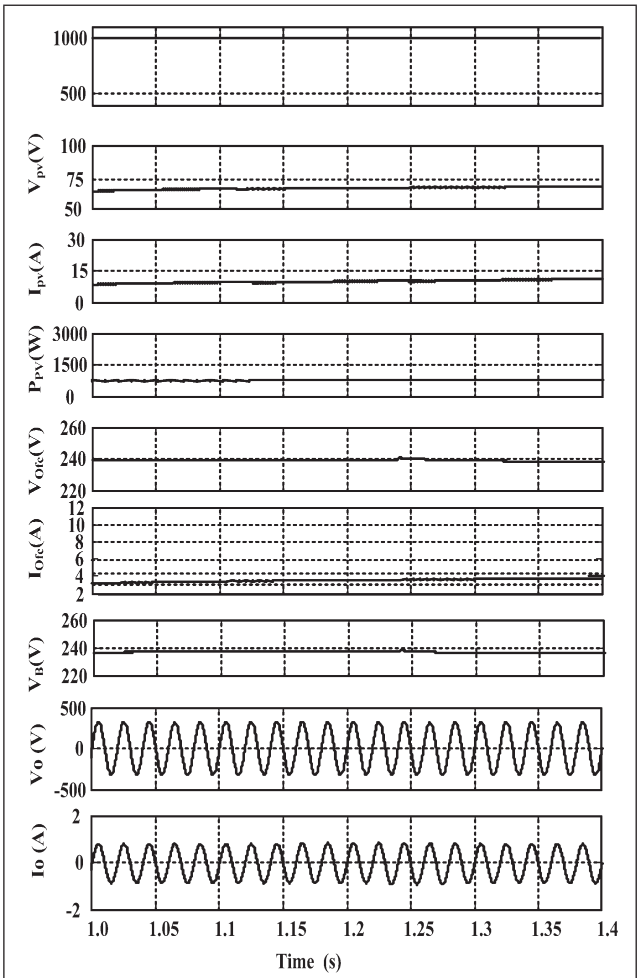

FIG. 12 SHOWS THE RESULTS FROM PANEL-B

5.0 CONCLUSION

The design and performance study of a standalone solar PV energy system under different shading conditions has been carried out considering a system with flyback converter, battery and a single phase voltage source inverter. The battery charging has been achieved through maximum power tracking which improves system efficiency and gives sufficient backup. The controller performance under various load conditions has been investigated and it has been found to perform satisfactorily under nonlinear load conditions. Performance of the system for the load variation is regulated using a feedback PID control. The shading case studies are presented to evaluate the performance of the system that can be taken care of while implementing a plant.

REFERENCES

[1] H. Patel and V. Agarwal, "Maximum Power Point Tracking Scheme for PV Systems Operating Under Partially Shaded Conditions," IEEE Tranasction on Industrial Electronics, Vol. 55, No. 4, pp. 1689-1698, April 2008.

[2] C. Deline, J. Meydbrey, M. Donovan and J. Forrest, "Photovoltaic Shading Testbed for Module-Level Power Electronics," NREL Technical Report NRELTP-5200-54876.

[3] Benavides, N. D and P. L. Chapman, Modeling the Effect of Voltage Ripple on the Power Output of Photovoltaic Modules., IEEE Transactions onIndustrial Electronics, Vol. 55, No. 7, pp. 2638-2643, 2008.

[4] De Soto, W., S. Klein, and W. Beckman, Improvement and validation of a model for photovoltaic array performance, Journal of Solar Energy, Vol. 80, No. 1, pp. 78-88, 2008.

[5] T. Noguchi , S. Togashi and R. Nakamoto "Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic and converter module system", IEEE Transaction on Industrial Electronics, Vol. 49, No. 1, pp.217 -, 2002.

[6] E. V. Solodovnik , S. Liu and R. A. Dougal "Power controller design for maximum power tracking in solar installations", IEEE Transaction on Power Electronics, Vol. 19, No. 5, pp.1295 -1304, 2004.

[7] Young-HyokJi, Doo-Yong Jung, Chung-Yuen Won, Byoung-Kuk Lee, Jin-Wook Kim , "Maximum power point tracking method for PV array under partially shaded condition," Energy Conversion Congress and Exposition, 2009. ECCE 2009. pp.307-312, 20-24 Sept. 2009.

[8] K. Kobayashi , I. Takano and Y. Sawada "A study on a two stage maximum power point tracking control of a photovoltaic system under partially shaded insolation conditions", Proc. of IEEE Power Engineering Society General Meeting, pp.2612 -2617 2003.

[9] Michael Jensen, Russell louie, Mehdi Etezadi and M.Samifadali, "Model and Simulation of 75kW PV Solar Array", IEEE Transmission and Distribution Conference and Exposition, April 2010, New Orleans, LA, USA.

[10] Masoum, Ali S.Padovan, Frank Masoum, Mohammad A.S. "Impact of partial shading on voltage- and current-based maximum power point tracking of solar modules," 2010 IEEE Power and Energy Society General Meeting, pp.1-5, 25-29 July 2010.

[11] K. Zhang, T. X.Wu, H.Hu, Z. Qian, F.Chen, K.Rustom, N.Kutkut, J.Shen and I.Batarseh, "Analysis and design of distributed transformers for solar power conversion," 2011 IEEE Applied Power Electronics Conference and Exposition (APEC), pp.1692-1697, 6-11 March 2011.

[12] Q. Li and P. Wolfs, "A review of the single phase photovoltaic module integrated converter topologies with three different DC link configurations," IEEE Transactionon Power Electronics, Vol. 23, No. 3, pp. 1320-1333, May 2008.

[13] M. Jain, M. Daniele, and P. K. Jain, "A bidirectional DC-DC converter topology for low power application," IEEE Transaction on Power Electronics, Vol. 15, No. 4, pp. 595-606, Jul. 2000.

[14] Linear Techonology Application Notes Datasheet of Isolated Flyback Converter Without an Opto-Coupler, http://cds.linear.com/docs/Datasheet/3574f

[15] Abdel Rahim Naser M andQuaicoe John E, “Analysis and design of a multiple feedback loop control strategy for single-phase voltage-source UPS inverters,” IEEE Transactions on Power Electronics, Vol. 11, No. 4, pp. 532-541, July 1996.

[16] Tzann-Shin Lee, S. J. Chiang, and Jhy-Ming Chang, "Loop-shaping controller designs for the single-phase UPS inverters," IEEE Trans. Power Electon., Vol. 16, No. 4, pp. 473-481, 2001.

[17] Hua C. "Two-level switching pattern deadbeat DSP controlled PWM Inverter," IEEE Trans. Power Electronics, Vol. 10, No. 5, pp. 310-317, 1995