Effects of Solar Irradiance on Load Sharing of Integrated Photovoltaic System with IEEE Standard Bus Network

Rabindra Nath Shaw, Debayan Basu, Pratima Walde, Ankush Ghosh

Abstract**: *This paper attempts to highlight the effect of change in load and irradiance on Photovoltaic integrated Power system network. The Power system network considered here is IEEE 14 bus system. The simulation is done on MATLAB platform and variation of Voltage, Power and Total Harmonic Distortion (THD) has been studied. The results indicates that how power quality of the power system is affected by the irradiance on Photovoltaic cell. The study is performed considering the other environmental factors such as wind velocity, ambient temperature and humidity have a negligible effect on the photovoltaic module. In a steady-state controlled environment, the simulation results show that the output voltage, current and its power decrease with time as the irradiance on the photovoltaic panel decreases.***

Keywords: Photovoltaic cell, panel temperature, power quality, solar irradiance.

I. INTRODUCTION

Now a days, the global power industry is transiting towards the Renewable energy system. This is not only to mitigate the increasing demand of power throughout the world but also to protect the environment from adverse effects of burning of fossil fuels. It is well known that to get a clean as well as reliable power supply both the renewable and renewable energy system source should be work together and as a result the integration of Photovoltaic (PV) systems is increasing drastically. However, utility companies may be concerned about the implications of variable solar generation on the power quality, its impact on the low-tension (LT) distribution grid. Therefore, there are lot of challenges and issues in integrating distributed energy sources like Photovoltaic (PV) systems [1].

The grid integrated system has some responsibility to maintain a reliable grid supply with respect to harmonics [2], flicker [3], and DC injection [4] as they are connected to a power system network. Hence due to the power quality problems power converters are required for interface with grid. Solar photovoltaic (PV) needs only power electronic converters like DC to DC and DC to AC for interconnection. There are three basic interfacing technologies for PV module [5]. Fig. 1 represents block diagram of grid integrated PV system.

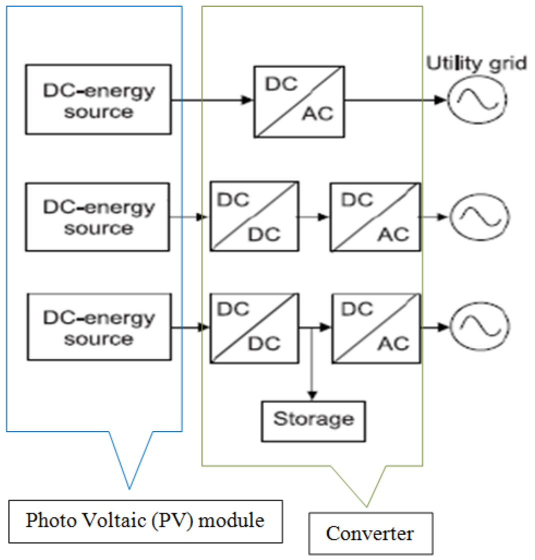

Fig. 1 Block Diagram of Grid Integrated PV System

II. MATERIALS AND METHODS

Fig. 2 represents equivalent circuit of an actual PV cell. The photovoltaic current of the PV cell is

$$I_{ph} = \left[I_{sc} + K_i \cdot (T_c - T_r) \right] \cdot \frac{G}{G_r} \qquad (1)$$

Here,
I_{ph}: Photovoltaic current of the PV cell
I_{sc}: Short circuit current
K_i: Temperature factor of short circuit current
T_c: PV cell temperature (in Kelvin)
T_r: Reference temperature
G: Solar radiation level under W/m²
G_r: Reference solar radiation level (1000 W/m²)

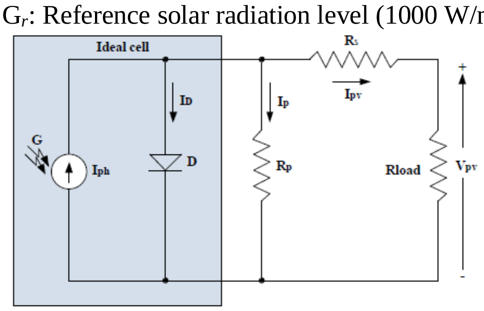

Fig 2. The circuit of PV cell[6]

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Diode current

$$I_D = I_o \cdot \left(e^{\frac{q \cdot V_d}{A \cdot k \cdot T_c}} - 1 \right) \qquad (2)$$

q: Electric charge
k: Boltzman constant
A: Quality factor of diode

Current flowing through the parallel resistance

$$I_p = \frac{V_D}{R_p} = \frac{V_{pv} + I_{pv} \cdot R_s}{R_p} \qquad (3)$$

PV Cell output current

$$I_{pv} = I_{ph} - \left[e^{\left(\frac{q \cdot (V_{pv} + I_{pv} \cdot R_s)}{A \cdot k \cdot T_c} \right)} - 1 \right] - \frac{V_{pv} + I_{pv} \cdot R_s}{R_p}$$

$$\left[I_{sc} + K_i \cdot (T_c - T_r) \right] \cdot \frac{G}{G_r} \qquad (4)$$

$$= \left[e^{\left(\frac{q \cdot (V_{pv} + I_{pv} \cdot R_s)}{A \cdot k \cdot T_c} \right)} - 1 \right] + \frac{V_{pv} + I_{pv} \cdot R_s}{R_p} \qquad (5)$$

From the equation 5 it is concluded that there is a non linear relationship between Photovoltaic current (I_{ph}) and Solar radiation (G) Photovoltaic current of the PV cell.

PV Cell output voltage is

$$V_{pv} = V_D - I_{pv} \cdot R_s \qquad (6)$$

There is a voltage fluctuation at the output of the PV module due to irradiation, partial shading effect which makes the voltage flicker.

III. POWER QUALITY ISSUES

The converter portion in Fig. 1 is designed with non-linear power electronics appliances, produced various power quality related problems as mentioned in table 1 when connected to grid.

Table- I: Categories of Power Quality Problems [7]

S. No.	Cause	Effect
1.	Harmonics	Frequency disturbance Waveform distortion
2.	Low Power Factor	Low power factor causes equipment damage Increases in Energy bills
3.	Transients in Power System	Produces distortion like impulse and notches Long and Short duration event
4.	Electro Magnetic Interferences	Interference between electric and magnetic field High frequency phenomenon
5.	Power Frequency Disturbances	Low frequency phenomenon Produces voltage sags and swells
6.	Low Power Factor	Low power factor causes equipment damage Increases in Energy bills
7.	Transients in Power System	Produces distortion like impulse and notches Long and Short duration event
8.	Electro Magnetic Interferences	Interference between electric and magnetic field High frequency phenomenon
9.	Power Frequency Disturbances	Low frequency phenomenon Produces voltage sags and swells

Among the various power qualities related problems Sl. No. 1 and 9 are applicable in case of power electronic converter used in PV system. Apart from the converter many power electronic devices are used to maintain to voltage level of the system and those are also contributor of harmonics.

IV. MODELING OF PV INTEGRATED POWER SYSTEM

The operation of Grid integrated PV module has been done in MATLAB platform. Fig. 3 represents the simulink model of integrated PV module. The utility grid considered as IEEE 14 bus system.

V. IEEE 14 BUS SYSTEM

IEEE 14 bus system consists of 14 numbers of buses, 5 numbers of generators, and 11 numbers of loads [Fig 4]. The PV model has 66 strings with 5 series-connected PV modules that are connected in parallel. Each PV module has 96 numbers of series-connected cells. The open circuit voltage (Voc) and short-circuit current (Isc) of PV module is 64.2 V and 5.96 A, respectively. The Voltage (V) and current (I) of PV module at maximum power is 55 V and 5.5 A, respectively. The PV array delivers a maximum power of 100 kW at 1000 W/m^{2}sun irradiance. 5-kHz DC-DC boost converter increases the PV natural voltage from 275 V DC to 500 V DC. MPPT controller automatically varies the duty cycle in order to generate the required voltage to extract maximum power. 1980-Hz 3-level 3-phase VSC converts the 500 V DC link voltage to 260 V AC and keeps unity power factor. 10-kvar capacitor bank is used for filtering harmonics produced by VSC. A 100-kVA 260V/25kV three-phase coupling transformer is used to connect the converter to the bus 9 of IEEE 14 bus system [Fig 5].

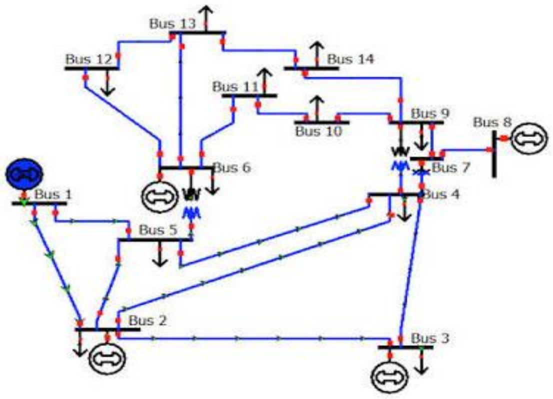

Fig 4. IEEE14 BUS system

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VI. SIMULATION

For simulation, Grid and PV power output is plotted with the variation of irradiance is for a fixed load connected in the distribution system. From equation 5 and 6 mathematically it has proven that variation in irradiance will have an impact on the power generation of PV system.

For analysis we have selected that PV output power as 100 kW. The input irradiance to the PV array model is initially set at 1000 W/m^2. It is shown that that PV voltage under steady-state is 300V.

VII. RESULTS AND DISCUSSIONS

At t=3 sec, irradiance is varied from 1000 W/m^2 to 50 W/m^2.

The power output of PV will be less for the low value of irradiance. Here the irradiance is changed from 1000 W/m^2 to 50 W/m^2 at time (t) = 3 sec.

The power output from PV array is limited to 25 kW, when irradiance reaches at 50 W/m^2. Again at t=6 sec, as the irradiance is increased from 50 W/m^2 to 1000 W/m^2, PV power increases and reached to its rated maximum power at t=8.5 sec.

Irradiance is kept constant at 50 W/m^2 from t=5.5 to t=6 sec and then further becomes normal to 1000 W/m2 at 8.5 sec. Consider a case of 100 kW load connected in the system.

The variations in various parameters with respect to time are represented graphically as in the fig.6.

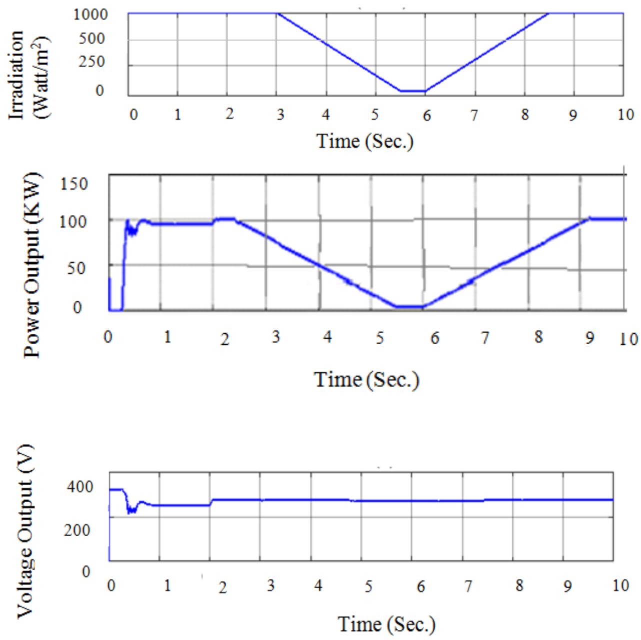

Fig. 6. Variation of Output of Grid integrated PV system with change in Irradiance with respect to time

During this period Load sharing overall PV integrated System as well as of PV system separately has also been studied and represented graphically in fig. 6 and 7.

In fig. 4, Load sharing overall PV integrated System as well as of PV system separately has also been plotted up to the steady state operation of PV System.

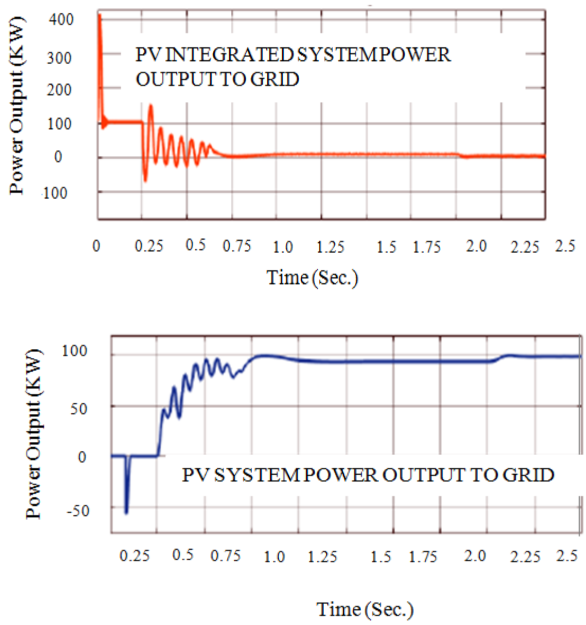

Fig. 7. Power Output of Grid integrated PV system and PV System separately with respect to time (up to the steady state period)

From the fig. 7, it is observed that during time (t) = 0 to 0.25 sec. the power output of PV integrated System is 100 kW and power output from PV system is 0 kW, hence it is concluded that during the initial period, the load is mainly shared by non existing power system, in between t=0 and 0.25 sec. the power output from PV system becomes negative and this may be due to the inductance and capacitance present in converter of PV system. From t=0.25 sec. power system oscillation starts and PV system gradually comes into picture and nearly at t=0.78 sec. PV system takes the load over the entire 100 kW load from existing power system and the PV system operates at steady state condition.From equation 5 it is observed that the solar irradiance has a large impact on PV output and typical V-I characteristics of a PV cell is presented in fig. 8.

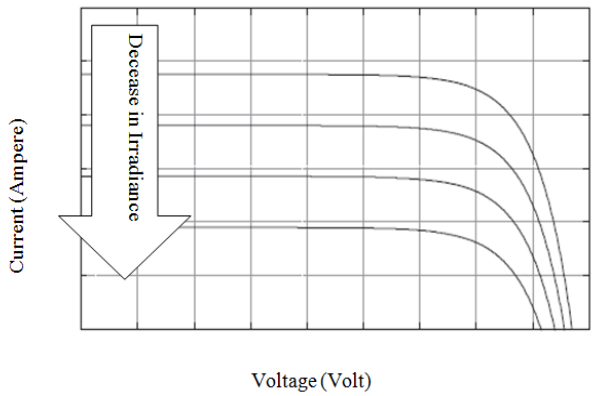

Fig. 8. Performance of PV system with varying irradiance and constant temperature

From the fig. 8 it is observed that effect of irradiance is a major concern because short circuit current, open circuit voltage are changed as a result the cells become reverse biased by other cells in PV module and thus exhibit higher resistance and non uniform temperatures in the entire area of the solar cell. High power dissipation in a small area can cause breakdown in localized regions of the PV cell's p-n junction and can damage an entire module by creating hot spots. Variations and irradiance then a large circulating current will flow through it, which results in excessive heating and formation of hot spots; if used for a long period.

Now the load sharing overall PV integrated System (existing power system) as well as of PV system separately has been plotted studied and plotted in fig. 6. It is observed that changing the value of irradiance will have an impact on the power generation of PV system. Lower the value of irradiance, lower will be the power output of PV module. Here the irradiance is changed from 1000 W/m^2 to 500 W/m^2

At time (t) = 0.5sec. Irradiance is kept constant at 500 W/m^2 from t=0.6 to t=0.7sec and then further becomes normal to 1000 W/m^2 at 0.8 sec. Consider a case of 100 kW load connected in the system. The maximum power that PV system generates comes out to be 100 kW at 1000 W/m^2. However, at t=0.6 sec, PV array is generating only 48 kW under 500 W/m^2 as compared to 100 kW at 1000 W/m^2.

Under this condition, Grid is supplying 52 kW to the load i.e. the deficiency in load power. This is mainly fed from PV and is compensated by the grid power. It is observed that the power curve of the grid system increases proportionally with decrease of solar power.

From Fig. 9 it is observed that when at time t = 0 when the PV module just enter into grid it does cater load immediately but oscillate and reached to the final value of 100 kW and t = 0.5 sec and t = 0.8 sec. when irradiance changes the PV module does act instantaneously. This is due to the power electronic and other reactive components of the converter of the PV module. Partial shading of PV installations has a disproportionate impact on power sharing.

VIII. CONCLUSION

This work shows the impact of solar irradiance on load sharing of PV integrated system thus the integration of the PV module with grid is discussed and verified using MATLAB simulations results. In this simulation it is presumed that the load is invariant when the irradiance is varying. The non linearity of power electronic converter also been studied with the change in irradiance. From the simulation results it can be concluded that in a steady-state controlled environment, the output voltage, current and its power decrease with time as the irradiance on the photovoltaic panel decreases.

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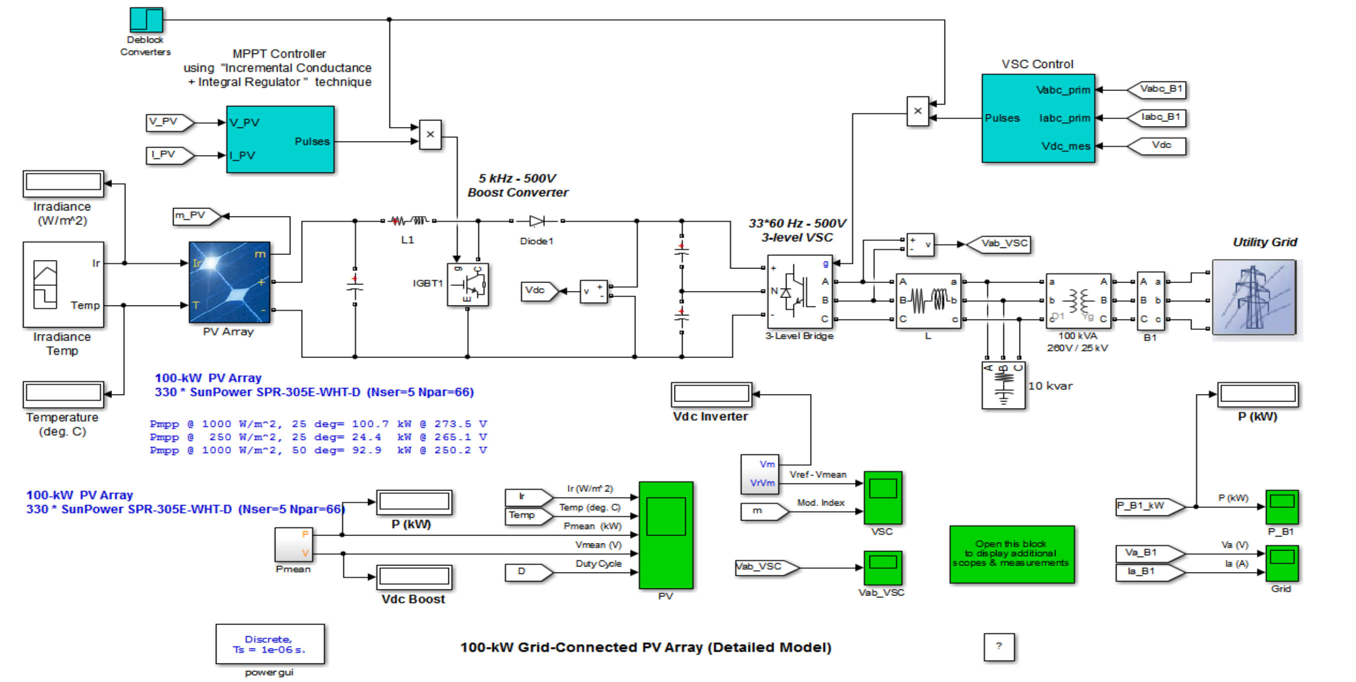

Fig 3. Integrated PV module

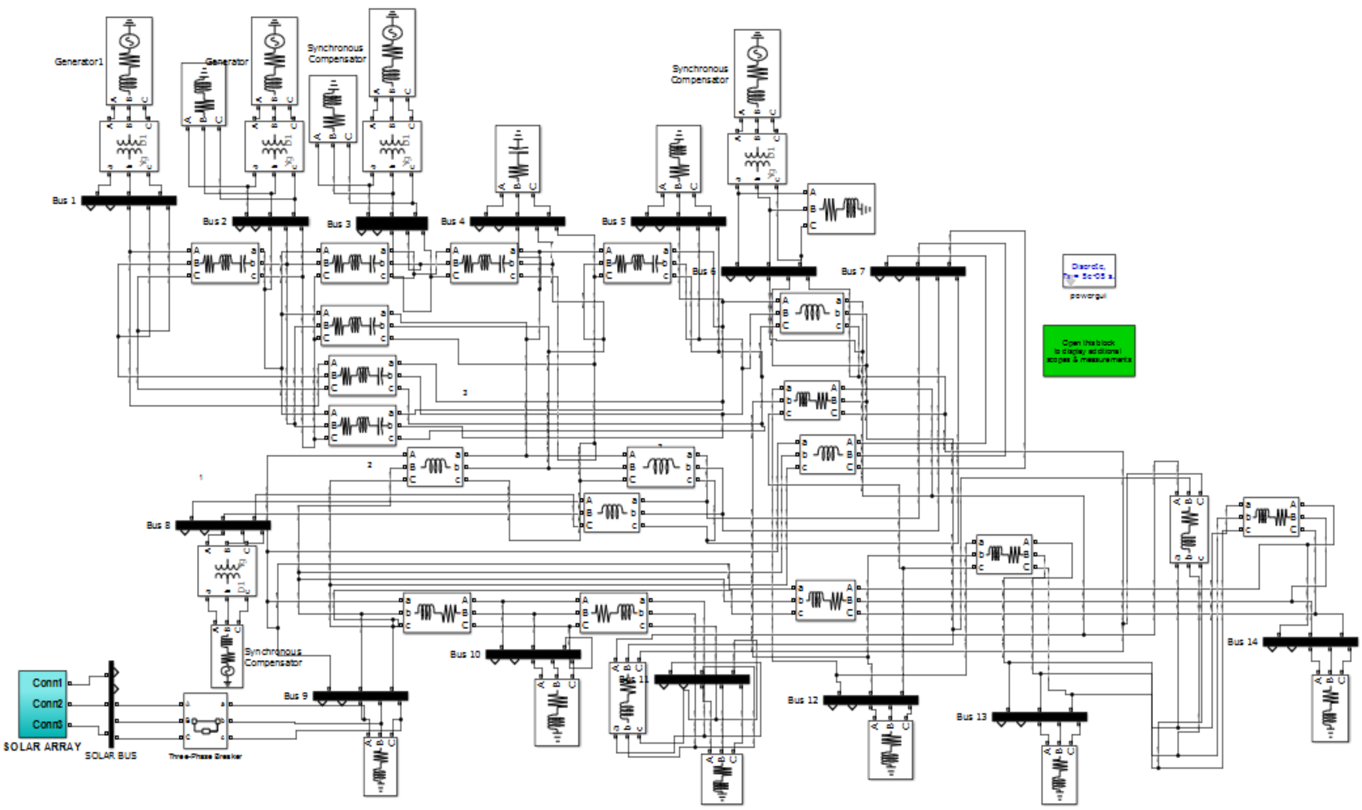

Fig 5. PV Integrated IEEE 14 bus system

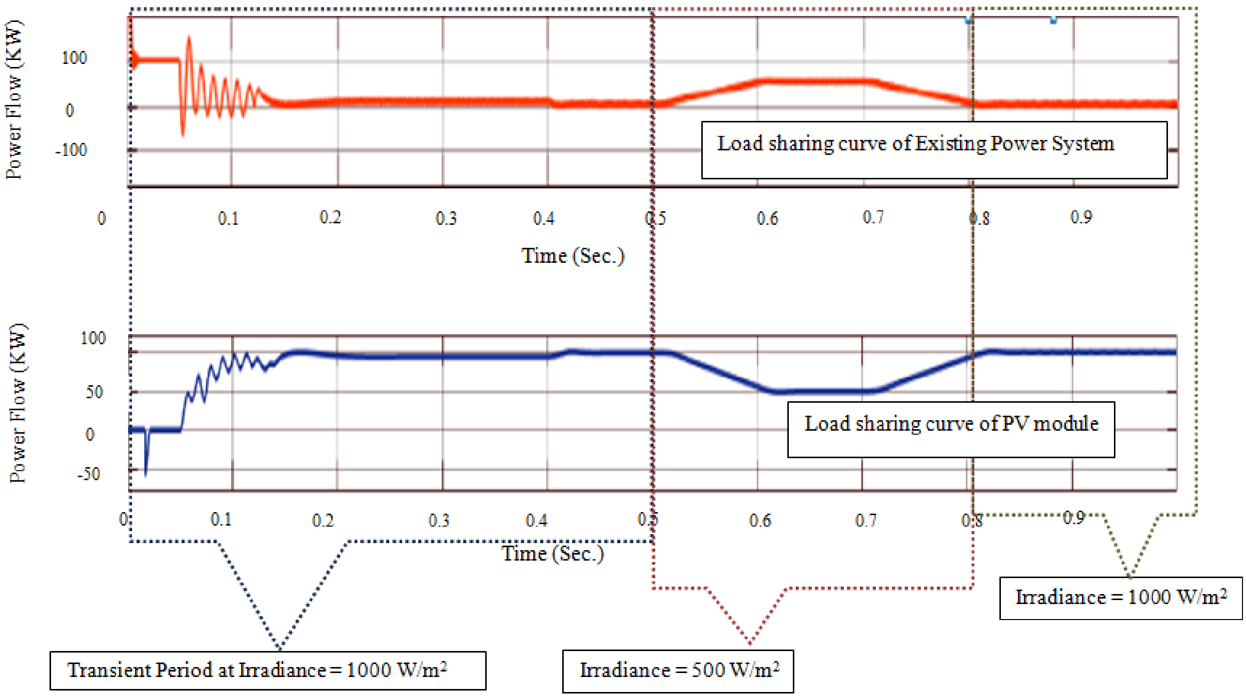

Fig. 9. Flow of Power from Grid and PV under varying Irradiance condition

AUTHORS PROFILE

Rabindra Nath Shaw is doing PhD in Electrical Engineering from Galgotias University, India since 2017. He did his Master of Technology in Electrical Engineering from University of Calcutta, India. He has more than ten years teaching experience in leading institutes in UG and PG. He is the author of several International book chapters, conference Proceedings and Journals. His primary area of research is Renewable Energy, Rural Electrification, optimisation techniques and power Electronics converters. He has successfully organised many International conference as Conference Chair, Publication Chair and Editor.

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