EFFECTS OF PHOTOVOLTAIC POWER TRANSIENTS DUE TO CLOUDS IN GRID INTEGRATED SOLAR PLANT ON POWER SYSTEM - A Review

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Abstract: Photovoltaic power has become a progressively universal alternative source of energy in power systems, as the all the countries looking for alternative energy sources. The work presented in this article discusses the effects that photovoltaic power generation has on the existing power systems. Along with the addition of this emerging alternative energy source comes the volatility of photovoltaic power generation, as cloud passage over plant produces uncertain variations in irradiance and photovoltaic power production. Such unwanted fluctuations in irradiance and power generation may result in unfavorable operating conditions and power system failures. This work presents a review on solar plant grid Integration, stability, power quality problems associated with the plant integration and role of FACTS & power electronic devices related to these issues. The problems discussed in this paper includes, power system failures study caused by PV power fluctuations due to cloud shadow. Such issues must be discussed, so as to provide a better knowledge on the effects that PV power variations occurring due to cloud shadow.

Keywords: Photovoltaic, Grid Integrated Solar Plant, cloud effect, MPPT, power transients

1. Introduction

The recent goal of the 21st century can be described with one word: “sustainability.” Such a word has so many connotations and meanings; most of which, however, pertain to environmental pursuits. Sustainability has not only transformed the consumer world, but also has greatly influenced the energy market as well. No longer is energy only procured via rotating mechanical machines. Such “green” endeavors have evolved the energy production market leading to the emergence of new alternative energies. While photovoltaic generation has been around since the 70’s, applying them in mass quantities to power grids has become a trend only recently. With the growing emergence of PV generation in power systems, the effect of their introduction to traditional grid designs and power protection schemes, and the variability in their power production can lead to unfavorable operating conditions and power system failures.

The traditional power grid comprised of a system of large-scale, high voltage, power procuring, mechanically-rotating generators. The power produced by these generators was delivered long distances over high voltage transmission lines at which point substations stepped down the voltage and dispersed the power among distribution networks. Such a system employed high voltage generation and low voltage distribution networks, where power was solely delivered from the high voltage generation source to the low voltage load. Additionally, the power system protection systems were designed with the assumption that the power system adhered to this traditional system framework.

However, modern technologies have allowed for new sources of generation, such as PV arrays, to connect to power grids, which invalidate traditional power system assumptions and their interdependent protection systems.

When analyzing the effects of incorporating PV generation into a system, one must note that there are two different categories that PV generation usually falls into. The first category is known as distributed generation, which describes small- to medium-scale PV arrays connected at the distribution level. Such PV arrays are privately owned, produce less than a MW of power, and are often connected to a power system for economic and environmental reasons. Such reasons include a reduction in a facility's reliance on the utility grid for power. These privately owned PV implementations are less worried about how their PV generation affects power system reliability and stability and more concerned about how reducing their reliance on utility reduces their economic expenditures in the long run. With the addition of distribution level PV arrays, the current electric grid and its power protection schemes must be re-engineered so as to incorporate these new changes without compromising reliable and safe delivery of power.

The second category of PV generation is known as large-scale generation. PV plants within this category generate in the 10's to 100's of MW of power. With the recent technological advances in photovoltaic energy-conversion efficiencies, large-scale PV generation plants have become more of an economically feasible option. However, the larger a generation source is, the more that deviations in power generation affect the surrounding power system and its protection.

Both small and large scale photovoltaic arrays are affecting with the solar insolation variations which is the amount of radiation received by a panel surface in a given interval of time. Irradiance and solar insolation are frequently used substitutable to explain the amount of the solar radiation received by a PV array. While lesser photovoltaic power generation tends to go after the variations in solar insolation more closely. Larger photovoltaic arrays likely to have more of an inherent delay time and smooth for more gradual power ramp for a given solar irradiance change. However research on the effects that cloud shading has on large scale photovoltaic arrays and their cloud induced power fluctuations still being done. References [1] and [2] discussed the solar irradiance distribution and photovoltaic power fluctuations over a fixed interval of time i e 1 second, 10 seconds, 1 minutes and 10 minute etc. However the magnitude and duration of photovoltaic power changes and solar irradiance have not been utilized to study their effects on power systems and their protective schemes. While research proves that a solar irradiance change leads to photovoltaic array operating voltage variation and output power variation. System planners and operators need to have knowledge on what type of uncertainty and variability are related with photovoltaic power plants Such information would allow in better management of grid to which a photovoltaic system is being connected. Moreover such effects like PV uncertainties and fluctuations on performance of grid or power system also must be studied, so that solutions for unfavorable issues can be developed. Understanding photovoltaic power fluctuations also allow in making of implementable standards for reliability. Conversely standards provide limits recommended for effective operating environment; however they don't explain how to fulfill such requirements [2]. The aim of this work is to examine the cloud shadow effect has on output of PV. Such problems must be studied to have insight knowledge in integrating photovoltaic systems with most reliable, advantageous and cost effective manner.

2. Issues and Challenges

The solar and wind energy integration into existing system results in technical issues like voltage regulation, harmonic distortion, stability and flicker, etc, these power issues are to be confined to IEEE and IEC standards. Research from last few years' shows that these power quality issues can occur at the generation, transmission and distribution [5].

Renewable sources of energy are irregular in nature hence it is therefore a challenging task to integrate renewable energy resources into the power grid. Some of the challenges and issues related with the grid integration of various renewable energy sources particularly solar photovoltaic and wind energy conversion systems. Further these challenges are broadly classified into technical and non-technical and described below.

A. Technical Issues
1. Gird Integration Issues for small scale generation:
    - Cost, Reliability & Efficiency of Grid Interface
    - Grid congestion, weak grids
    - Variability of renewable production
    - Low Power Quality
    - Protection issues
2. Change of short circuit levels
3. Reverse power flow
4. Lack of sustained fault current
5. Islanding
6. Bidirectional power flow in distribution network,
7. localized voltage stability problems

B. Non-Technical Issues
1. Lack of technical skilled man power
2. Less availability of transmission line to accommodate RES.
3. RES technologies are excluded from the competition by giving them priority to dispatch which discourage the installation of new power plant for reserve purpose.

3. Solar Irradiance Transients

Solar irradiance is largely affected by weather changes, ac Weather frequently brings much uncertainty and variation. PV power variations are referred to as photovoltaic power transients. the values of solar irradiance are high in Sunny days while days with cloudy climate limit solar irradiance availability . Hence, large impact will be there on solar irradiance, the panel receives due to clouds. finding the speed at which irradiation varies over time gives useful data for better understanding how rapidly power output from PV would drop if exposed to such changes in solar irradiance [6].

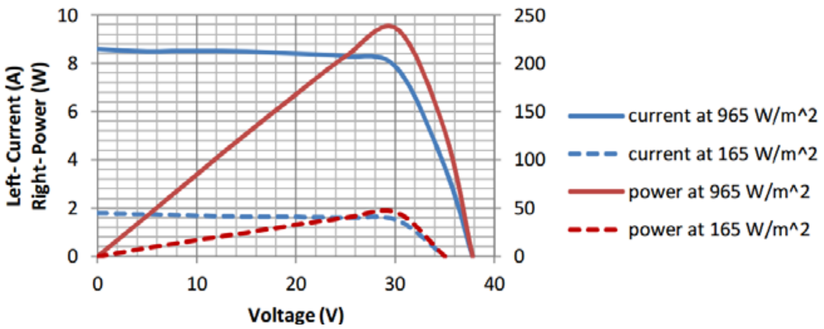

Figure 1. Measured power and I-V curves for the photovoltaic panel without shading, 965 W/m2, and with shading effect at 165 W/m2.

4. Clouds Shadow Effect

The solar irradiance change will affect but not limited, the power output of a photovoltaic module, or photovoltaic string and also the supplied power by the inverter connected to grid. The majority grid-connected photovoltaic systems operate with MPPT controllers. Mainly, MPPT is integrated within inverter setup for the purpose of operating the plant at a point that generates maximum power. However, maintaining photovoltaic array near to its maximum power point is a complex task when the weather conditions leads to solar irradiance variations [6, 7]. In addition, rapid changes in solar irradiance can possibly may lead a photovoltaic system to operate at higher voltage levels which outside the inverter's DC operating values. This situation may force the inverters to shut down and discontinue power supplying to grid. As a result large variations in photovoltaic power output can takes place with simultaneous tripping of inverter. Such power changes due to inverter-tripping frequently exceed the severity and size of any cloud-induced photovoltaic power variations [6, 7].

4.1 Irradiation Vs Current and Voltage

The voltage and current are dependent on the irradiation. The Irradiation available on an area changes for every instant with respect to solar time and clouds passage above the place of measurement. The voltage and current measured in a solar module are related to the irradiation as shown in the formulas below,

$$I_{ref} = I_m \times (1 + \alpha_{rel} \times (T_2 - T_1)) \times \frac{G_{ref}}{G_m}$$

$$V_{ref} = V_m + V_{OCm} \times \left(\beta_{rel} \times (T_{ref} - T_m) + a \times \ln\left(\frac{G_{ref}}{G_m}\right)\right) - R_s \times (I_{ref} - I_m) - K^1 I_{ref}(T_{ref} - T_m)$$

Where:

The subscripts ref and m refer to the reference of the irradiance level required, respectively the measured, conditions; V is the voltage; VOC is the module open voltage; I is the current; G is the irradiance; αrel and βrel are the relative current and voltage temperature coefficients; a is a constant (usually taken equal to 0.06); Rs is the internal series resistance; k' can be interpreted as the temperature coefficient of the internal series resistance.

Because of the reference where the formulas are extracted from and the results obtained in this project show it's possible to simplify the formulas, and the current through a module is approximately proportional to the irradiance. Those ones can be reduced as:

$$I_{ref} = I_m \times \frac{G_m}{G_{ref}}$$

$$V_{ref} \cong V_m$$

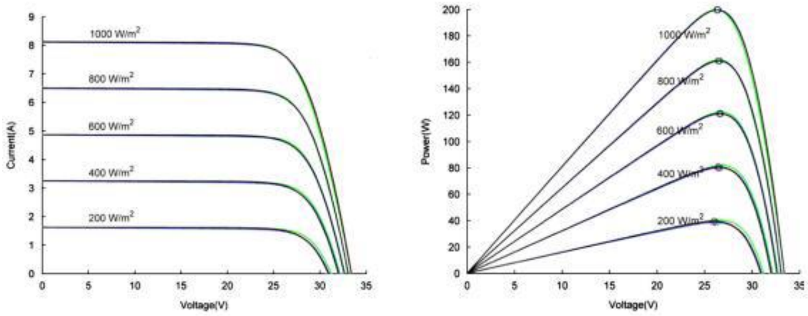

Figure 2. Current – Voltage and Power – Voltage curve for different irradiations

As it can be seen, irradiation level is proportional to the current; hence the power output increases as irradiation level does.

5. LAB Experiments, Results and Discussion

A First of all, to the better understanding of how PV modules works when shading effect appears on them it has been measured a PV module in a laboratory at GNI. At the laboratory special lighting was used to act as a solar irradiation with a constant irradiation about 1000 $W/m2$. It has been measured a PV module of 36 cell with 4 columns and 9 rows. Its electrical specifications are shown in the following table 1.

Table 1. Technical Specifications of Solar Module

Rated Max Power	50 W
Voc	22.1 V
Vmpp	18.2 V
Isc	2.95 A
Impp	2.75 A
Cell Dimensions	62mm * 56 mm
Module area	680mm * 680 mm

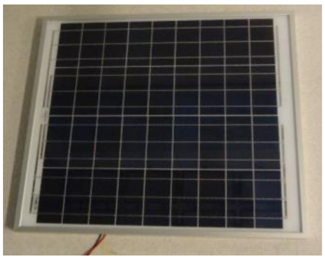

Figure 3. 50 W Solar Module

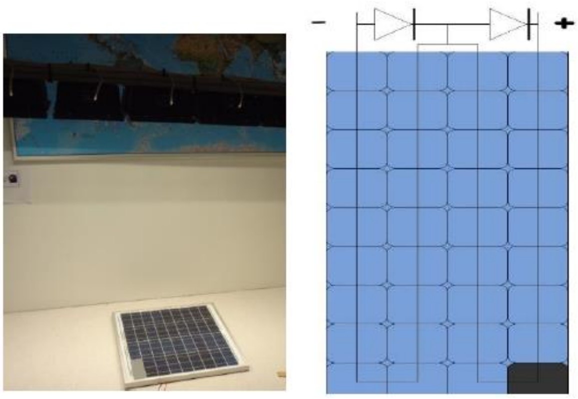

Figure 4. Images of the module shaded. On the right side it shows the module with tape and the light simulated. On the left side it is shown the covered cell

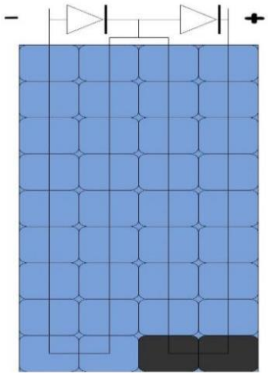

Figure 5. Module with Two Cell Shaded

In order to show there is one bypass diode each two adjacent columns another measurement has been taken in two contiguous cells in the same row as it is shown in the figure on the right. But, what would happen if one cell is partially shaded? When one cell is shaded at 50% that means the 50% of the cell is shadowed, the cell will have the same voltage but the current through the cell will be limited about 50% as it has been shown in the theory (see Shadowing on solar cells). However bypass diodes are connected in order to get the maximum current through the PV panel. The figure 6 shows how the shadow was applied:

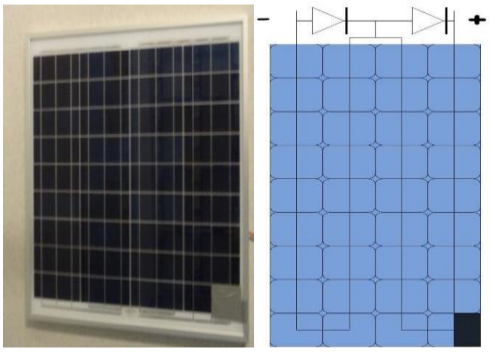

Figure 6. Module with 50% of one cell shaded

One special measurement consist on a shadow about 50% of a cell in two different columns with different bypass diodes as it can be observed in the image on the right, since it's expected the IV tracer will get the MPP in a point where the voltage is the maximum of the module whereas the current is expected to be the half of the one that no shadow affects.

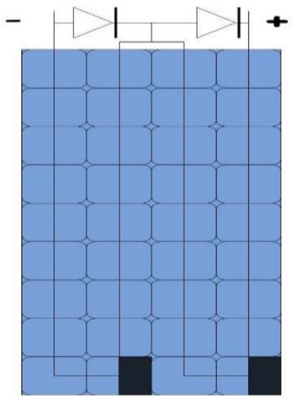

Figure 7. Module with a shadow about 50% on two cells

5.1. Results of experiment

Then different configurations have been used in order to investigate how the I-V curves and the PV module act. It should be noticed since the same radiation level was used to measure the different shadowing configurations; the power output can be easily compared between the different types of shadowing. Several configurations of shadowing effect have been carried out: Because of the better comprehension of how and when diodes work, it has measured several configurations of the panels. This panel has two bypass diodes, divided in four columns; therefore there will be one diode for each two columns. Since all the cells are series connected and there is one bypass diode for two columns it has been measured the module with one cell shaded. In this case it is expected that the I-V curve will show the MPP (Maximum Power Point) is found in a point about the half of the case of the module with no shadowing problems.

A. No Shadowing Effects on the Module.

It is remarkable to say at lower voltage values the current is not completely constant as it can be observed in figure 8. Moreover, the current does not completely drop for one voltage value; this is because of the parasitic resistances affecting the solar panel.

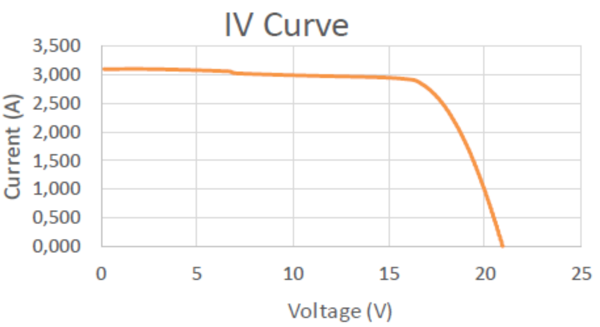

Figure 8. I-V Curve of the module with no shadow

B. One Cell Shaded

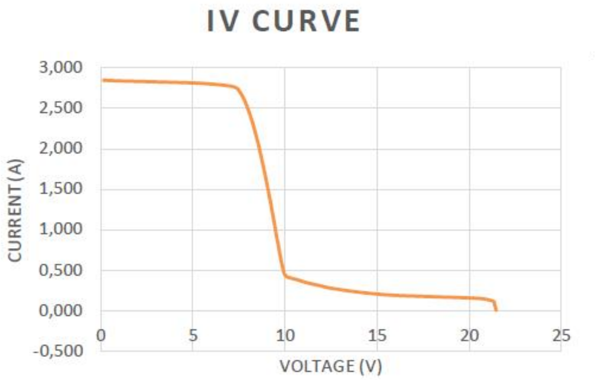

Figure 9. I-V Curve of the module with no shadow

C. Two Contiguous Cell Shaded

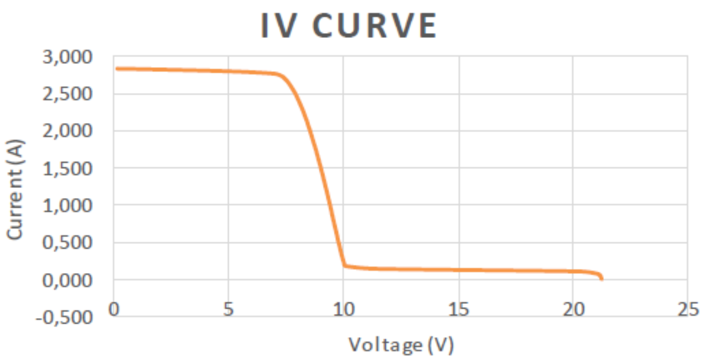

Figure 10. I-V Curve of the module with two contiguous cell shaded

D. **50% of a Cell Shaded**

This means half of one cell in the module is shadowed. The I-V curve for this case is shown in figure 11.

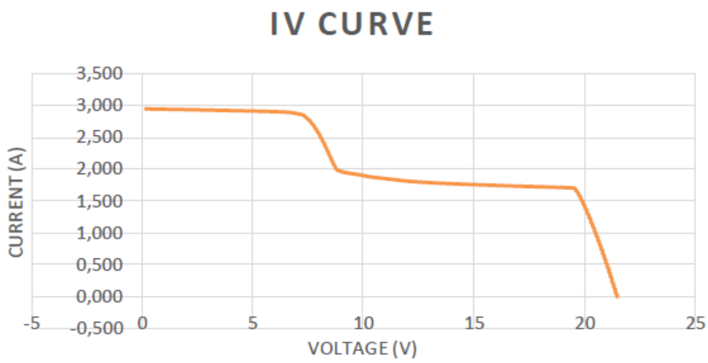

Figure 11. I-V Curve of the module with 50% of a Cell Shaded

E. 50% of Two Cells Shaded

That means the 50 percent of two cells in two different circuits in the module are shade. Its I-V curve is shown in figure 12.

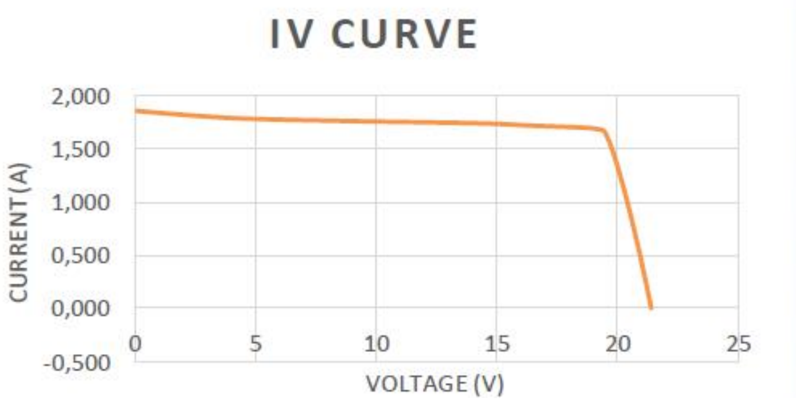

Figure 12. I-V Curve of the module with 50% of Two Cells Shaded

F. One Row Partially Covered

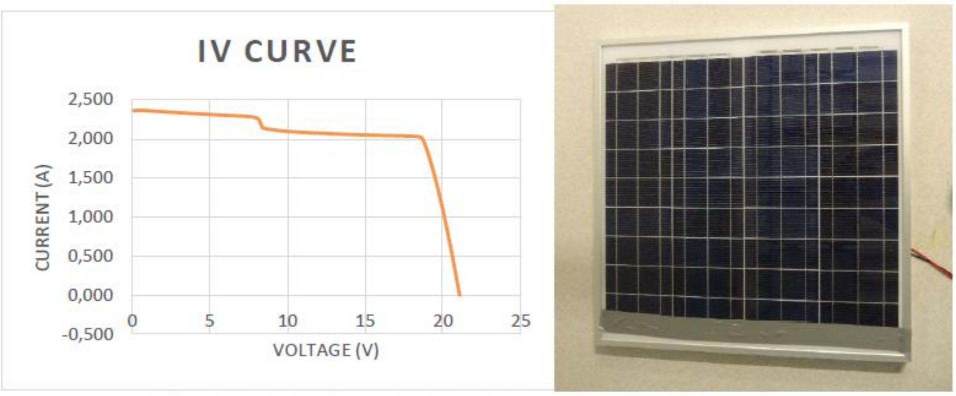

Figure 13. I-V Curve of the module with One Row Partially Covered

Table 2. Data collected for all the cases

Case	MPP				
	Voc (V)	Isc (A)	Pmax (W)	Vmp (V)	Imp (A)
No Shadow	20.9	3.1	47.5	16.5	2.9
One Cell Shaded	21.5	2.8	20.4	7.6	2.7
Two Contiguous Cells Shaded	21.3	2.8	20.1	7.6	2.7
50 % Cell Shaded	21.5	2.9	33.3	19.5	1.7
50 % of Two Cells Shaded	21.4	1.9	32.5	19.4	1.7
One Row Partially Covered	21.1	2.4	37.5	18.5	2.0

6. Experiment on 50 Kwp System:

Actual data is taken from the 50 kWp PV plant at GNIT. The readings taken at the inverter output near LT panel therefore data shows the AC power actually fed to the grid. Three days data collected for sample i.e on 6th, 22nd of October and 20 and 24th of November 2018 to analyze the cloud shadow effect on the power generation. On 6th of October as shown in figure 14, the effect due to cloud induced shadow is clear and the power transients can be observed at each time interval. There was a observable power dip during 11:45 AM to 12:00 PM which is from 40.28 kW to 9.71 kW approximately. The slope can be observed is 2.03 kW/min. Again due to change in light intensity during the time interval 12:00 PM to 12.15 PM, the power is raised from 9.71 kW to 22.91 kW. The slope of the rise is 880 W/min. This rapid transients in power at a larger scale leads instability in grid further we can say that if the slope is sharper instability is higher. The additional power transients can also seen from the power generation curve but with a smaller slope represents less effect on stability. The power generation curve for 22 of october is shown in figure 15. The power curve was almost smooth as there was no shadow which can be noticeable. A change in the shadow intensity can be observed on November 24th due to passage of clouds from 10:00 AM to 10:15 AM and the power change from 33.37 kW to 31.60 kW as shown in figure 16, which does not produce any instability in the grid. Figure 17 shows the November 25th power generation and it was noticed that noticeable clouds leads to large variations in the generated power. As shown in Figures 17, shadow effect is high from 2:15 PM to 2:45 PM leading to a considerable change in generated power. Also between 12:45 PM to 1:30 PM another problem occurred, however the deviation is not due to clouds rather it was happen due to shutdown of power from the grid leads to the power drop.

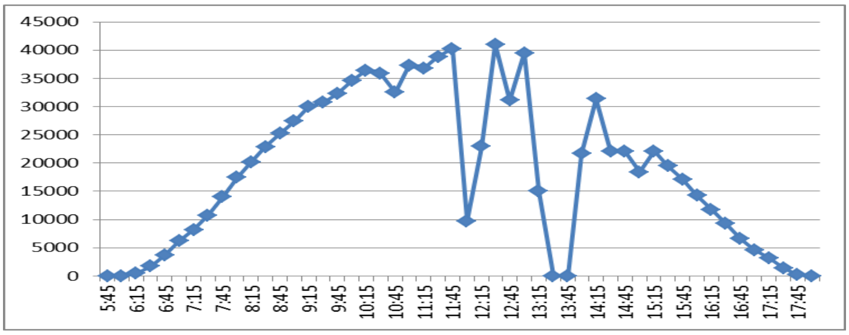

Figure 14 . Power generation on 06/10/2018

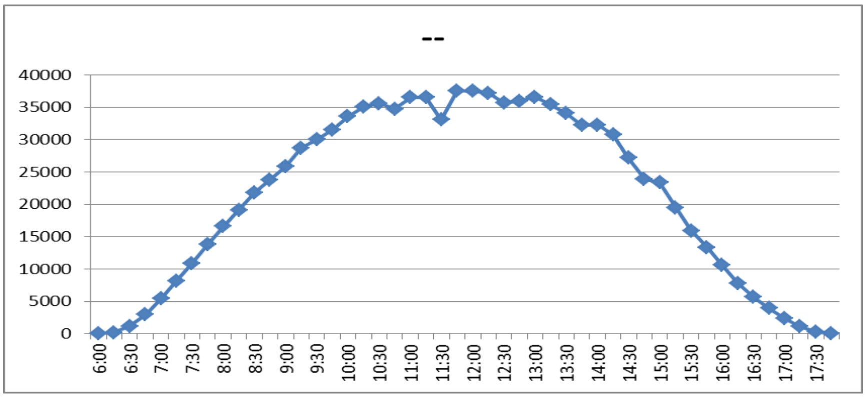

Figure 15 . Power generation on 22/10/2018

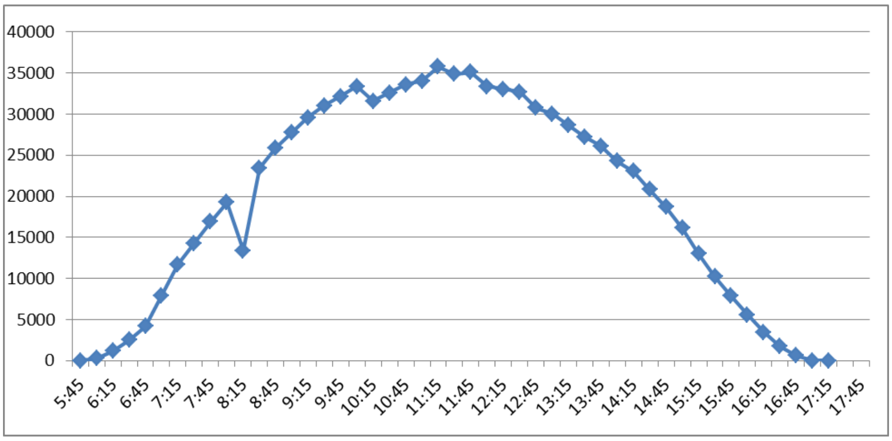

Figure 16 . Power generation on 24/11/2018

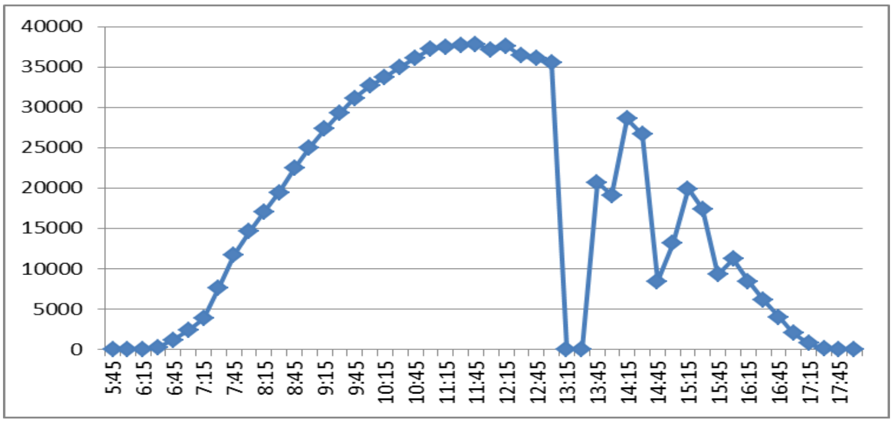

Figure 17 . Power generation on 25/11/2018

7. Possible Solutions

The increasing number of renewable sources of energy requires new methods for the management and operation of the grid in to maintain and improve the power-supply quality and reliability. for the same, some of the possible solutions have been proposed by many researchers includes:

1. The power-electronic devices plays an considerable role in distributed generation and in integration of renewable sources of energy into the grid, and it is extensively used and rapidly expanding as these applications become more integrated with the grid- based systems.

2. Intermittence of power generation from the RES can be controlled by generating the power from distributing the RES to larger geographical area in small units instead of large unit concentrating in one area.

3. In case of irrigation load the load is fed during the night time or off peak load time and this is fed by conventional grid. On other hand power generated by RES like solar PV is generated during day time so we can use this power for irrigation purposes instead of storing the energy for later time which increases the cost of the overall system. Using the solar water pumping for irrigation gives very high efficiency approximately 80% to 90% and the cost of solar water pumping is much lesser than the induction motor pumping type.

4. In large solar PV plant output power is fluctuating during the whole day and this power is fed to the grid and continuously fluctuating power gives rise to the security concern to the grid for making stable grid. Solar PV plant owner have to

install the different type of storage system which gives additional cost to the plant owner. Once the storage system is fully charged then this storage elements gives no profit to the system owner. Therefore solar based water pumping system may be installed instead of storage system.

5. Assessing Cloud Transient Impacts on Grid with Solar and Battery Energy Systems

8. Conclusion

In this paper, grid integration and power quality issues of Wind and Solar energy System and their possible solutions available in the literature have been presented. The causes, affects, mitigation technologies featuring their topologies, highlighting the advantages of the grid integrated solar and particularly wind power systems are examined.

To minimize the fluctuations and intermittent problems power electronics devices are the viable options. Further, energy storage systems and MPPT controllers could be used to reduce the power variations in photovoltaic systems. In addition to that, upgradation in balancing systems by incorporating the storage elements and new materials could reduce the issues associated with integration of grid. The reliable and cost effective solutions of FACTS devices and custom power devices will be highlighted in giving an insight to the scope for research in various voltage level networks with 1Ø and 3Ø grids technologies.

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