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Technical Issues of Grid Connected Solar Photovoltaic Cell – A Survey

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Abstract: The use of renewable energy sources as distributed generators increased significantly with new trends in power electronic technology. This paper presents technical issues associated with the Grid integration of Solar Photovoltaic (PV) system. The main objective of this work is to study the behavior of solar system under different environmental conditions and the power quality problems with power electronic converters. With the switching sequence in the power electronic converters harmonics are created which damage the equipment on the grid side sensitive load on consumer side. Solar penetration will also change the voltage profile and frequency of the system which effects the transmission and distribution system.

Keywords: PV System, Grid Integration, Power Quality Issues, Mitigation Methods.

1. INTRODUCTION

The consumption of electrical energy is an ever growing need worldwide. Yet, growing in tandem to it are concerns about environmental pollution, global warming and the steady depletion of fossil fuels [21]. Electricity generation from renewable resources might be considered as a feasible solution for the next generations [1, 21]. Demand for solar energy is increased from 20% to 25% over the past 15 years. From the survey solar energy provides around 4800 GW [9]. Solar energy with grid connected reached 21 GW between 2004 and 2009 [10]. India receives 5 to 7 kWh/m^2 of solar energy for 300 to 330 days in a year. This energy is sufficient to set up 20 MW solar power plants per square kilometer land area. The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 with about 1500–2000 sunshine hours per year (depending upon location) [11].

It is very important to evaluate the technical issues of renewable energy systems with grid connected and islanding mode on the power quality and stability. In order to minimize possible problems a proper design and management unit is required [15, 23].

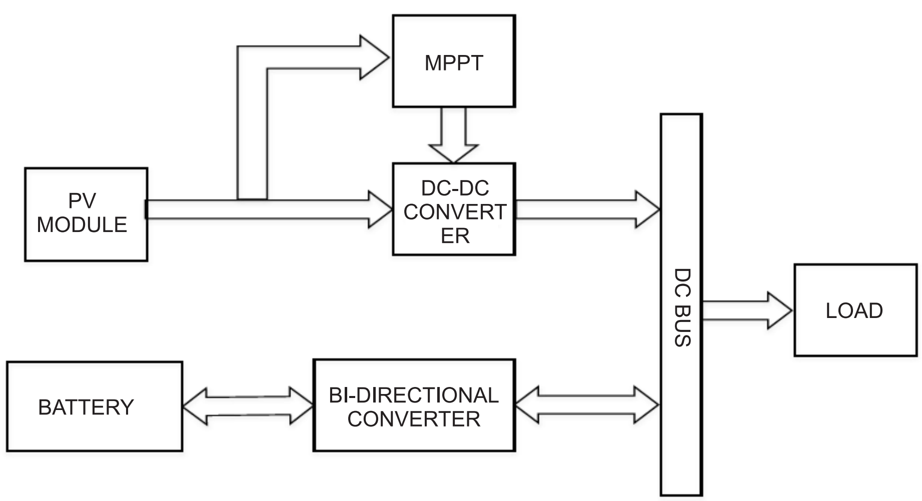

Figure 1: Block Diagram of PV-Battery System

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Figure 1 shows the block diagram of PV-Battery System. This type of system requires energy storage device in the form of a battery to keep "critical load" circuits in ON state during a utility outage [16]. When a power outage occurs the critical loads must disconnects from the utility. These critical loads are connected from a sub panel which is separated from the other electrical circuits. If the power outage occurs during daylight hours, the PV system is able to aid the battery in supplying the house loads. If the power outage occurs at night time, the battery will supplies the load [16]. The operate time period of critical loads depends upon the power consumed and the energy stored in the batter system. A 1-kW is the average usage of load for a residential when not running an air conditioner [16].

2. PV SYSTEM

Alexander E. Becquerel, French physicist discovered the photovoltaic effect which converters the solar energy into electrical energy in semiconductor element in 1839 and in 1905 Albert Einstein described the nature of light and photovoltaic effect, for which he later won a Nobel prize. The conversion of solar energy into electrical energy is called photovoltaic effect. When semiconductor materials are exposed to sunlight, photons are absorbed by the semiconductor crystal which causes free electrons in the negative layer shown in Figure 2. This is the basic reason of producing electricity.

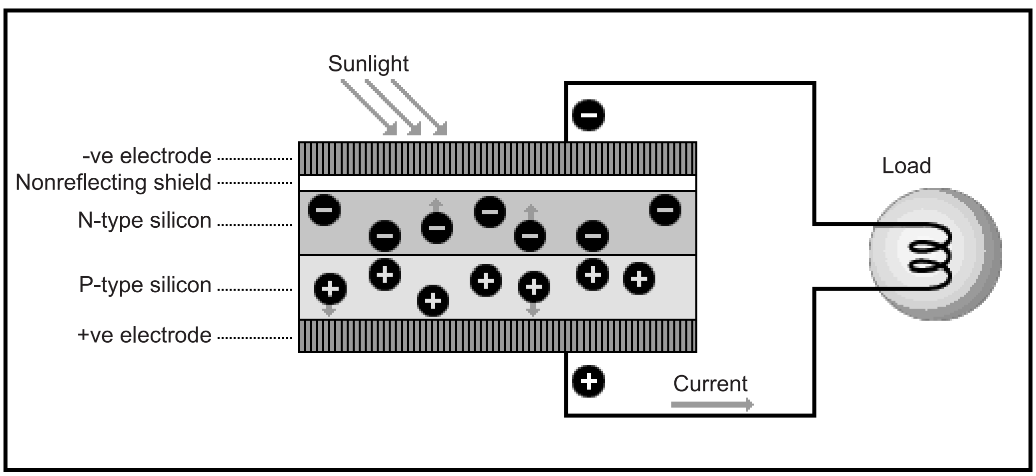

Figure 2: Working of Photovoltaic system

Generally a PV cell generates a small voltage around 0.5 to 0.8V depending on the semiconductor device. This small voltage is not enough to use therefore a number of PV cells are connected in series to form a PV module. These modules are connected in series and parallel to form a PV panel.

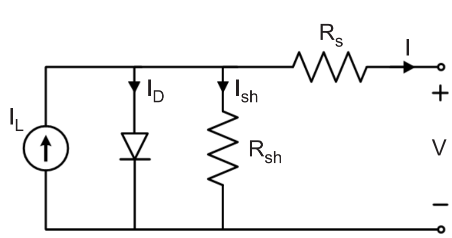

Figure 3: Equivalent Circuit of PV Cell

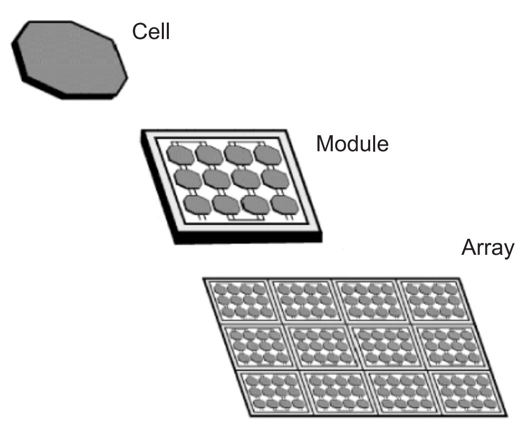

Figure 4: Photovoltaic system

A PV cell has a non-linear current-voltage (I-V) characteristic which can be modeled using current source, shunt diode, series resistor and shunt resistor shown in Figure 3 [14]. To simulate the PV characteristics Single-diode and double-diode models are widely used. Single-diode model gives the PV characteristics fairly and accurately [14]. The manufacturer provides information about the electrical I-V characteristics of PV by specifying certain points [12][14] shown in Figure 5.

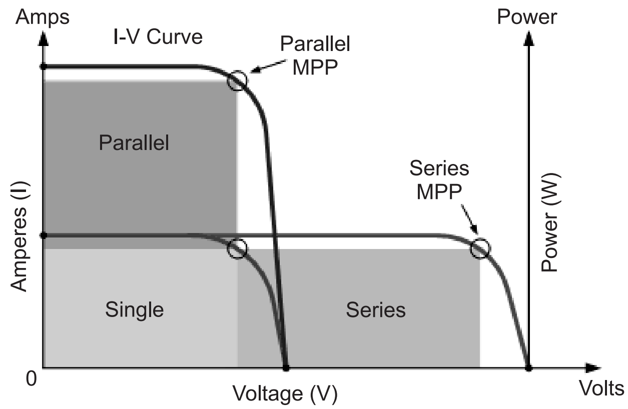

Figure 5: I-V and P-V Characteristics of Solar PV Cell

3. GRID INTERFACING TECHNOLOGIES

Some technologies like induction generator based wind or small hydro can be directly connected to the grid. However, due to power quality issues and starting transients they require power converters for interfacing 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 DGs [7].

DGs with renewable energy source at input generally use power electronic converter for interfacing with AC grid. The sources like fuel cells, photovoltaic cells and battery storage generate DC power [22]. This power is then converted to AC power of desired voltage and frequency using Voltage Source Converters (VSC) and fed into the AC grid through filter as shown in Figure 6 [22].

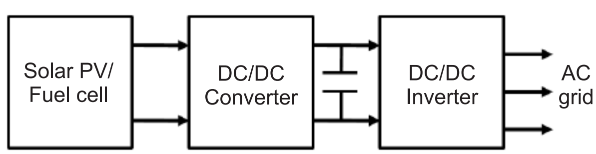

Figure 6: Block diagram of Converter interfaced DG System

The DG system consists of a renewable energy source, a DC/DC converter and an inverter. The VSCs use insulated gate bipolar transistor (IGBT) switches that are controlled by pulse width modulation (PWM). PWM technique provides better control and minimizes power quality issues [8]. The most common PWM techniques are Hysteresis Band PWM and Sine PWM. The advantage of using inverters is that they respond very quickly to the load changes and in the events of faults. This has enabled the application of islanding operation in micro-grids. However, due to no inertia it cannot provide energy buffer during step load changes [9].

Table 1 summarizes the interfacing technologies and their performance. Based on the comparison it can be concluded that the trade-off needs to be made between the performance and the cost of installation the DG interfacing technology. The power quality issues caused by integration of DG are discussed in the next section [22].

Table 1
Grid Interfacing Technologies

Interfacing Technology	*Type of Source*	*Performance*	*Major issues*
Synchronous Generator	Micro-turbines and small hydro	Highly robust, easy control and better efficiency	Less economic
Induction Generator	Wind and small hydro	Economic and better efficiency	Requires reactive power and less robust
Power Electronic Converters	Fuel cells, photovoltaics wind, biomass, battery, microturbines and small hydro	Fast control, highly efficient and most Economic	No-inertia and requires energy storage device

4. POWER QUALITY ISSUES IN GRID CONNECTED SOLAR PV SYSTEM

A. Back Ground

Power conversion systems of distributed generation (DG) vary according to the nature of the input energy source. They may be implemented by using partially rated power electronics interface, as in wind turbine systems with doubly fed induction generators, or with fully rated power electronics interface [2]. The latter interface is the dominating one in applications related to fuel cells, solar cells, micro turbines and wind turbine systems [3]. There can be one or more power conversion stages in order to adjust the power of the energy source with the grid requirements, as shown in Figure [3]. With DC energy sources, the power electronics interface may consist of one DC/AC converter, or an intermediate DC/DC conversion stage can be added to achieve a specific goal, e.g. in order to regulate the output voltage so that the maximum available power is extracted [3]. The same is valid for AC sources, where they have to be adjusted to match the grid requirement by a DC intermediate stage shown in Figure 7.

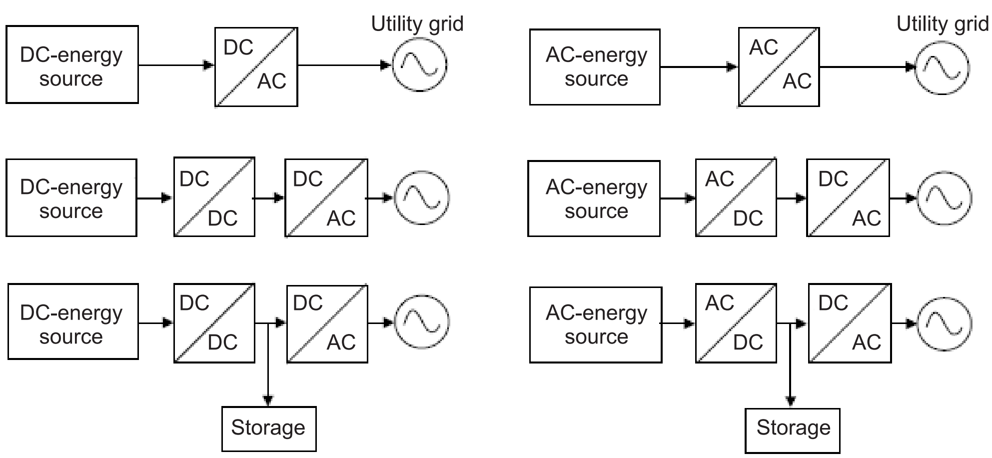

Figure 7: Full-rated power electronics interfaced DG systems

There are certain issues in the integration of Solar PV system with grid. For grid integration we use grid tie inverter, the purpose of this inverter is to take energy from grid when PV energy is insufficient and supply energy when excess power is generated [19]. The integration of grid with PV system and disconnection is done in 100 ms.The block diagram for grid connected Solar PV array is shown in Figure 8 [19].

The main function of converter block in Solar PV array integrated to grid system is to correct the magnitude and phase angle at output of PV system by taking the feedback from utility grid [17][19].

There are several technical issues in the integrated systems like harmonics, voltage fluctuations, frequency fluctuations, Storage, Protection issues, Islanding which are discussed in Table 2.

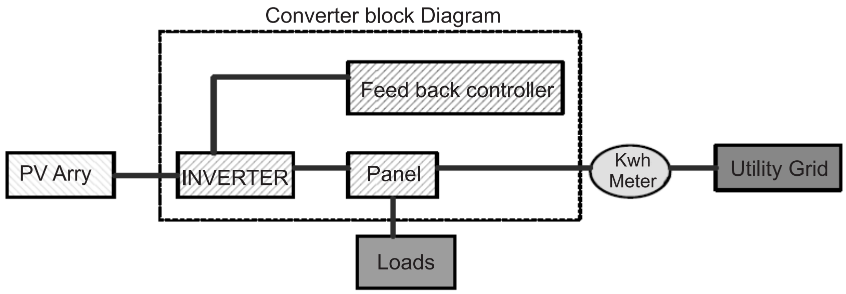

Figure 8: Block Diagram of Grid connected Solar PV System

Table 2
Categories of Power Quality Problems

Harmonics	• Frequency disturbance • Waveform distortion
Low Power Factor	• Low power factor causes equipment damage • Increases in Energy bills
Transients in Power System	• Produces distortion like impulse and notches • Long and Short duration event
Electro Magnetic Interferences	• Interference between electric and magnetic field • High frequency phenomenon
Power Frequency Disturbances	• Low frequency phenomenon • Produces voltage sags and swells

Figure 8 shows the grid-connected solar PV generation system. PV array is connected to DC-DC converter and then interconnected to the utility grid via DC-AC inverter [19]. The DC-DC and DC-AC power electronic converter is designed with non-linear power electronics appliances, which injects harmonics to the grid. There is a voltage fluctuation at the output of the solar due to irradiation, partial shading effect which makes the unstable in terms of grid connection. Therefore a controller is needed to design of the inverter.

A grid-connected PV system is unable to control reactive and harmonics currents which are drawn from non-linear loads

5. VARIOUS SOLUTIONS

The increasing number of renewable energy sources and distributed generators requires new strategies for the operation and management of the electricity grid in order to maintain or even to improve the power-supply reliability and quality[20]. The renewable energy sources such as solar, wind etc. has accelerated the transition towards greener energy sources [4] , keeping in view of the aforesaid some of the key solutions for RES utilizations are:

1. The power balance using RES can be carried out by integrating RES with energy storage unit. The benefits of battery energy storage system (BESS) are classified based on end – users as: Transmission level uses, System level uses, ISO Market uses [5][6][18][20].
2. The power-electronic technology plays an important role in distributed generation and in integration of renewable energy sources into the electrical grid, and rapidly expanding as these applications become more integrated with the grid- based systems[20]. During the last few years, power electronics has undergone a fast evolution, due to two factors, the development of fast semiconductor switches that are capable of switching quickly and handling high powers and introduction of real-time computer controllers that can implement advanced and complex control algorithms [20].

These factors have led to the development of cost- effective and grid-friendly converters. The performance of power electronic systems, especially in terms of efficiency and power density, has been continuously improved by the intensive research and advancements in circuit topologies, control schemes, semiconductors, passive components, digital signal processors, and system integration technologies [5, 6, 18, 20].

3. Intermittence of power generation from the RES can be controlled by generating the power from distributing RES to larger geographical area in small units instead of large unit concentrating in one area [5, 6, 18, 20]
4. 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 [20]. 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 approx 80% to 90% and the cost of solar water pumping is much lesser than the induction motor pumping type [5, 6, 18, 20].
5. In large solar PV plant output power is fluctuating during the whole day and this power is fed to the grid, continuously fluctuating power gives rise to the security concern to the grid for making stable grid [6, 20].

6. CONCLUSION

Recent trends in power transmission and distribution shows the penetration level of Distributed Generation into the grid has increased considerably. Consumer loads are more sensitive to the power quality condition. This case study presents a behavior of solar PV panel and technical issues of power quality which are associated with renewable energy system. In this paper some technical issues which are related to grid integration, available and utilization in the literature have been presented. To minimize the voltage fluctuation in PV system power electronic devices are viable options. The usage of energy storages devices and MPPT, reduces the voltage fluctuations in the PV system. Suitable control techniques are also discussed. The main intention of the authors was to provide groundwork to the readers interested in power quality issues in PV integration system.

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