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# Power analysis of PV-Grid connected system with different irradiance level

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## Abstract

The general trends in the past decade of increasing solar cell efficiency, decreasing PV system costs, increasing government incentive programs, and several other factors have all combined synergistically to reduce the barriers of entry for PV systems to enter the market and expand their contribution to the global energy portfolio. This paper proposes a generalized model of the PV-Grid connected system in MATLAB/Simulink. This proposed model is based on basic mathematical equation of solar photovoltaic cell and grid requirements. The PV modules have non-linear output characteristics. The output I-V and P-V characteristics of photovoltaic cell are depend on sunlight irradiance and cell temperature. This paper describes the comparison of different solar insolation. Finally, percentage of harmonic level, due to presence of power electronics devices in PV system, is also shown through the simulink model.

**Keywords:** Photovoltaic cell; MPPT; boost converter; MATLAB/Simulink

## 1. Introduction

In recent years, the average rate of world primary power consumption has increased to about 78.47 Btu (AEO 2012). Additionally, the environmental impacts on usage of the conventional sources have been disintegrative with the environmental issues such as pollution, global warming, excessive greenhouse effect etc. Because of these problems and our declining supply of petroleum, finding sustainable alternatives is becoming more and more urgent. Perhaps, the greatest challenge is in devising a sustainable future, which relies on integration and control of renewable energy sources in grid distributed generation. Generation of power locally at distribution voltage level by using non-conventional (or) renewable energy sources like, solar photo voltaic cells, wind power, biogas, and fuel cell is known as distributed generation (DG).

Among renewable energy solar energy is a vast and ultimate source of energy. If used in appropriate way, it has a capacity to achieve numerous energy needs of the world. There are two topologies used to connect the PV with the grid; two stages and single stage PV system. A two stage is the traditional type and consists of a DC/DC converter direct coupled with PV array and a grid connected inverter. In single stage PV system, the DC/AC inverter has more complex control goals; Maximum Power Point Tracking (MPPT) and output current control. Regardless its control complicity, single stage PV system is more efficient and cheaper than two stages system. Grid-connected photovoltaic (PV) power systems are energized by PV panels which are connected to the utility grid via an inverter can upload the excess energy to the grid during average or low peak demands. Grid connected PV systems reduces the line losses as the consumer power is generated close to the load demand. In addition, grid connected system benefits the utilities economically in delaying the line upgrades by means of peak load reduction [7]. However, integration of solar PV into grid has several impacts contributing to operational problems due to its intermittent nature. Integrating solar PV effects the functional operation of the power system network like load/frequency control, load following, unbalancing of voltage and current levels in the network and PQ issues including voltage disturbance, poor power factor, reactive power compensation flicker and harmonic distortions. Though integration issues/effects are not the major focus of this paper it is essential to study some of the effects of the Grid connected PV system that has to be analyzed for efficient power generation and distribution for sustainable energy flow. A PV-Grid connected model is developed using MATLAB and simulations are analyzed considering different irradiance level with reference to voltage and harmonic analysis.

## 2. Proposed photovoltaic system

Solar cells which exist usually in the form of modules are the major components of photovoltaic power generation system. As a direct energy provider, photovoltaic arrays play a prominent role in PV systems [1-2]. In recent years, with the rapid development of photovoltaic power generation, establishing the exact mathematical model of Photovoltaic Array for studying is of great significance.

### *A. Basics of PV Module*

A solar cell, or photovoltaic cell, is a semiconductor based electrical device that converts the photons of the sun’s rays directly into electricity by the photovoltaic effect. Whenever the solar cell comes under sunlight, its electrical properties like current, voltage, resistance alters. Solar cells or PV cells are the basic unit of photovoltaic panels. A photovoltaic cell directly or indirectly converts sunrays into electricity. Photon from Sun falls on the solar cell generates electric power by producing both current and voltage. For this process, such kind of material is required that can absorbs the light and then makes the flow of electrons from cell to the external circuit. Practically, p-n junction semiconductor materials are used for the photovoltaic energy conversion. Fig.1 shown below illustrates the operation of a photovoltaic cell.

We selected a suite of real-world, large-scale Java and C/Cþþ programs, including JDBC connector, SQLite HawkNL and MySQL [1-2]. They contain totally 15 real deadlocks. All these benchmarks were available online and had been used in deadlock related experiments. We have implemented ASN for Java and C/Cþþ using ASM 3.2 and Pin 2.10 (probe mode) with Pth reads, respectively. By comparing ASN to PCT Magic Scheduler and Deadlock Fuzzer AN, and SN on the same framework [3-5]. Although DF for Java is available from the current release of Ca lfuzzer, yet Cal fuzzer only instrumented the test harness but did not instrument the JDBC Connector library that contains the deadlocks. Besides, the released DF is different the algorithm reported [6]. Finally, we faithfully implemented DF based on both and Cal fuzzer (including the optimization. The original tool of PCT was not publicly available. However, this solution could only detect deadlocks between pairs of threads.

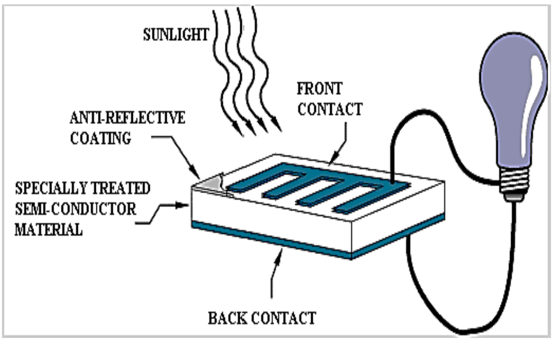


**Fig. 1 Operation of Photovoltaic cell**

There is a metal substrate or an anti-reflecting coating, n-type and p-type layers. The n-type layer is very thin so that whenever the light falls on the top surface then it made the light penetrates up to the junction level. To collect the charges there is a metal contact at one side of the wafer but at the top there will be semiconductor layer. So, for that there is a grid of metal contact. But, to capture more light, the grid should not be extensive to avoid the blocking of sunlight [3]. So, instead of covering the whole surface with the metal contact, a collection of the metal fingers are laid on the surface of semiconductor layer which captures the charges on the other end.

*A. Equivalent Circuit of PV cell*

The equivalent circuit model for a photovoltaic cell shown in Fig. 2 [4-5].

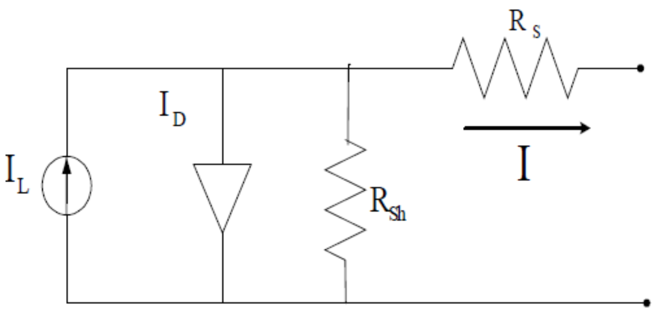


**Fig.2 Equivalent circuit of PV cell with R**

The equations that describe I-V characteristics of the solar cell based on simple equivalent circuit in fig. 2 are given below-

$$I_L = I_d + I \qquad (1)$$

$$I_D = I_0 \left[ e^{\frac{q(V+IR_S)}{KTA}} - 1 \right] \qquad (2)$$

$I_0$=cell saturation current

Hence,

$$I = I_L - I_0 \left[ e^{\frac{q(V+IR_S)}{KTA}} - 1 \right] - \frac{V+IR_S}{R_{Sh}} \qquad (3)$$

Where,

*I* is the cell current (A).

*q* is the charge of electron = 1.6x10-19 (coil).

*K* is the Boltzmann constant (j/K) (i.e. 1.38x10-23

j/K)

*T* is the cell temperature (K).

*I* is the light generated current (A).

*Io* is the diode saturation current.

$R_S$, $R_{Sh}$ are cell series and shunt resistance (ohms).

*V* is the cell output voltage (V).

*A* is an ideal factor depend on PV technology (2.5)

## 3. MPPT Charge Controller

Photovoltaic panel has very low efficiency. So, several methods are to be undertaken to match the generating source and load properly in order to increase the efficiency of system. Therefore, Maximum Power Point Tracking (MPPT) technique is used to obtain the maximum possible power from a varying source. The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point).[6] There are different methods to track down the maximum power point, a few of which are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

As the fig.3, shows the maximum power point(Pmp) on the characteristic curve that includes various parameters like maximum power voltage(Vmp), maximum power current(Imp), open circuit voltage(Voc), short circuit current(Isc) shows variation with the change in radiations, temperature and internal resistance and hence affect the panel efficiency.

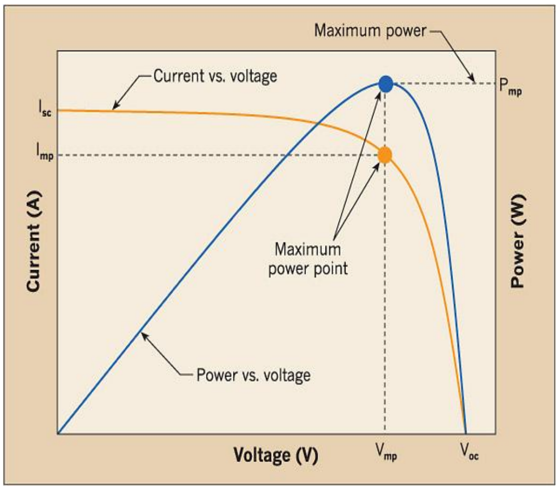


**Fig.3 Characteristics of PV showing maximum power point**

Perturb and Observe is the most regularly utilized MPPT strategy because of its simplicity of execution.[7-8] The working voltage is expanded the length of (dP)/dV is sure, i.e. the voltage is expanded the length of we get more power. On the off chance that (dP)/dV is detected negative, the working voltage is diminished. The voltage is kept put if (dP)/dV is close to zero inside of a preset band. The time multifaceted nature of this calculation is less however on coming to near to the MPP it doesn't stop at the MPP and continues annoying. This calculation is not suitable when the variety in the sun oriented illumination is high [9]. The voltage never really achieves a careful esteem yet annoys around the most extreme force point (MPP).

## 4. Boost Converter

In photovoltaic systems the nature of I-V curve is non-linear; hence it might be difficult to be used to power a certain load end. This is done by utilizing a boost converter whose duty cycle is varied by using an MPPT algorithm. A boost converter is connected on the load side and power to this converter is through a solar panel.

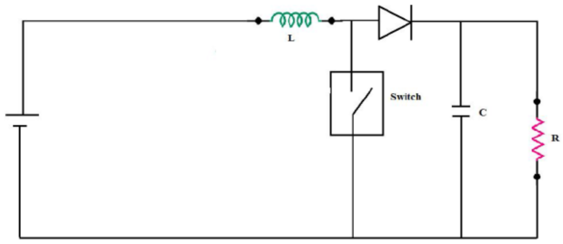


**Fig.4 A Boost Converter**

A typical boost converter can be shown in Fig.3. As the output of the PV panel is very low and in order to connect it to the grid, its voltage has to be increased. The output of the solar panel is a DC voltage of very low magnitude. Hence a boost converter is required for boosting the voltage to higher level without use of the transformer. The primary parts of a support converter are an inductor, a diode and a high recurrence switch. These in a composed way supply energy to the heap at a voltage more prominent than the information voltage extent. One capacitor is joined over the heap end to keep up the heap voltage consistent.

*Modes of Operation*

Two methods of operation are there in a help converter. These are in light of the end and opening of the switch. In the first mode the switch is shut; this is known as the charging method of operation. The second mode is the point at which the switch is open; this is known as the releasing method of operation.

1. *Charging Mode*

The switch is shut and the inductor is charged by the source through the switch. The charging current is exponential in nature and for straightforwardness it is thought to be straight fluctuating. The diode limits the stream of current from the source to the heap and the interest of the heap is met by the releasing of the capacitor [10-11].

2. *Discharging Mode*

In the releasing method of operation the switch is open and the diode is forward one-sided. The inductor now releases and together with the source charges the capacitor and takes care of the heap requests [12]. The heap current variety is little and by and large is expected consistent all through the operation.

## 5. Simulation Results of Proposed PV-Grid connected system

The PV-Grid connected system is taken into consideration has following specification. The grid voltage is 22 KV and the system is connected to the purely resistive load.  There are three solar panels are connected to the grid through star-delta transformer. The system is connected to three set of three phase load. The three phase load has minimum and maximum values is 14.65 KW and 25.95 KW respectively. The load connected here is assumed to be purely resistive load so reactive power requirement is almost zero. The small amount of reactive power drawn by the system is of coupling inductors, transformer reactance and line inductance.

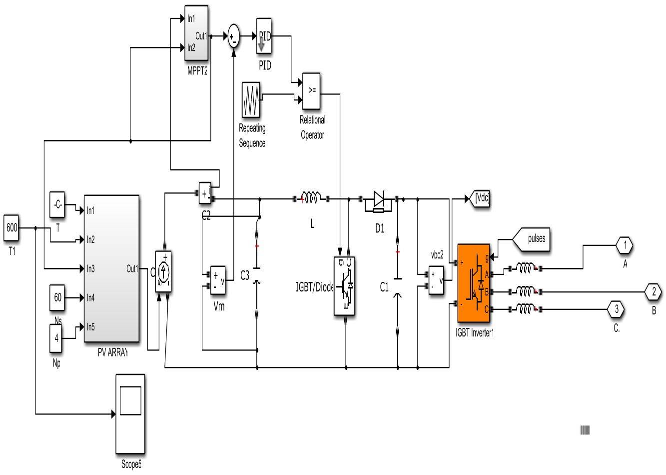


**Fig.5 MATLAB/Simulink model of PV array connected to the boost converter and inverter**.

As the PV system is has to be connected to the three phase grid, the PV output is to be converted in to the suitable form so that it can be synchronized with the grid. The PV current output of the PV system is fed to the current controlled voltage source. The voltage of this voltage source is very small as compared to the load requirement. This has to be boosted up with the help of boost converter. The function of boost converter is to extract maximum available power with the help of MPPT algorithm applied to the system.

- *Change in Irradiance Level*

The irradiance level is varied at time 0.3 sec, 0.5 and 0.6 sec and load at 1.5 sec. The various results obtained are shown in the following waveforms.

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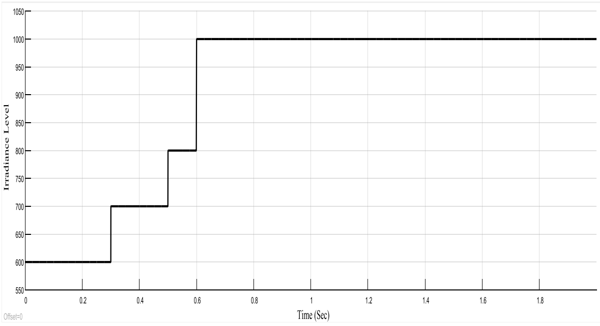


**Fig. 6 Change in irradiance level**

From time 0.0 to 0.3 sec irradiance value is 600 KW/m2. The between time 0.3 to0.5 sec. it is 700 KW/m2 , between time 0.5 to 0.6 sec. it is 800KW/m2 and between time 0.6 to 2 sec. it is 1000 KW/m2. As the irradiance level is changed the power generated by the PV system is also varied accordingly.

- *Active and Reactive power of grid*

When the share of the PV system increase with constant load in the first part of the simulation, the power drawn from the grid reduces. This is shown in the fig.7 Active power of the grid reduces as the share of the PV system increases.

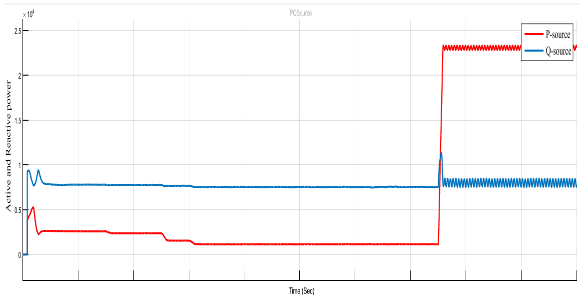


**Fig.7 Grid active and reactive power**

- *Active and Reactive Power of Load*

Fig.8 shows the waveform of the active and reactive power taken by the load. As the load increases at time 1.5 second, the active power drawn by the load is also changes.

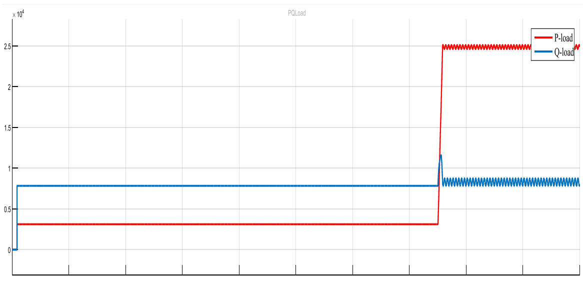


**Fig.8 Load active and reactive power**

- *Active and Reactive Power of Inverter*

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In this fig. the waveforms of the active and reactive power generated by the PV system are shown. The active power increases at time 0.3, 0.5, 0.6 sec. when the irradiance level is increased.

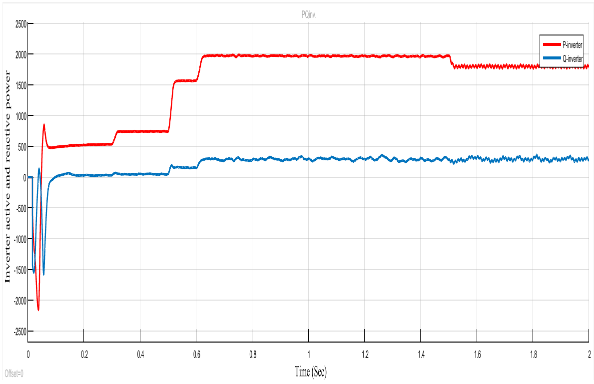


**Fig.9 Inverter Active and Reactive Power**

- *THD Analysis of Grid Connected PV System*

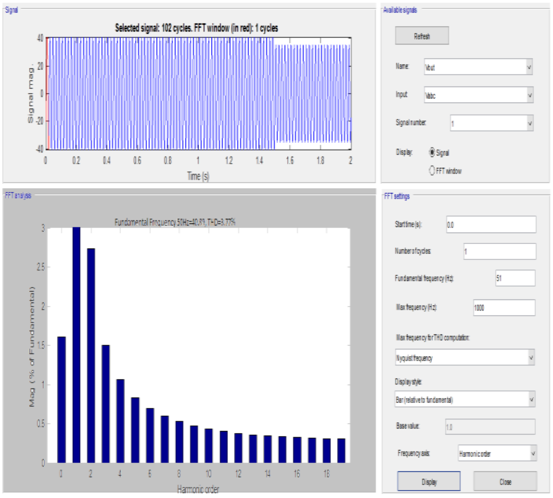


**Fig.10 THD analysis of grid connected PV system.**

Fig.10 show the THD found in the system and it is to be 3.77%, which is well below the 5% prescribed limit.

## 6. Conclusion

The dynamic characteristics of the Photovoltaic cell, Module and Array are obtained for different values of insolation as well as different values of cell temperature at MATLAB/Simulink platform. Modelling scenarios show that increased PV system penetrations are likely to cause increased voltage levels as well as have a detrimental effect on the system power factor. With the change in irradiance level, there is considerable change in output power of whole system. When there is maximum irradiance and load is kept minimum, the power drawn from grid is very less. This condition is required for power system but maximum irradiance cause drastic effect on power quality of system like voltage fluctuation, harmonics which reduces the efficiency of system. In this context, future work will extended this analysis to investigate the model with storage under higher penetrations and lower load demands to optimize the provision of power from PV system and support the network for sustainable energy generation and distribution.

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