Impact of Grid-Connected PV Systems on Power Quality Problems

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Abstract**—** This paper describes the problem of voltage sags and swells and its severe impact on non linear loads or sensitive loads. Simulations of Grid connected PV system is carried out for 5 KW system. Increasing concern on pollution and global warming has prompted Photovoltaic (PV) system as one of the potential renewable and clean energy in power system generation. Power quality issue such as Total Harmonic Distortion (THD) has become an increasingly serious concern as more PV is integrated into the grid system. This encourages an extensive study to identify the challenge in power system network. In this paper, the impact of solar irradiance to current and voltage THD is studied using the simulation model developed in MATLAB/Simulink. The results show that the developed PV model is able to predict the PV system behaviour, particularly on THD. Voltage sags/swells can occurs more frequently than other Power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system.

Index Terms**— Gid-connected, Power Quality, PV system, Solar Irradiance, THD, Voltage Sag, Voltage Swell.**

I. INTRODUCTION

Due to growing concerns about environmental issues and ever-increasing demand for low-cost energy, the utilization of renewable energy sources is attracting enormous interest. Among the renewable energy sources, the solar energy is freely and abundantly available and can be easily converted into electrical energy using photovoltaic (PV) cells [l, 12]. However, the increasing use of PV energy, demands attention on various issues such as maximum power point tracking (MPPT)[8-9], power quality [6-10], and operation under various environmental conditions [10, 11].

The boost converter performs the Maximum Power Point Tacking (MPPT) in addition to boosting the input voltage. The inverter stage is a full-bridge inverter that controls the dc-link voltage by means of injecting the proper current in phase with the grid voltage into the grid. The voltage, current, power generations and THD patterns are observed according to the solar irradiance and the result from the simulation model will be discussed and compared with the measurement result [2, 13].

II. Power Quality:

In an ideal power system, generating electricity from power producer should invariably and perfectly display a sinusoidal voltage waveform at every customer locations even though it is hard to save such desirable conditions. The standard deviation of the current waveforms and the voltage from sinusoidal are described in terms of waveform distortion, such as, voltage fluctuation, and harmonic distortion [3, 4, and 14].

Total Harmonic Distortion (THD) of voltage is defined as the ratio of the RMS value of all harmonic components of the Voltage (Vn), to the fundamental Voltage (V1) based on the following Eq. (1)[4,11]

$$THD_V = \frac{\sqrt{\sum 3,5,7,\ldots V_{n(rms)}^2}}{V_{1(rms)}} \quad (1)$$

Where,
Vn(rms) is the value of the harmonic voltage number n.
V1(rms) is the voltage at the fundamental frequency of 50 Hz

III. PV SYSTEM

Photovoltaic (PV) technology has been one of the promising renewable energy due to its ability to produce electricity without any pollution to the environment.

PV system is a type of renewable energy that highly dependent to environment condition. The variations in the solar irradiance caused by the movement of clouds, leads to fluctuation of output power of PV system which highly potential to some operational problems which make the PV system ineffective. The most severe fluctuations in the output power of PV systems usually occur at maximum irradiance level at noon. This period usually coincides with the off-peak loading period of the electric network, thus, the operating penetration level of the PV system is greatest [5].

The lack of PV power output performance on grid line was influenced by several factors, such as [3];

i. Type of clouds
ii. Penetration level
iii. Size of PV system
iv. Location of the PV system
v. Topology of the PV system
vi. Topology of the electric network

IV. GRID CONNECTED PV SYSTEM

These systems are connected to broader electricity network. The PV system is connected to the utility grid using high quality inverter which converts DC power from the solar array into AC power that confirms to the grid's electrical requirements. During the day, solar electricity generated by the system is either used immediately or sold off to electricity supply companies. In the evening, when the system is unable to supply immediate power, electricity can be bought back from the network [6, 10, and 13].

Because as day by day the demand of electricity is increased and that much demand cannot be meeting up by the conventional power plants. And also these plants create pollution. So if we go for the renewable energy it will be better but throughout the year the generation of all renewable energy power plants. Grid tied PV system is more reliable than other PV system. No use of battery reduces its capital cost so we go for the grid connected topology. If generated solar energy is integrated to the conventional grid, it can supply the demand from morning to afternoon. Grid connected systems have demonstrated an advantage in natural disasters by providing emergency power capabilities when utility power is interrupted. Although PV power is generally more expensive than utility provided power, the use of grid connected system is increasing [3,713].

In grid-connected PV systems, batteries are not needed since all of the power generated by the PV plant is uploaded to the grid for direct transmission, distribution, and consumption. Hence, the generated PV power reduces the use of other energy sources feeding the grid, such as hydro or fossil fuels, whose savings act as energy storage in the system, providing the same function of power regulation and backup as a battery would deliver in a stand-alone system.

V. COMPONENTS OF GRID-CONNECTED PV SYSTEM:

The main component for grid-connected solar PV power systems comprise of Solar PV modules, connected in series and parallel, depending on the solar PV array size, to generate DC power directly from the sun's intercepted solar power. Maximum power point tracker (MPPT), making sure the solar PV modules generated DC power at their best power output at any given time during sunshine hours. Grid-connected DC/AC inverter, making sure the generated and converted AC power is safely fed into the utility grid whenever the grid is available. Grid connection safety equipment like DC/AC breakers fuses etc., according to the local utility's rules and regulations [3, 5].

Table 1 shows harmonic voltage distortion limit for non-linear load at the point of common coupling as per IEEE standards.

TABLE I. HARMONIC VOLTAGE DISTORTION LIMIT FOR NONLINEAR LOAD AT THE POINT OF COMMON COUPLING (PCC) (IEEE REGULATION STANDARD IEEE 519-1992) [6]

Harmonic Voltage Distortion in % at PCC			
	2.3-69 kV	***69-161 kV***	***>161 KV***
Maximum for Individual Harmonic	3.0	1.5	1.0
Total Harmonic Distortion	5.0	2.5	1.5

Table 2 shows standards of interconnection of PV system to the grid.

TABLE II. STANDARDS OF INTERCONNECTION OF PV SYSTEM TO THE GRID [5]

Issues	**IEC 61727**		**IEEE 1547**	
Nominal Power	**10 kW**		**30kW**	
Harmonic Current Limits	**Harmonics (n^th^)**	**THD (%)**	**Harmonics (n^th^)**	**THD (%)**
	3-9	4	3-9	4
	11-15	2	11-15	2
	17-21	1.5	17-21	1.5
	23-33	0.6	23-33	0.6
			> 35	0.3
Max. Current THD	5 %		5 %	

VI. POWER QUALITY ISSUES

Voltage Sag: Sag (dip) a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 minute.

Based on the time duration and voltage magnitude, sag is further classified as:

a) Instantaneous Sag: Instantaneous sag is said to occur when the r.m.s voltage decreases to between 0.1 and 0.9 per unit for time duration of 0.008333 second to 0.5 second.

b) Momentary Sag: Momentary sag is said to occur when the r.m.s voltage decreases to between 0.1 and 0.9 per unit for time duration of 0.5 second to 3 seconds.

c) Temporary Sag: Temporary sag is said to occur when the r.m.s voltage decreases to between 0.1 and 0.9 per unit for time duration of 3 to 60 seconds.

Voltage Swell: Swell - an increase to between 1.1 pu and 1.8 pu in rms voltage or current at the power frequency durations from 0.5 to 1 minute.

Under voltage – decrease in the rms voltage to less than 90% of the nominal voltage.

Over voltage – increase in the rms voltage to more than 110% of the nominal voltage [15].

VII. SIMULATION PARAMETERS

The System installed capacity is taken 5 kWp which is composed of solar panels Poly Crystalline Module Size 250 Wp located at P&N Engineering & Marketing, Ahmedabad. The simulation designed for PV system to the Grid.

Table 1: PV Module Parameters

PV Module Parameters	**Value**
Cells per module	60
Open circuit voltage Voc (V)	37.2
Short-circuit current Isc (A)	9.20
Voltage at maximum power point Vmp (V)	30.3
Current at maximum power point Imp (A)	8.26
Temperature coefficient of Voc (%/deg.C)	-0.35
Temperature coefficient of Isc (%/deg.C)	0.05
Irradiances (W/m2)	500, 1000

Table: 2 Simulation Parameters

Parameters	**Value**
PV output voltage Vpv	330 V
DC Boost output Voltage Vdc	630 Volt
Input capacitor C	8300 µF
Boost Inductor	139 mH
Output Filter L	55 mH
Grid Phase voltage	415Volt

From Simulation Parameters,

CALCULATION OF PV

Max. Voltage of 1 PV = 30.3 Volt
Series-connected modules per string =10
Parallel-connected modules per string = 2
Therefore, Output voltage of PV = 10*30.3 V = 303 Volt
Max. Power of 1 PV = 250.278 W
Therefore PV output power = 20 *250.278 = 5 KW
Load Current Io = P/V = 16 A
But Parallel connected modules are 2 so load current = 16/2 = 8

9. SIMULATION AND EXPERIMENTAL RESULTS

Figure 1 shows the simulation model made for 5 KW System in MATLAB/Simulink.

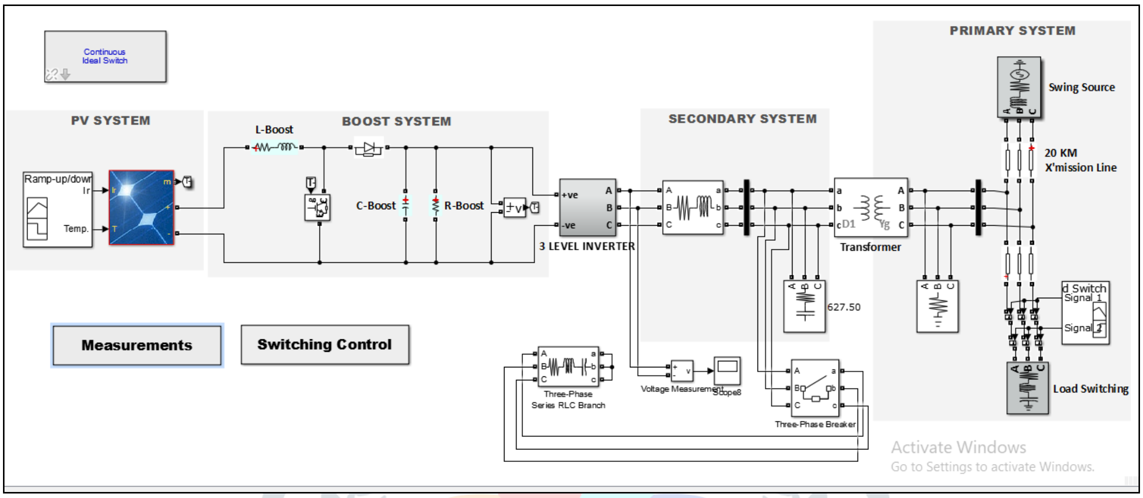

Fig. 1 Simulation Model

The Matlab model I-V and P-V curves for temperature 25° and 45° as shown in figure 2. As the temperature increases the rate of photon generation increases thus reverse saturation current increases rapidly and this reduces the band gap. Hence this leads to marginal changes in current but major changes in voltage. Temperature acts like a negative factor affecting solar cell performance. Therefore solar cells give their full performance on cold and sunny days rather on hot and sunny weather.

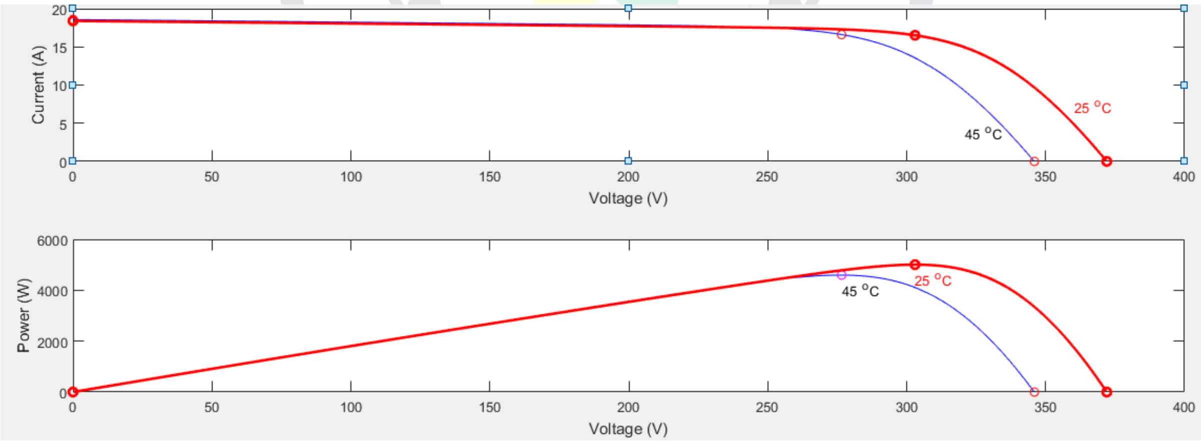

Fig. 2 Matlab model I-V and P-V curves for various irradiation levels

The Matlab model I-V and P-V curves for irradiation 1000 w/m^2 as shown in figure 3. With the increasing solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies.

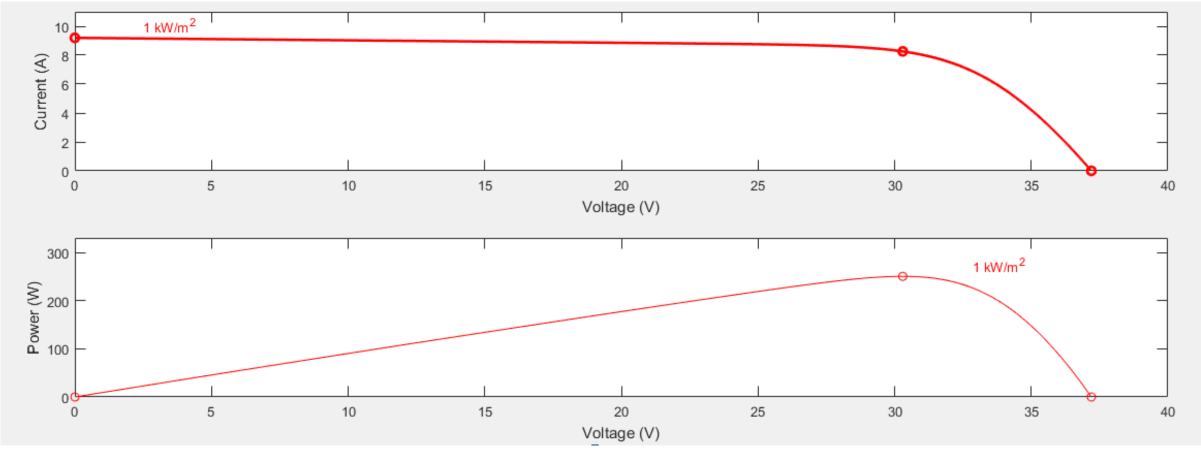

Fig. 3 Matlab model I-V and P-V curves for various irradiation levels

Figure 4 Shows the Output Voltage of PV system. Output voltage is 330 volt determined from simulation.

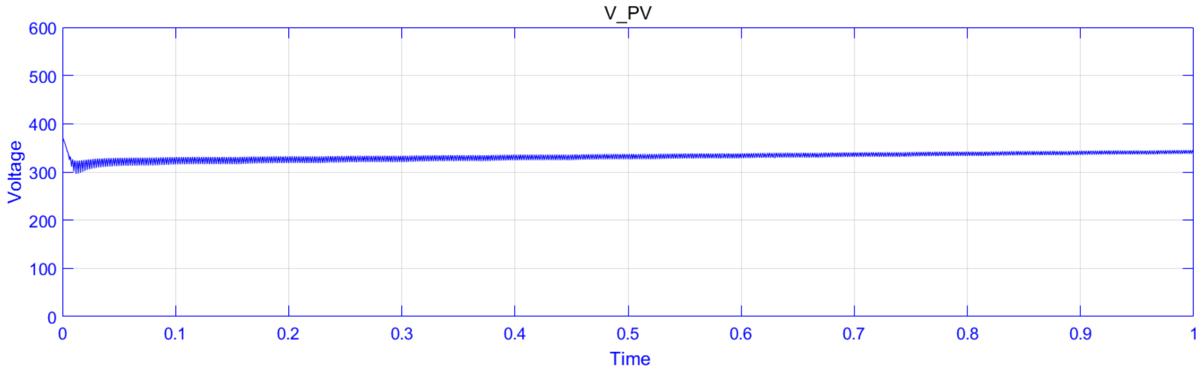

Fig.4 PV Output Voltage

Figure 5 Shows the Output Voltage Boost Converter. Output voltage is 620 volt determined from simulation.

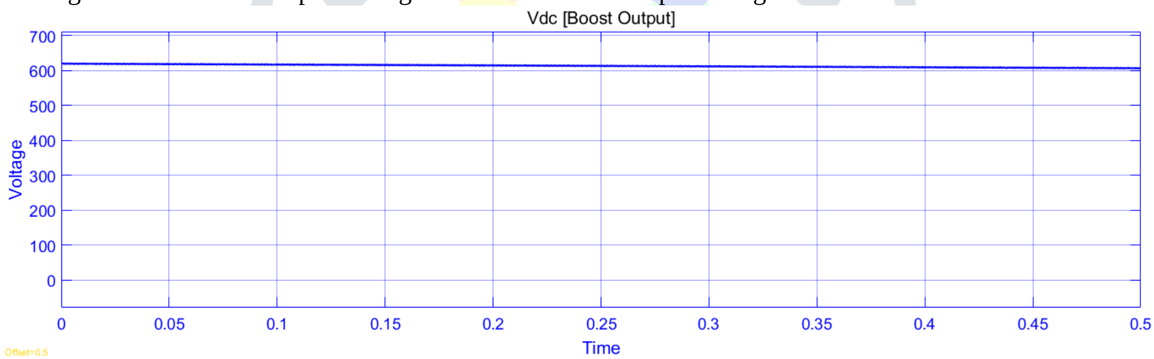

Fig.5 Boost Output Voltage

Figure 6 Shows the Output Power of Solar and Grid. PV Output Power and Grid Power is determined using simulation of 5 kW system.

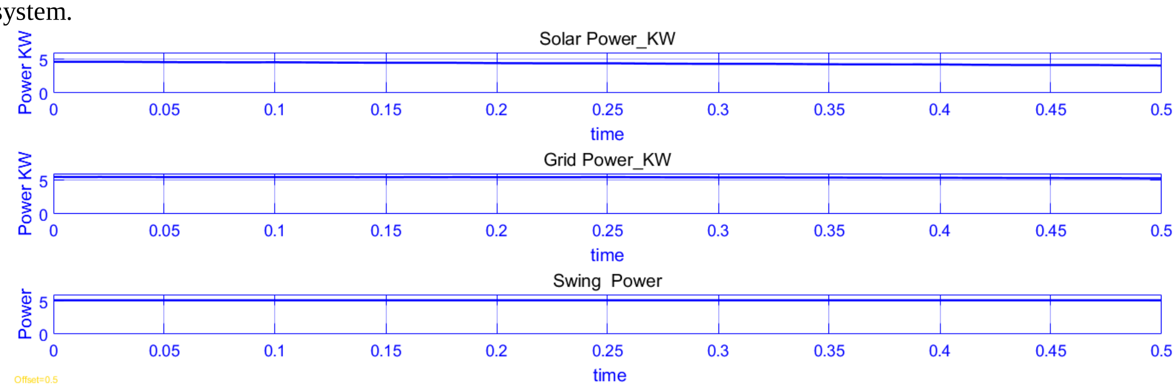

Fig.6 Output Power of Solar and Grid

Figure 7 shows the voltage swell waveform. According to definition, voltage swell is obtained 1.1 pu value in rms voltage therefore voltage swell= 1.1*400 =440 volt determined.

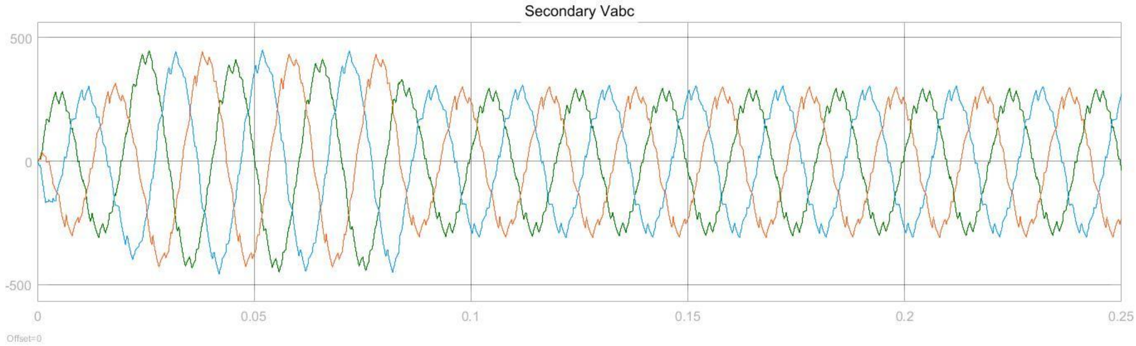

Fig. 7 Voltage swell waveform

Figure 8 shows the voltage sag waveform. According to definition, voltage sag is obtained 0.9 pu value in rms voltage therefore voltage sag= 0.9*400 = 360 volt determined.

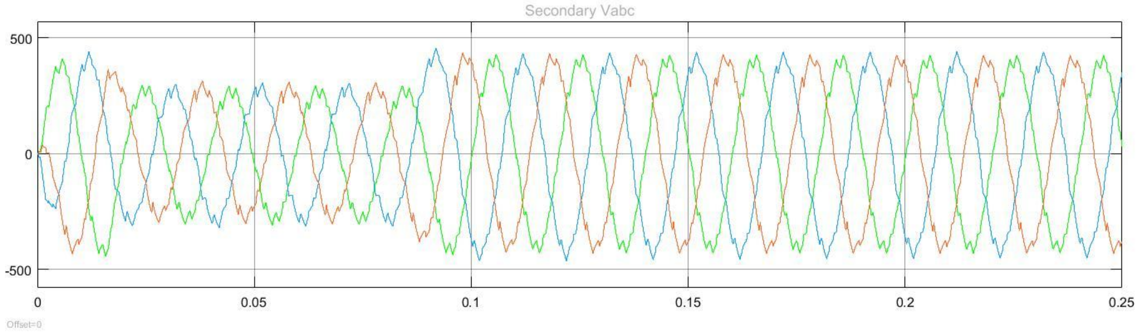

Fig. 8 Voltage sag waveform

Figure 9 shows Harmonic injected in Secondary Grid System. THd is reduced to 6.25 %.

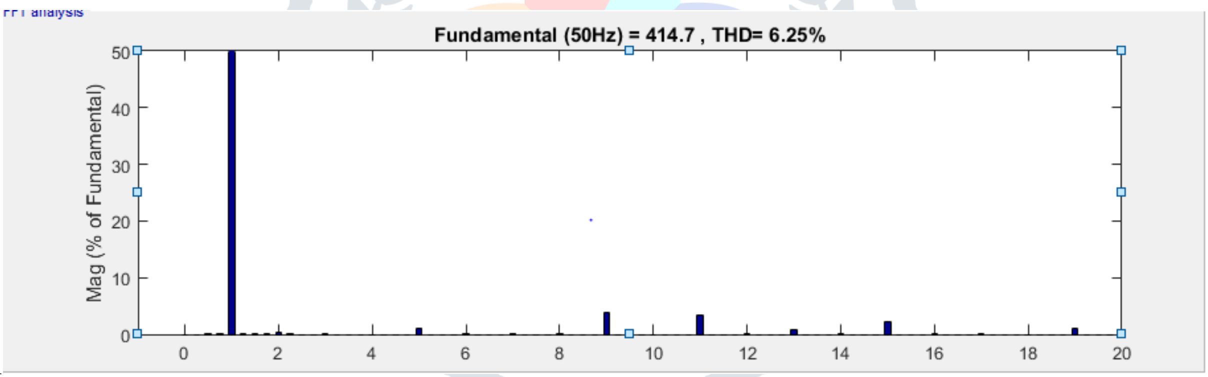

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Fig. 9 FFT Analysis Secondary Grid System

Conclusion: Grid-connected systems do not need batteries; they are more cost-effective and require less maintenance and reinvestment than stand-alone systems. Electricity generated by a grid connected photovoltaic power system will reduce power bill and may be able to sell surplus electricity produced to local electricity supplier .If PV is connected to Grid system systems are essentially maintenance free, generate no pollution and are as silent as the sun. It can be observed that the voltage profile is not much affected by the different levels of solar irradiance since the p-n junction voltage in the PV cell is temperature dependence. In this paper simulink model is designed and THD and voltage sag swell problems determined. As THD reduced easier digital implementation and very low switching losses therefore quality of power is improved.

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