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# Modelling Of Grid Connected PV System with Constant Current Controller

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***ABSTRACT***
*The Solar Energy has huge potential for the electrical Energy Protection in recent days. The PV System is developing very fastas compared to its counterparts of therenewable energies. This Paper proposes Modelling and Design of Grid integrated PVsystem with Constant Current Controller. The DC voltage generated by the PV systemis increased by the DC-DC Boost converter. The utility grid is incorporated with the PV Solar Power Generator through the 3-ɸ PWMDC-AC inverter, whose control is provided by a constant current controller. This controller uses a 3-ɸ phase locked loop (PLL) for tracking the phase angle of the utility grid and reacts fast enough to the changes in load or grid connection states, as a result, it seems to be efficient in supplying to load the constant voltage without phase jump. The complete mathematical model for the grid connected PV system is developed and simulated using MATLAB/SIMULINK.*

***Keywords*** – *PLL, Boost Converter,MATLAB/SIMULINK.*

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## I. INTRODUCTION

The continuous increase in the electrical energy with the clean environment needs the decentralized renewable energy production. The increasing energy consumption may overload the distribution grid as well as power station and may cause the negative impact on power availability, security and quality. The only solution to overcome this problem is integrating the utility grid with therenewable energy systems like solar, wind or hydro. The grid can be connected to the renewable energy system as per theavailability of renewable energy sources. Renewable energy is expected to make up 30percent of the world's energy by 2024, according to the International EnergyAgency, and most of this is driven by solar and wind projects that continue to be rolled out at a starting pace. Recently the solar power generation systems are getting more attention because solar energy is abundantly available, more efficient and more environment friendly as compared to the conventional power generation systems suchas fossil fuel, coal or nuclear. The PV systemsare still very expensive because of higher manufacturing cost of the PV panels, but the energy that drives them the light from the sun is free, available almost everywhere and willstill be present for millions of years, even allnon-renewable energy sources might be depleted. One of the major advantages of PVtechnology is that it has no moving parts. Therefore, the PV system is very robust, it has a long lifetime and low maintenance requirements. And, most importantly, it isone solution that offers environmentally friendly power generation. The disadvantageof the PV system is that it can supply the load only in sunny days. Therefore, for improving the performance and supplying the power in all day, it is necessary to hybrid the PV system into another power generation systems or to integrate with the utility grid. The integration of the PV system with the utility grid requires the solar inverter for interfacing the utility grid and results some interface issues. Due to this the inverter mayproduce distorted output which can affect theloads [1].

The inverters suitable for the PV system are central inverters, string inverters, Module integrated or module oriented inverters, multistring PV inverter. If these solar inverters areconnected with the grid, the control of these inverters can be provided such that ConstantCurrent is maintained [2], [3]. Power electronic systems can also be used for controlling the solar inverter for interfacing the Solar Power Generation system with the grid [4], [5]. In this paper, a model is proposed to control the output of solar inverter through constant current controller such that the output of solar inverter interfaces with grid voltage in terms of phase and magnitude and supply constant current to the loads in all conditions.

## II. MATHEMATICAL MODELING

The block diagram of PV system integrated with the grid using constantcurrent controller is shown in Figure.1, whichpractically shows the overall view of system.It consists of PV array for solar power generation, booster convertor, MPPT, 3- phase inverter, grid and constant current controller which takes feedback from grid toPWM inverter.

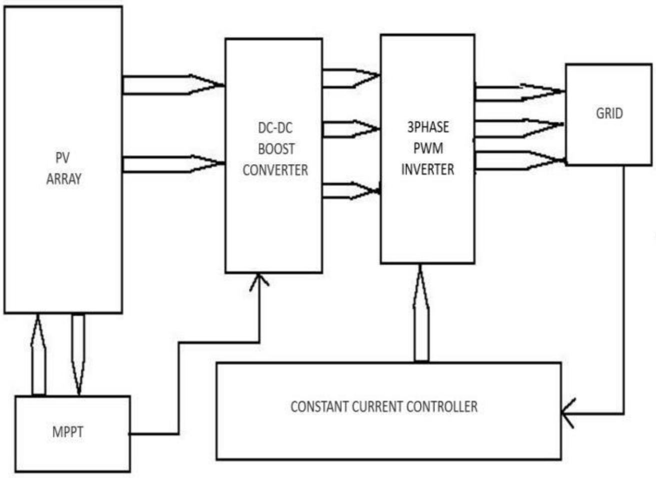


**Fig 1:** Block diagram of PV system integrated with the grid using constantcurrent controller.

### 2.1 PV Array:

The PV array is the combination of series and parallel connected PV module. Each PV module has series connected PV cellaccording to the voltage requirements. The PV cells are the medium to convert solar energy into the electrical power. These cells are made up of semiconductor materials, when sun beam is absorbed with these material electrons emits and releases the current and thus electric power is produced. The equivalent circuit for obtaining the V-I characteristic of the PV cell is shown in the Figure.2.

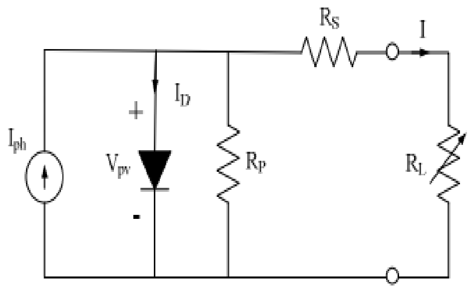


**Figure.2**: Equivalent Circuit of a PV Cell

The Mathematical modelling of the PV arraycan be given as:

$$I = N_P I_{ph} - N_P I_D \left[\exp\left(\frac{q}{kTA} * \frac{V_{pv}}{N_S}\right) - 1\right] \quad (1)$$

The diode reverse saturation current varies with the temperature according to the following equation.

$$I_D = I_{rr} \left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (2)$$

The photo current depends on the solarradiation and cell temperature as follows,

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100} \quad (3)$$

Solar irradiation and temperature plays an important for predicting the behaviour of the PV cell and effects of both the factors have tobe considered while designing the PV system. The solar irradiation affects the output and the temperature affects the terminal voltage.

### 2.2 Maximum Power Point Tracking:

Maximum power point tracking (MPPT) is a technique to maximize the energy obtained over all normal operating conditions. The use of MPPT can reduce the cost of energy by making the system more efficient. The problem raised by MPPT methods is to automatically find the voltage or current (Vmp, Imp) in which a PV array works on its maximum power point under a certain irradiance and temperature. However,most techniques respond to both irradiance and temperature variations but some responds to constant temperature.

**Various MPPT Techniques:**

1. Incremental conductance
2. Fractional open circuit voltage
3. Fuzzy logic based MPPT
4. Neural networks
5. Extreme seeking control
6. P&O algorithm

The P&O algorithm requires few mathematical calculations which makes the implementation of this algorithm fairly simple compared to other techniques. For thisreason, P&O method is heavily used in renewable energy systems. The Perturb and observe algorithm operates by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases, the control system moves the PV array operatingpoint in that direction, otherwise the operating point is moved in the opposite direction. In the next perturbation cycle, the algorithm continues in the same way. The logic of algorithm is shown in Figure.3.

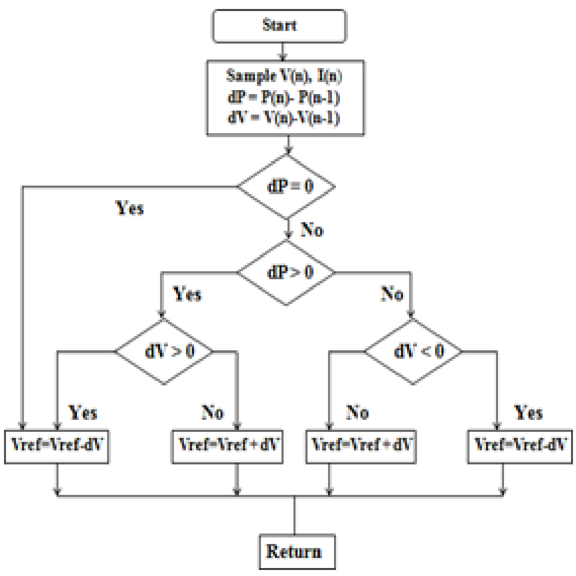


**Figure.3:** The flow diagram of P and O method MPPT

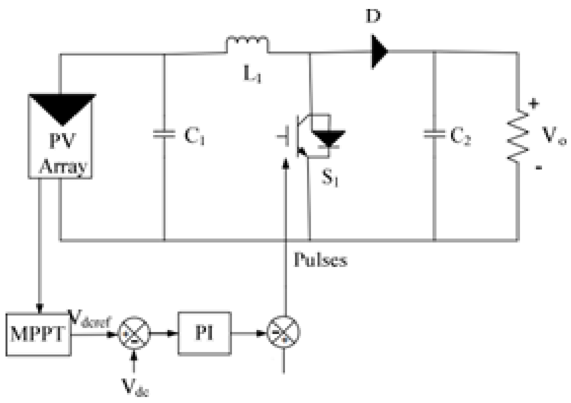


**Figure.4:** Closed loop control for boost converter

### 2.3 Boost Converter and Its Control:

The output voltage of the PV cell is very limited, which is very low for the application. The series and parallelcombination also does not provide the required output. Hence the boost converter isnecessary to enable the low voltage PV arrayto be used. A capacitor is also connected for reducing the high frequency harmonics between the PV array and boost converter. Figure.4 shows the closed loop controller forboost converter. When the switch S1 is in ON state, the inductor L1 is charged from the voltage generated by the PV array and the capacitor C1 discharges across the load. The boost converter operates in CCM (Continuous Conducting mode). The current supplied to the output RC circuit is discontinuous. Thus a large filter capacitor C is used to limit the output voltage ripple. The filter capacitor must provide the output dc current to the load when the diode D is in OFF state. The controlof the boost converter is provided through thePWM signal. The output of the filter which is the control signal is compared with the reference voltage. The PI controller attempts to minimize the error by adjusting the process control inputs. Then it is compared with the saw-tooth waveform to generate the PWM signal which is fed as gate signal to the IGBTswitch. The control circuit regulating the reference voltage $V_{dcref}$ , which is calculated by the MPPT techniques. Thus the PV array can be controlled by controlling the duty ratio for operating at the maximum power point.

### 2.4 Pulse Width Modulation:

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off ata fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. Along with maximum power point tracking (MPPT), it isone of the primary methods of reducing the output of solar panels to that which can be utilized by a battery. PWM is particularly suited for running inertial loads such as motors, which are not as easily affected by this discrete switching, because their inertia causes them to react slowly. The PWM switching frequency has to be high enough not to affect the load, which is to say that theresultant waveform perceived by the loadmust be as smooth as possible.

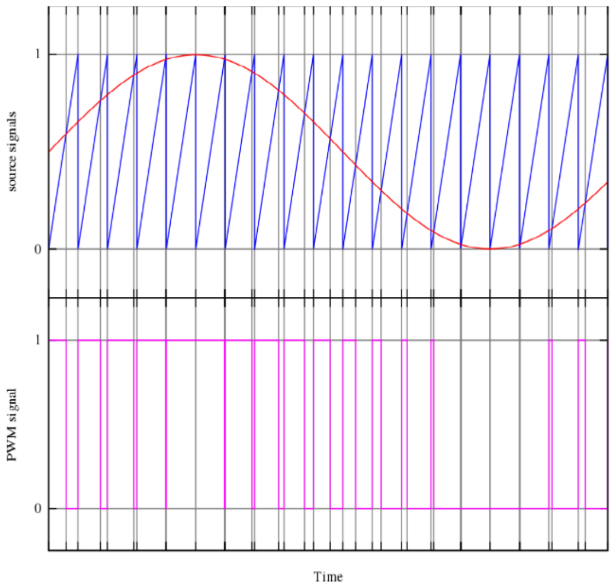


**Figure.5:** Generation of pulses using pulse width modulation

The simplest way to generate a PWM signal is the intersective method, which requiresonly a sawtooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the red sine wave in figure 5) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state.

### 2.5 Constant Current Controller:

Figure.6 shows the detailed block diagram of the constant current controller forgenerating the controlled switching pulses forthe solar inverter such that the output voltageshould be able to interface the grid. The 3-ɸ Phase Locked Loop calculates the phase angle of the utility grid and also gives the information about the frequency variation. According to the phase angle of the utility grid voltage, the constant current controller is modelled such that the controller is able to generate the switching pulses for solarinverter for tracking the phase of the grid voltage.

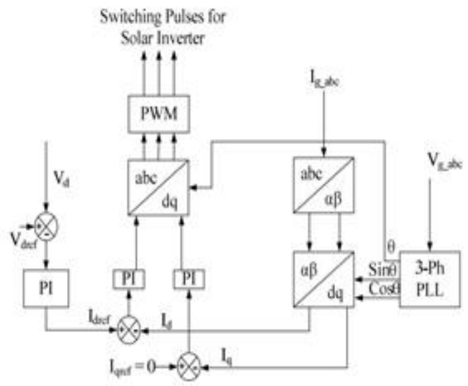


**Figure.6:** Block Diagram of Constant Current Controller

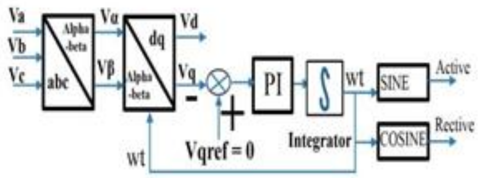


**Figure.7:** Block Diagram of Phase Locked Loop

The 3-ф grid current Igabc is converted into αβ variable using the Clarke transformation. The αβ variables are transformed into the dq variables. The current Id and Iq are compared with the Idref and Iqref for processing in the PI controller to minimize the errors. These signals are transformed into 3-ф signal using the inversepark's transform and then compared with thetriangular waveform for generating the PWMswitching pulse for the solar inverter. The Vdcand Vdcref is the DC link voltage of the PV array and expected DC voltage of the PV array.

**2.6. Three Phase PLL:**

The synchronous frame three phase PLL is widely used for tracking grid voltagesand currents and for providing asynchronization signal to inverter baseddistributed resources. The abc-to-dq transformation makes use of the dq rotating reference frame in which the d-axis leads theq-axis. The end result is alignment of the d-axis with the peak of phase A in a balanced set (positive rotation). The low pass filters remove noise and oscillations from the d andq-axes measurements.

## III. SIMULATION RESULTS

The simulation results are obtained by simulating the above mentioned mathematical models in MATLAB/ Simulink.

**3.1 P-V Characteristics of PV array forirradiance 1 kW/m²:**

The figure.8 shows the output voltageof PV array with 5 series modules and 66 parallel strings at 1kW/m² irradiance and at25 ºC temperature is 321V.

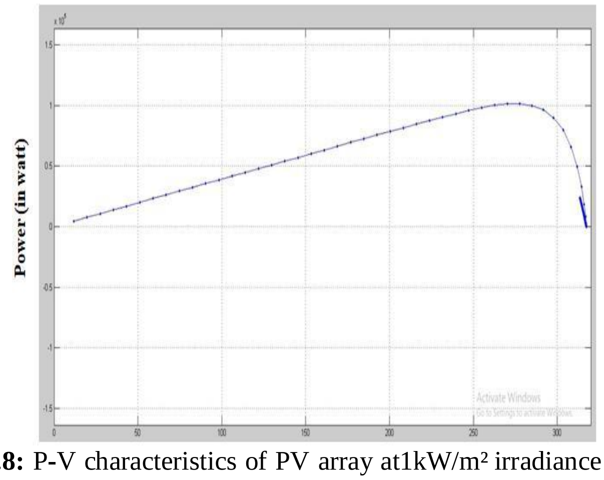


**Figure.8:** P-V characteristics of PV array at1kW/m² irradiance at 25ºC

**3.2 P-V Characteristics of PV array forirradiance 0.4 kW/m²:**
The figure.9 shows the output voltageof PV array with 5 series modules and 66 parallel strings at 0.4kW/m² and at 25 ºCtemperature is 301 V**.**

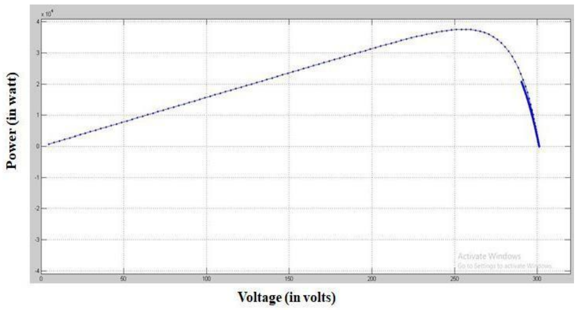


**Figure.9:** P-V characteristics of PV array at0.4kW/m² irradiance at 25ºC

**3.3 I-V Characteristics of PV array at1Kw/m² irradiance:**

The figure.10 shows the I-V characteristics of a PV array with 5 series modules and 66 parallel strings and output current is 400 A and output voltage is 321 V.

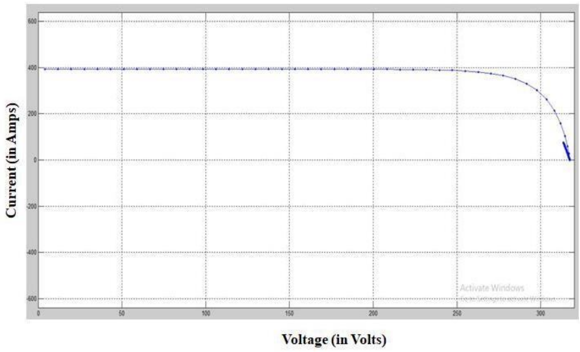


**Figure.10:** I-V characteristics of PV array at1kW/m² irradiance at 25ºC

**3.4 I-V Characteristics of PV array at 0.4Kw/m² irradiance:**
The figure.11 shows the I-V characteristics ofa PV array with 5 series modules and 66 parallel strings and output current is 152A and output voltage is 301 V.

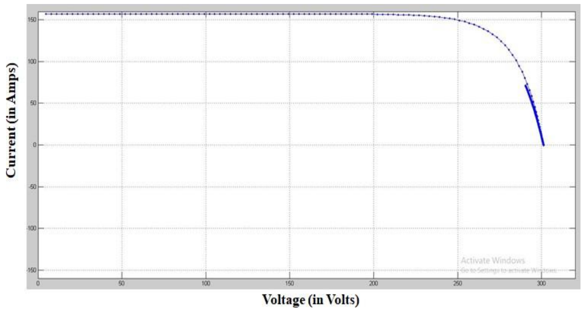


**Figure.11 :** I-V characteristics of PV array at0.4kw/m² irradiance at 25ºC

**3.5 Output voltage of PV array at 1kW/m²irradiance and 25ºC temperature:**

The figure.12 shows the output voltage of PV array with 5 series modules and 66 parallel strings. The output voltage at 1kw/m² irradiance,25 ºC temperature and at maximum power is 321 V.

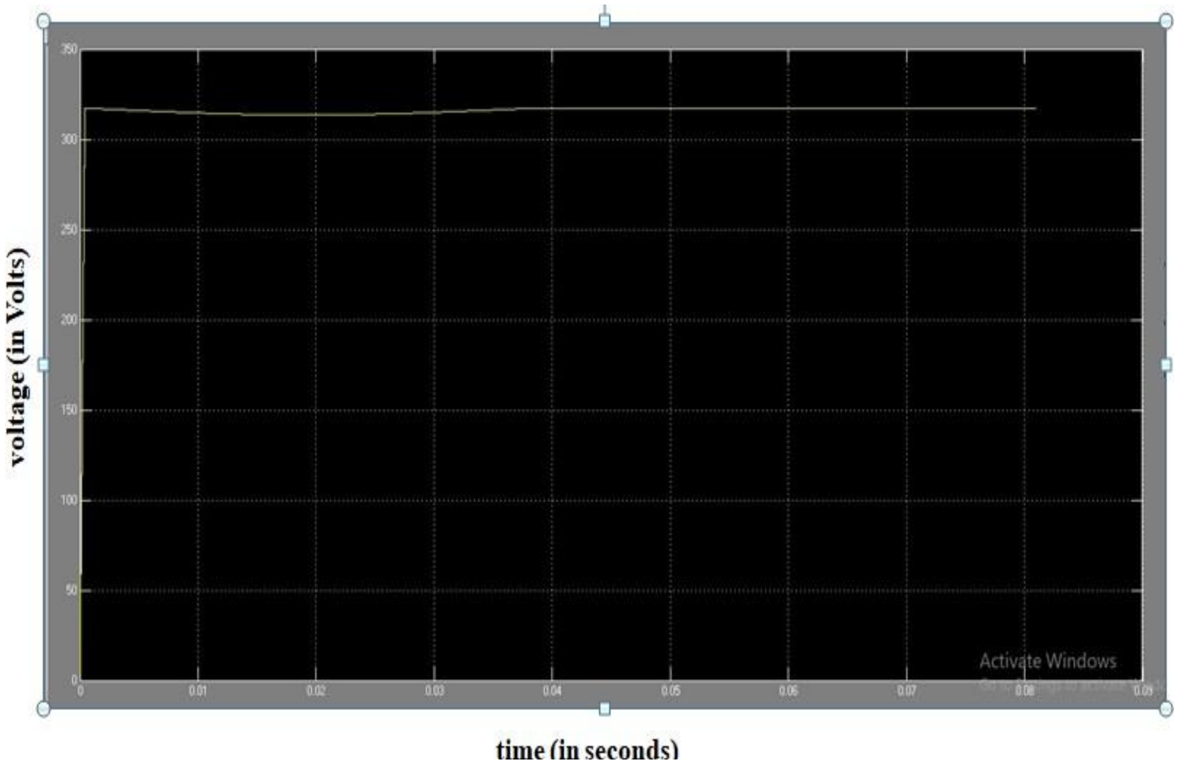


**Figure.12:** Output Voltage of PV array at1Kw/m² irradiance at 25 ºC

### 3.6 Output voltage of Booster Converter:

The boost converter increasing voltage from PV actual output voltage (321VDC at maximum power) to 620 V DC voltage. Switching duty cycle is optimized bythe closed loop controller that uses the PI controller according to load variation. The DC voltage delivered by the DC converter isshown in the Figure.13.

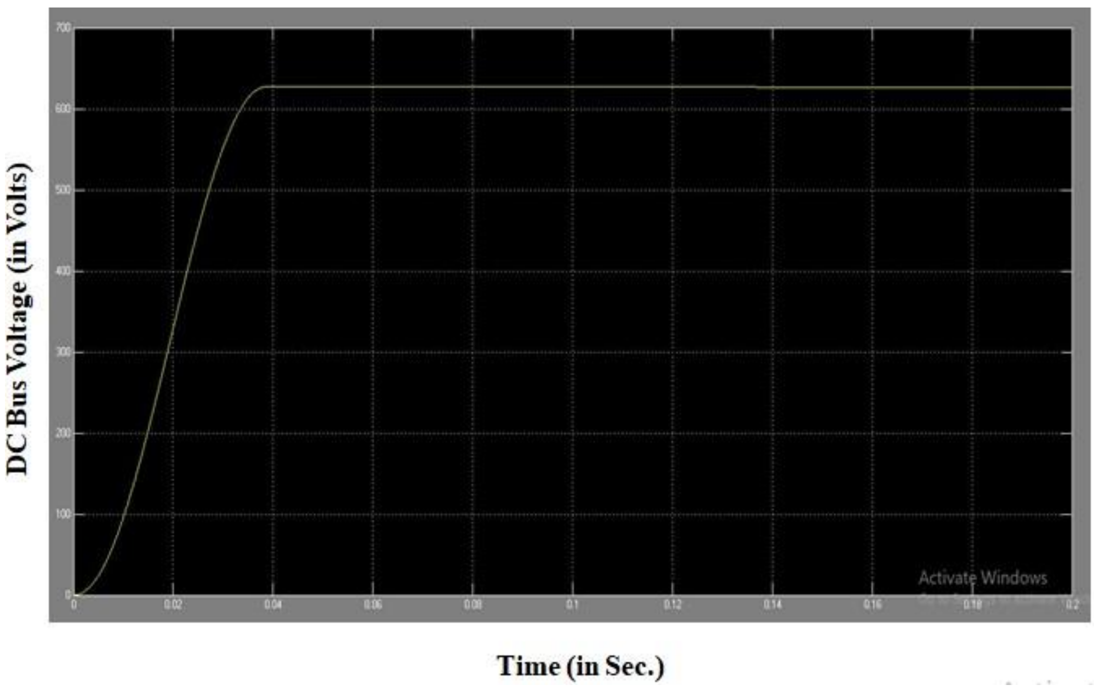


**Figure.13:** DC Output voltage of BoosterConverter

### 3.8 Output Voltage waveforms of SolarInverter:

The 2-level 3-phase voltage sourceinverter is converting the boosted DC voltageinto sinusoidal AC voltage. The LC filterhaving the series inductance branch of 250 μH with internal resistance 0.002 Ω and 10- kvar capacitor bank is filtering harmonics produced by VSC. The combination of VSCand LC filter converts the 620 V DC voltageinto the 415V pure sinusoidal AC voltage.

### 3.8.1 Inverter output voltage before filtering:

The inverter output voltage waveform before filtering is shown in Figure.14. This voltage signal contains harmonics which are further filtered by LC filter.

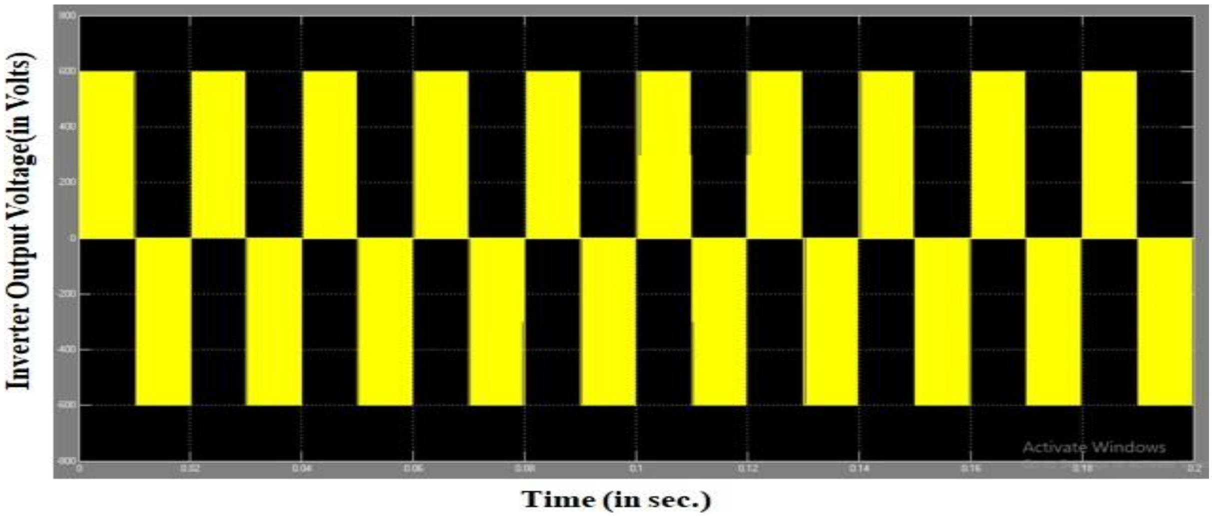


**Figure.14:** Inverter Output Voltage before filtering

### 3.8.2 Inverter Output voltage afterfiltering:

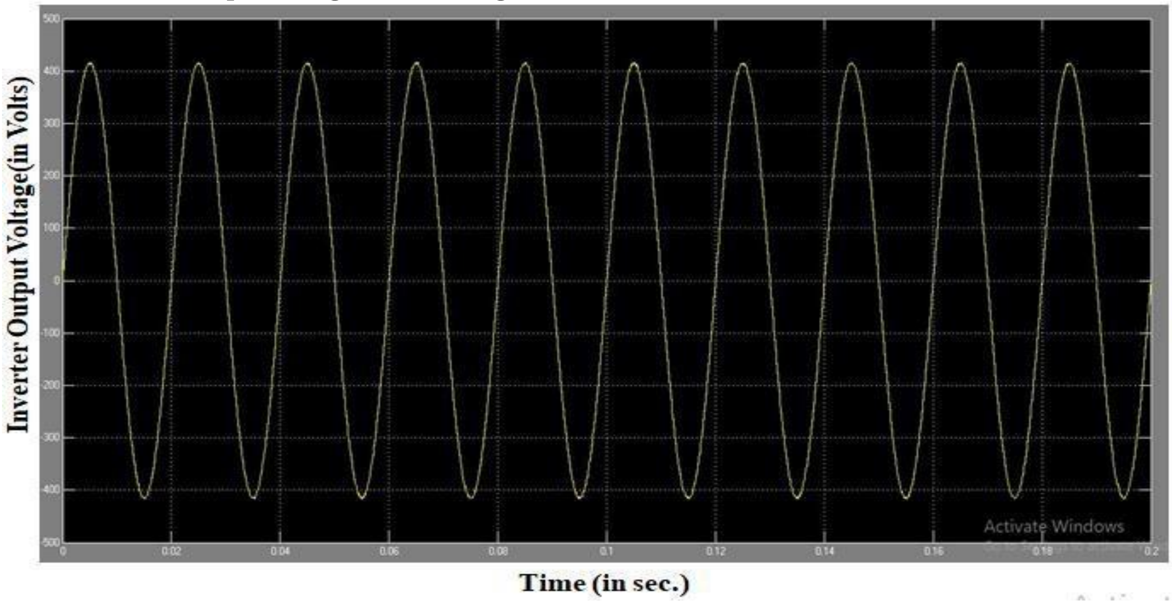


**Figure.15:** Inverter Output Voltage afterfiltering

**3.9 Load Currents for supplying theconsidered two different loads:**

**3.9.1 Load current for supplying 2 MW load:**

For integrating the modelled solar generation system into the utility grid there isneed of stepping up the voltage level from 415V to 25 kV. There is 2 MW load is connected using the 5 km transmission line. Figure.16 shows the load current for supplying the 2 MW load. By using constantcurrent controller, the system is able to supply the constant current to the load throughout the time.

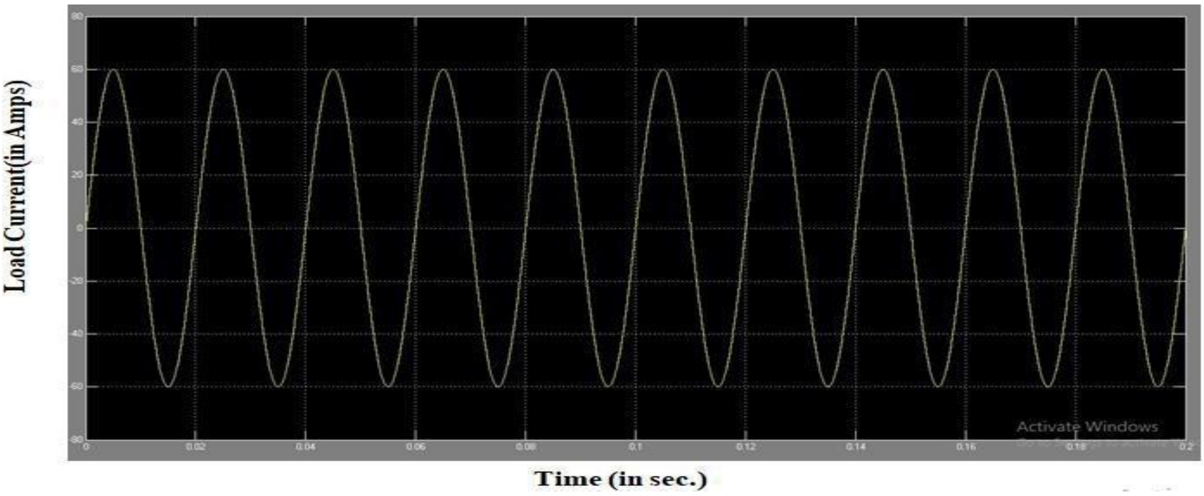


**Figure.16:** Load current for supplying 2 MWload

**3.9.2 Load Current for supplying 30 MW,2 MVAR Load:**

Another 30 MW, 2 MVAR load is connected using the 14 km transmission line. Figure.17 shows the load current for supplying the load of about 30 MW, 2 MVAR. The grid voltage is stepped down from 120 kV to 25 kV. The grounding transformer is used for the protection againstthe faults. The grounding resistance is taken as 3.3 Ω.

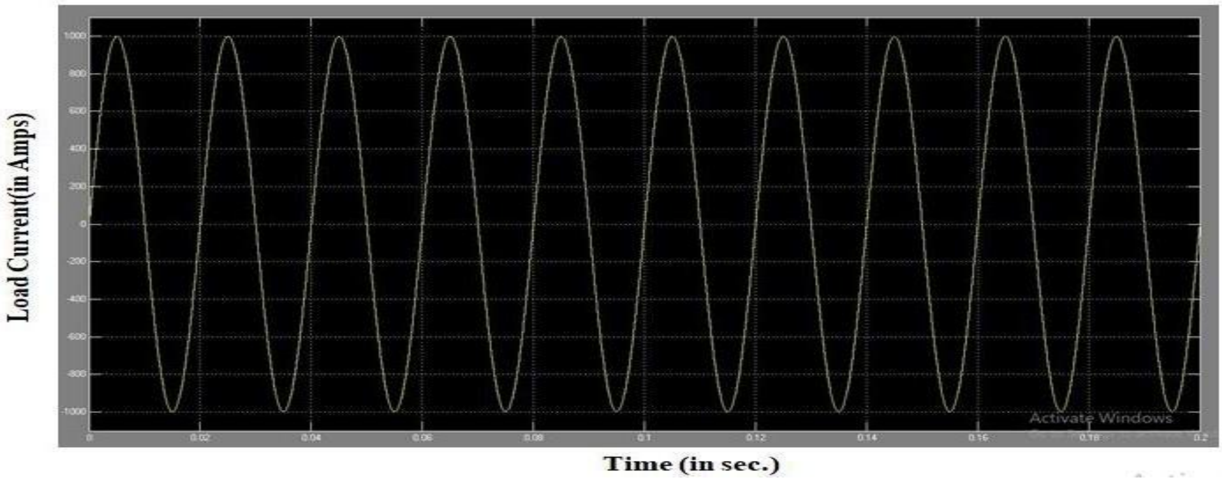


**Figure.17:** Load Current for supplying 30 MW, 2 MVAR Load

By using constant current controller, the system is able to supply the constant current to the load throughout the time. The FFT analysis of Load current at 2MW load and the THD value is observed as 0.44%, the FFT analysis of Load current at 30 MW, 2 MVAR load and the THD value is observed as 0.44% which is very low. So it canbe said that the distortion in the load current isvery low and constant current is supplied to the loads.

### 3.10 Comparison of Inverter output voltage and grid voltages:

The grid voltages and the solarinverter output voltages are compared as shown in the Figure.18.

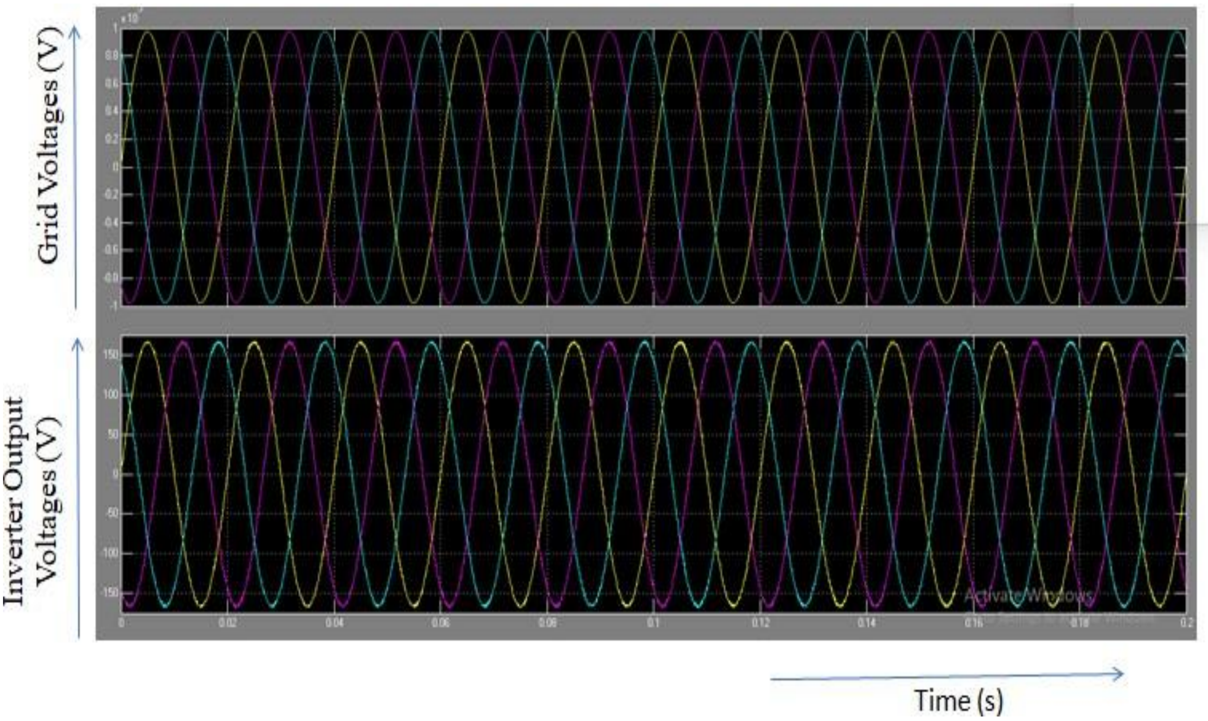


**Figure.18:** Comparison of grid voltages andinverter output voltage

Through Constant Current Controller, PLL which is a part of it senses the grid voltage and magnitude and send signals to thePI controller such that it generates switchingpulses to the solar inverter to interface with the grid. In the Figure we can see that both grid voltages and inverter output voltages areinterfaced in terms of phase angle throughoutthe time.

## IV. CONLUSIONS

For improving the energy efficiency and power quality issues, in this paper, the detailed modelling of grid connected PV generation system is developed. The DC-DC boost converter is used to optimize the PV array output with the closed loop control for keeping the DC bus voltage to be constant. The 2 level 3-phase inverter is converting the DC into the sinusoidal AC voltage. The control of the solar inverter is provided through the constant current controller. This controller tracks the phase and frequency of the utility grid voltage using the Phase-Locked-Loop (PLL) system and generates the switching pulses for the solar inverter. Using this controller, the output voltage of the solar inverter and the grid voltage are in phase. Thus the PV system can be integrated to the grid and distortion in the current supplied to the loads is also very less. The simulation results the presented in this paper to validate the grid connected PV system model and the applied control scheme.

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