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POWER QUALITY ANALYSIS OF A THREE PHASE GRID CONNECTED SOLAR PVSYSTEM

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ABSTRACT

The evaluation of power electronics has emerged since last few decades ago. In modern contest the world is moving from conventional energy sources to the renewable one. It is due to it greater abundance and environment friendly characteristics. Solar energy is one of the most promising renewable resources that can be used to produce electric energy through photovoltaic process. A significant advantage of photovoltaic (PV) systems is the use of the abundant and free energy from the sun. Power electronic devices used as interface between renewable power and its user. It makes the power generated by renewable sources suitable for utilization. Solar power contribution in power generation has been increasing very fast and cost of power generated by solar photovoltaic is falling rapidly.

Solar photovoltaic cell converts solar energy directly into dc power. Power is mostly transmitted and utilized in ac form because of advantages associated with it. To convert the dc power into ac, a highly efficient converter is required for optimum utilization of energy. The MPPT algorithm uses the IPV and VPV of the PV array and gives the MPP and a VDCREF. This voltage is then passed on to the inverter and then further to the three-phase grid. In this paper the behavior of the active and reactive power of the grid which is supplied by the PV array is investigated. The various currents such as inverter current, grid current and load currents are also investigated.

Keywords: Three Phase Grid; Solar PV; MPPT Controller; DC-DC Boost Converter.

1. INTRODUCTION

1.1. SYSTEM DESCRIPTION

The downward tendency in the price of the photovoltaic modules, together with their increasing efficiency, put solid-state inverters under the spot lights as enabling technology for integrating PV systems into grid. Grid synchronization unit plays important role for grid connected SPV systems. Fig. 1 shows the system design. The given system consists of a

- SPV array,
- DC/DC boost converter
- A three-phase voltage source converter with grid synchronization control schemes.

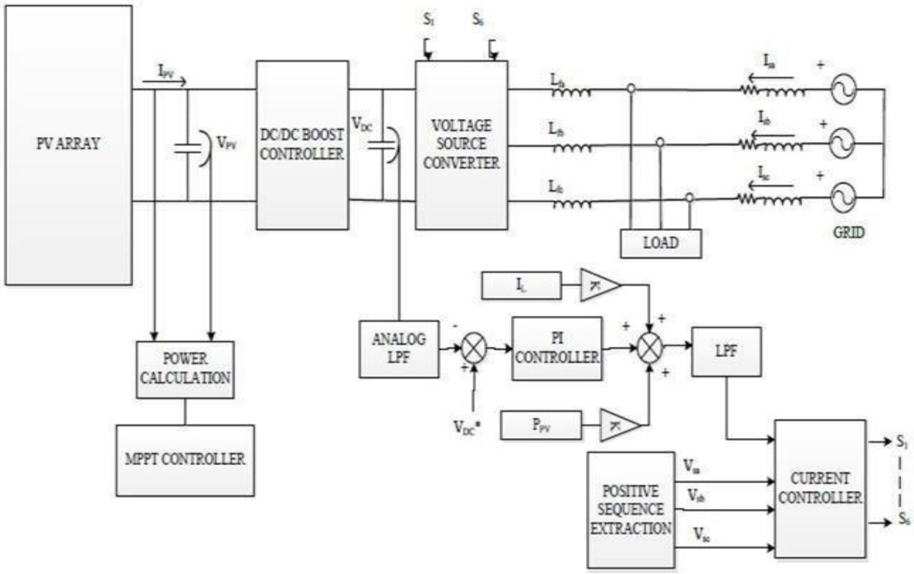

Fig 1: System Design

1.1.1. Three Phase Grid connected Solar PV System without Using Filters

Performing power quality analysis of a three-phase grid-connected solar PV system without using filters can still provide valuable insights into the system's performance. While filters can help isolate specific components for analysis, there are several power quality parameters that can be assessed directly without the need for filters.

a. Voltage and Current Waveform Analysis: Analyze the voltage and current waveforms to identify any irregularities or distortions. This can be done by examining the waveform shape, amplitude, and frequency. Look for abnormalities such as voltage or current imbalances, waveform distortions (e.g., harmonics or inter harmonics), voltage sags/swells, and transients.

b. Total Harmonic Distortion (THD): Calculate the THD of the grid-connected solar PV system. THD quantifies the distortion caused by harmonics in the voltage or current waveforms. It provides an indication of the system's harmonic content and can be compared against relevant standards or guidelines to assess compliance.

c. Power Factor Analysis: Evaluate the power factor of the system. Power factor represents the relationship between real power and apparent power. A low power factor can indicate reactive power issues, leading to increased line losses and reduced system efficiency. Assessing the power factor helps ensure efficient power transfer and utilization.

d. Voltage Fluctuations: Examine the voltage fluctuations in the grid-connected solar PV system. Assess parameters such as voltage flicker and rapid voltage changes. Voltage fluctuations can be caused by various factors, including load variations and intermittent solar irradiance. Analyzing these fluctuations helps ensure stable and reliable operation.

e. Transient Analysis: Identify and analyze transient events, such as voltage spikes or dips. Transients can occur due to switching operations, lightning strikes, or equipment faults. Monitoring and analyzing transients provide insights into the system's resilience and helps identify potential issues that may affect power quality.

f. Frequency Analysis: Assess the frequency stability of the grid-connected solar PV system. Measure the deviation from the nominal frequency and evaluate the system's ability to maintain a stable frequency within acceptable limits.

By analyzing these parameters, you can gain valuable information about the power quality characteristics of a three-phase grid-connected solar PV system. While filters can provide more detailed analysis of specific components, a filter-less approach can still offer insights into the overall performance, compliance with standards, and the impact of the PV system on the grid.

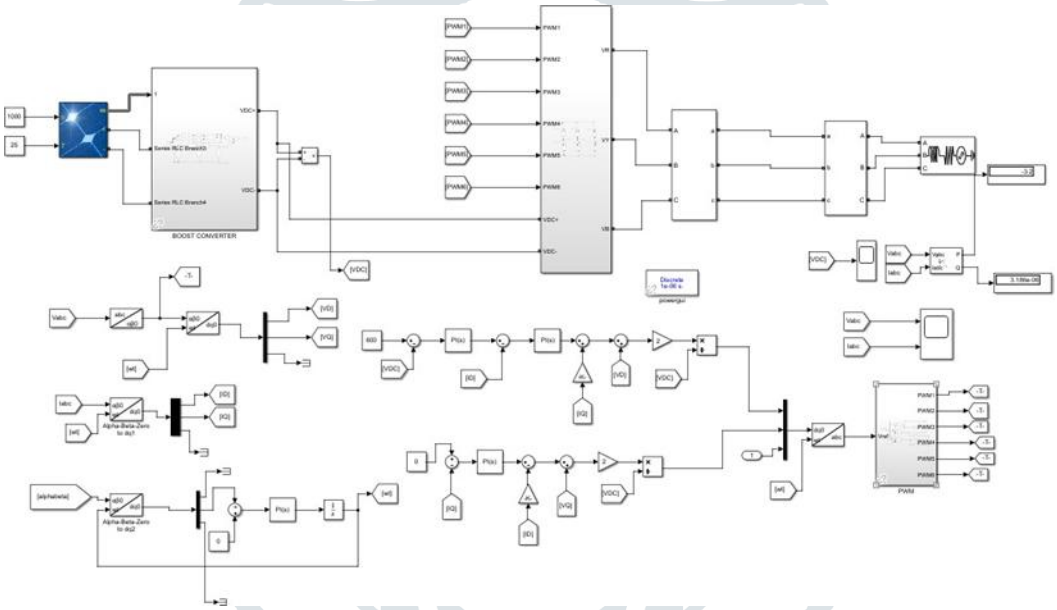

Fig. 2: Simulation diagram of grid connected solar PV system without filter

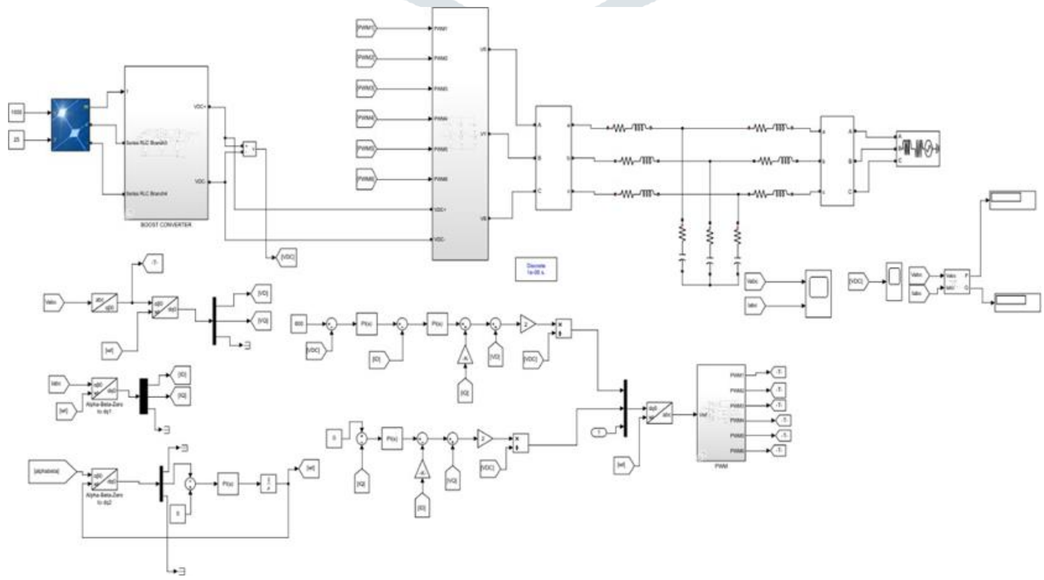

Fig. 3. Simulation diagram of grid connected solar PV system with filter

A 100-kW PV array is connected to a 0.4-kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC). Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of a Simulink model using the 'PO + Proportional Integral Regulator' technique. The detailed model contains the following components:

PV array delivering a maximum of 100 kW at 1000 W/m^2 sun irradiance.

5 kHz DC-DC boost converter increasing voltage from PV natural voltage (290 V DC at maximum power) to 700 V DC. The switching duty cycle is optimized by an MPPT controller that uses the 'Incremental Conductance + Integral Regulator' technique. This MPPT system automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

1980-Hz 3-level 3-phase VSC. The VSC converts the 700 V DC link voltage to 230 V AC and keeps the unity power factor. The VSC control system uses two control loops: an external control loop that regulates DC link voltage to +/- 250 V and an internal control loop that regulates Id and Iq grid currents (active and reactive current components). Id current reference is the output of the DC voltage external controller. Iq current reference is set to zero in order to maintain the unity power factor. Vd and Vq voltage outputs of the current controller are converted to three modulating signals Uabc_ref used by the PWM Generator. The control system uses a sample time of 100 microseconds for voltage and current controllers as well as for the PLL synchronization unit. Pulse generators of Boost and VSC converters use a fast sample time of 1 microsecond in order to get an appropriate resolution of PWM waveforms.

2. RESULTS AND DISCUSSIONS

The performance of three phase grid connected solar PV System is analyzed for different kind of loads. Also, the impacts of changing meteorological parameters especially irradiance is studied. Impacts of increasing percentage penetration of solar PV on the existing grid are also analyzed through THD and voltage at the PCC point.

Now, the MATLAB simulated model of a 3-phase grid connected system is shown in the below Figure which incorporate a PV array connected to a DC-DC boost converter, a DC to AC three phase voltage source inverter, a three phase 400V grid with the above-mentioned load connected at PCC point.

2.1. Performance of Three Phase Grid Connected System

A 100 KW grid connected solar PV system MATLAB model is simulated as shown in the Fig 2 & 3. Its performance is analyzed by observing the various parameters like dc power supplied by solar PV system, dc-dc boost converter, dc link voltage, inverter voltage and current.

2.1.1. DC Power Supplied by the Solar PV System:

Power supplied by solar PV system is dependent on the voltage and the current of solar panel which in turn dependent on the irradiance and temperature.

At constant ambient temperature DC power supplied by solar PV panel follows the irradiance pattern.

The output waveforms of solar panel and details of the solar panel is shown in below Fig. 4. The output waveform of solar PV shows Vpv, Ipv, Ir, Vdc, Ppv.

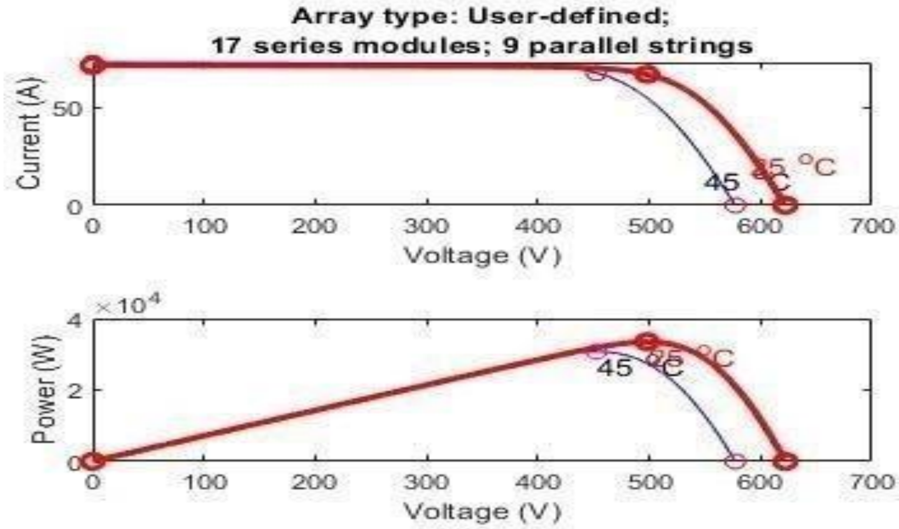

Fig. 4. Solar Panel Voltage V/S Power & Current Waveforms

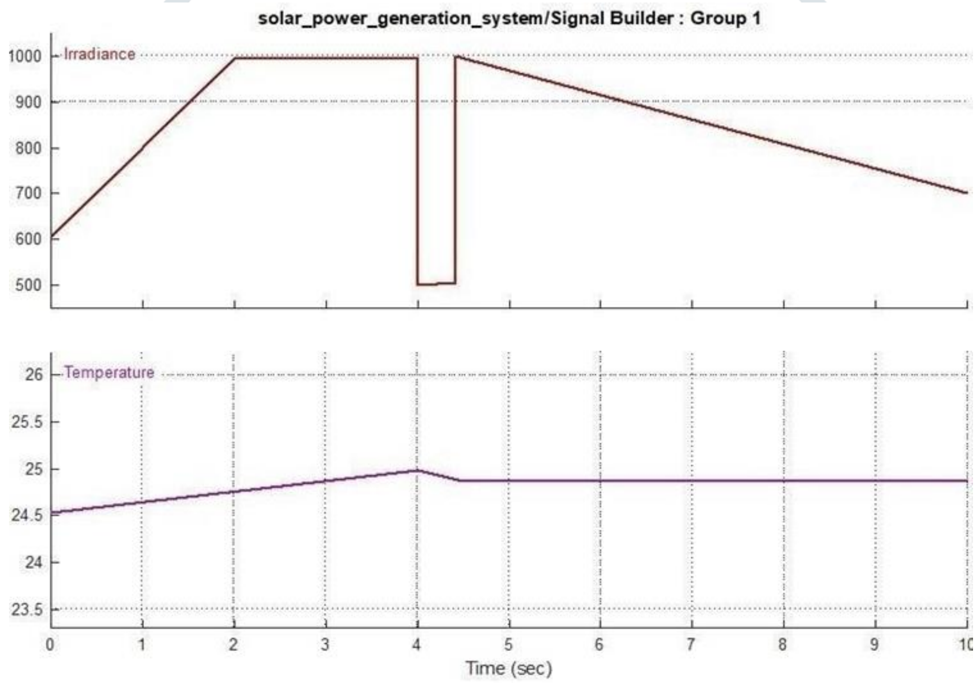

Fig. 5. Solar Panel Irradiance and Temperature Waveforms

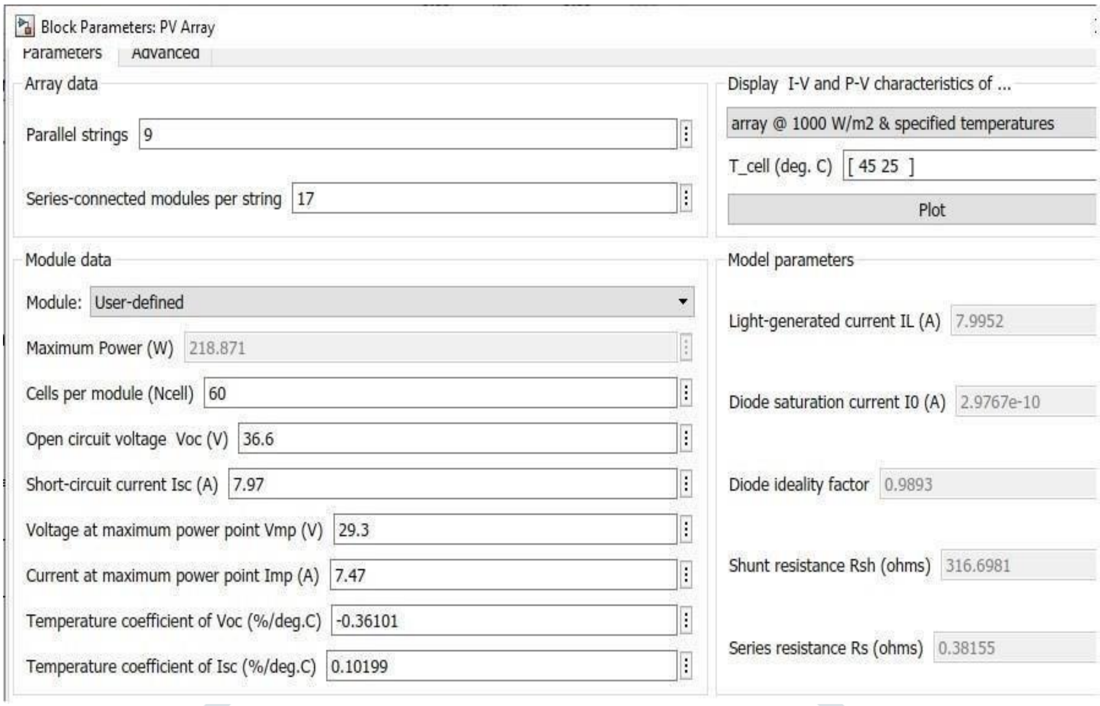

Fig. 6. Solar Panel Ratings

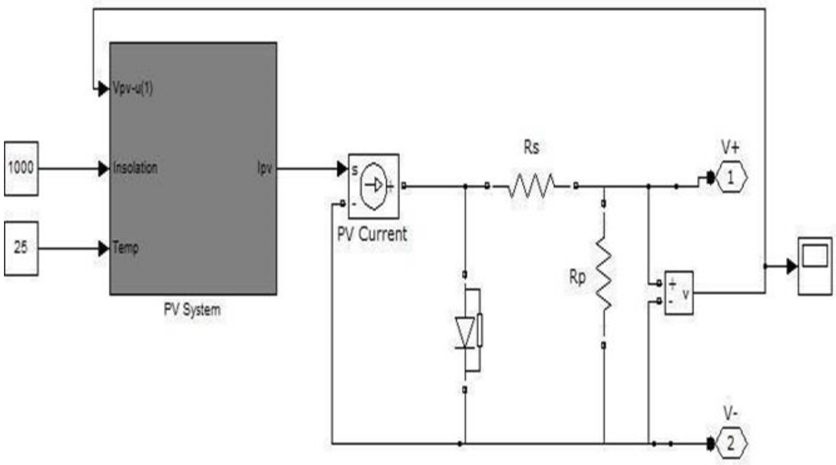

Fig. 7. MATLAB Simulation of Solar PV Panel

Solar PV voltage and current is very important parameter for the performance of solar PV system. These are the parameters which are used as input to MPPT control which in turn generate pulses for DC-DC boost converter. The PV voltage does not vary much due to change of irradiance but current is purely dependent on the irradiance pattern.

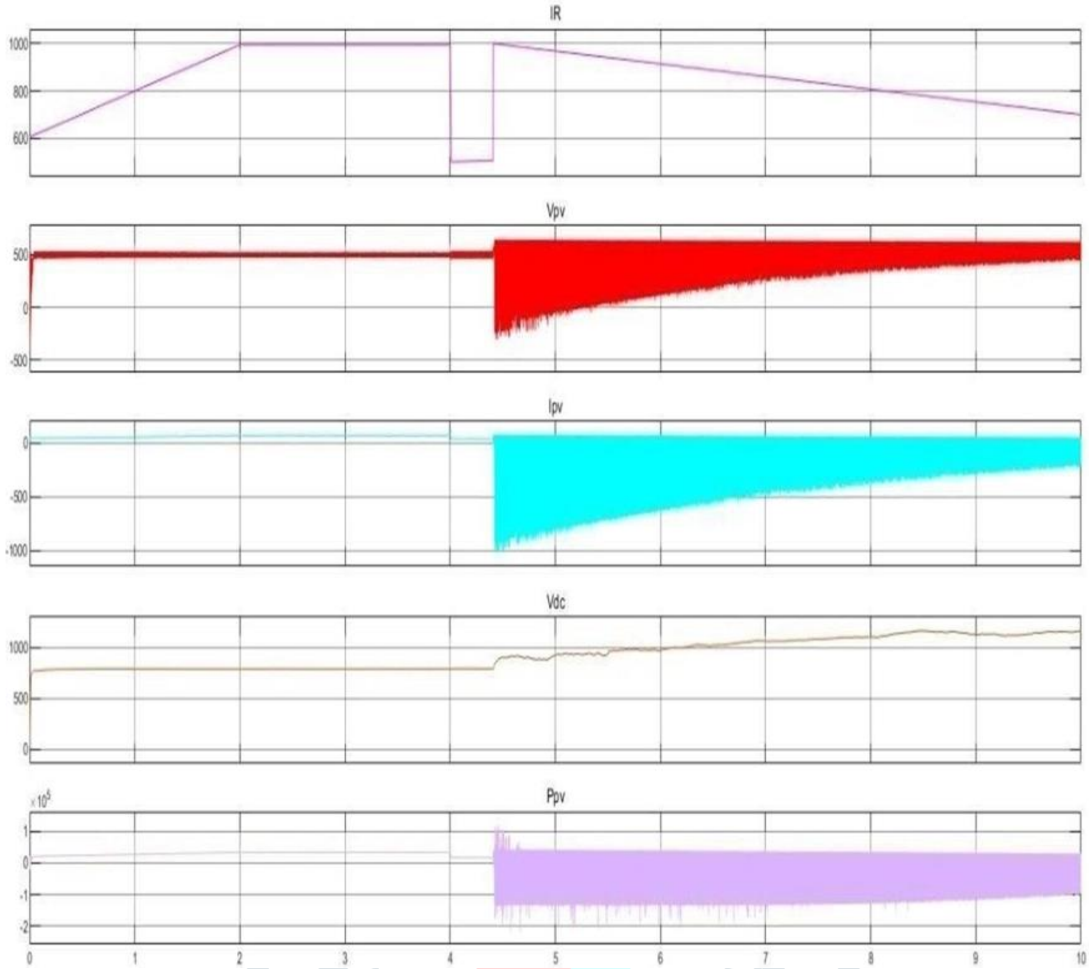

Fig. 8. Solar Panel Output Waveforms

2.1.2. MPPT Controller:

The Simulink diagram of P&O MPPT controller is shown in below Fig. 9.

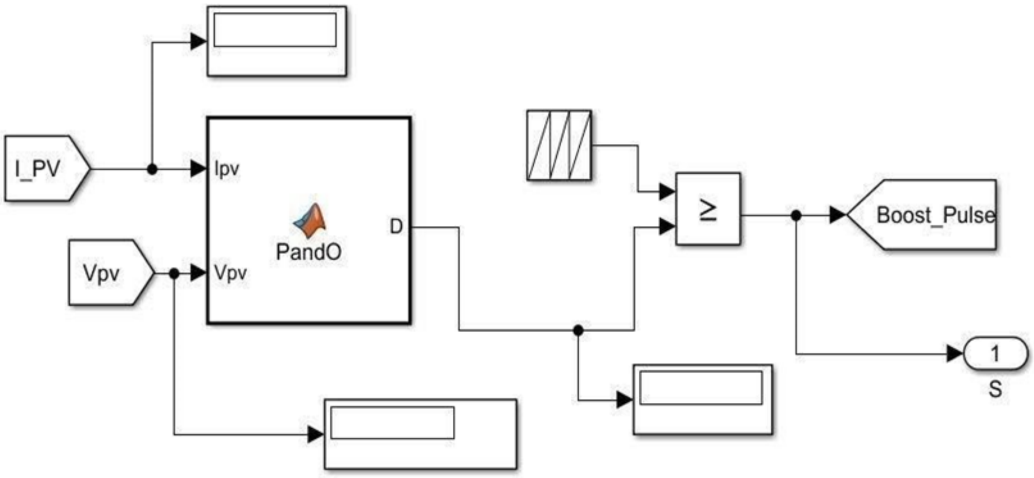

Fig. 9. MATLAB Simulation of P&O MPPT Controller

2.2. Perturbation and Observation (P&O) Algorithm

function Vref = RefGen (V, I) Vrefmax = 363;

Vrefmin = 0;

Vrefinit = 300;

deltaVref = 5;

persistent Vold Pold Vrefold; dataType = 'double';

if is empty (Vold) Vold= 0;

Pold= 0; Vrefold= Vrefinit;

end

P = V*I

dV = V - Vold; dP = P - Pold; if dP ~= 0

if dP < 0

```
if dV < 0
    Vref = Vrefold + deltaVref; else
    Vref = Vrefold - deltaVref; end
else
if dV < 0
    Vref = Vrefold - deltaVref; else
    Vref = Vrefold + deltaVref; end
    end else
    Vref = Vrefold; end
if Vref >= Vrefmax || Vref <= Vrefmin Vref = Vrefold;
end
Vrefold = Vref;
Vold = V;
Pold = P;
```

2.2.1. DC to DC Boost Converter

The Simulink diagram and output waveform of dc-dc boost converter is shown in Fig. 10. The output waveform shows the Vpv, Ipv, Vdc, Idc, I Boost & Vdc filter.

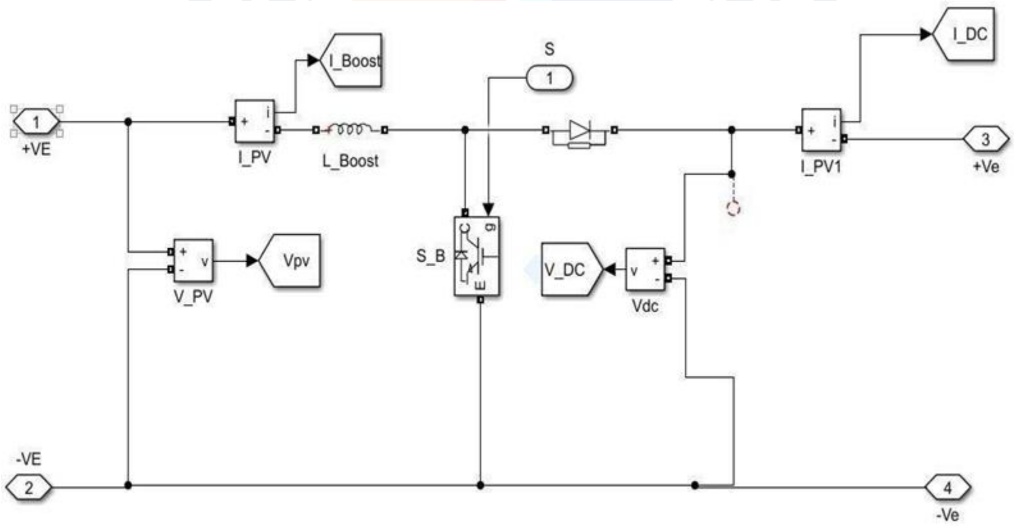

Fig. 10. MATLAB Simulink of DC-DC Boost Converter

2.2.2. Filter

The filter is connected between output terminal of solar PV and input terminal of dc- dc boost converter. The output waveform is shown in the Fig. 11 & 12. The output waveform shows Vgabc, Igabc, Vabc, Iabc, Vdc filter, Ila, Ilb.

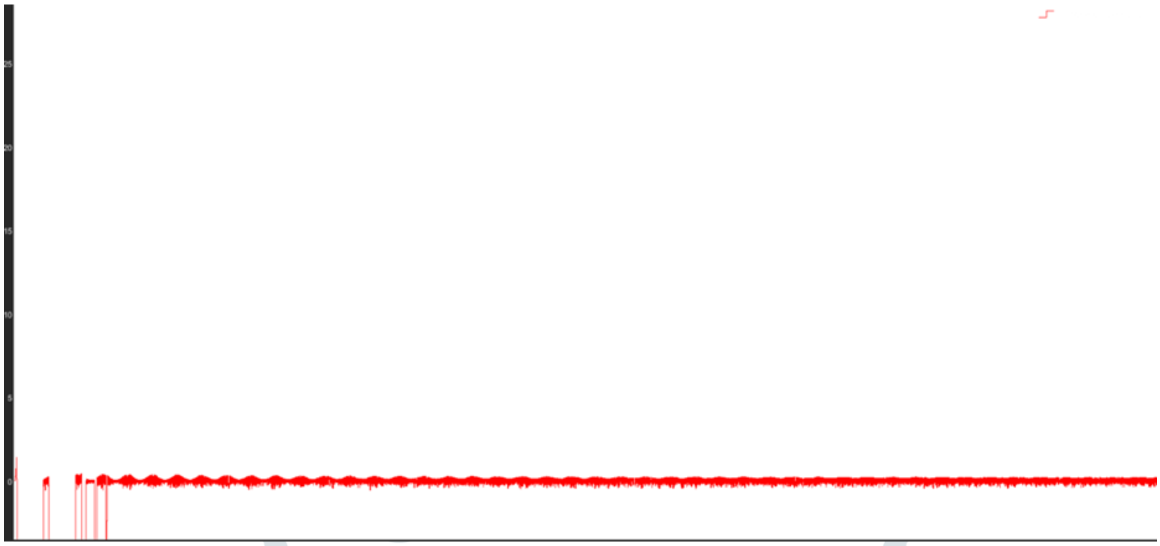

Fig. 11. DC output voltage waveform without filter

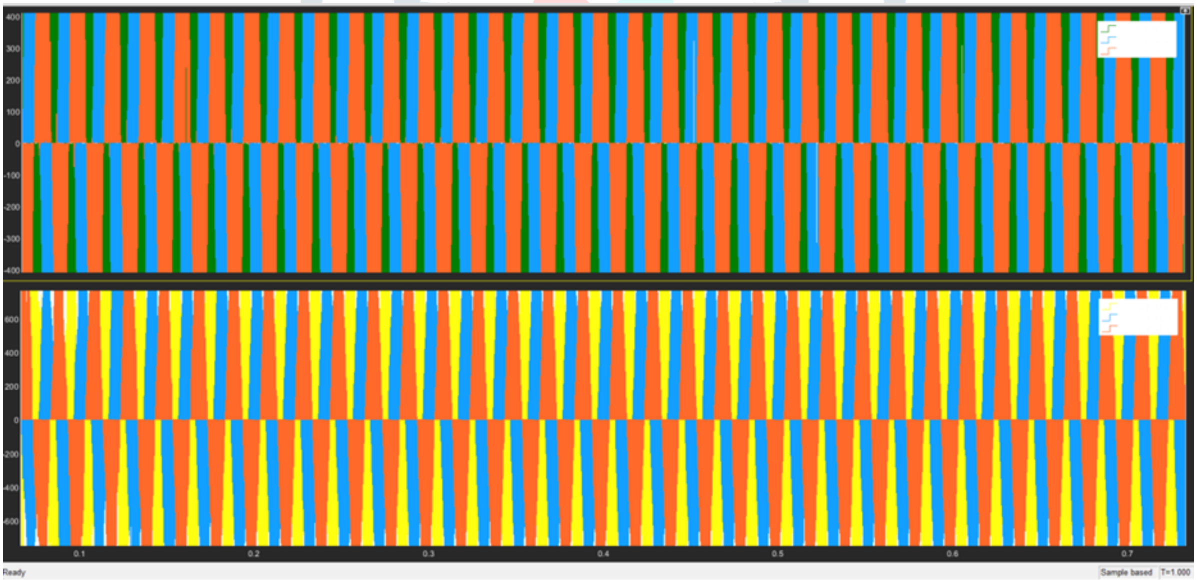

Fig. 12. Grid output waveforms of Solar PV system without filter

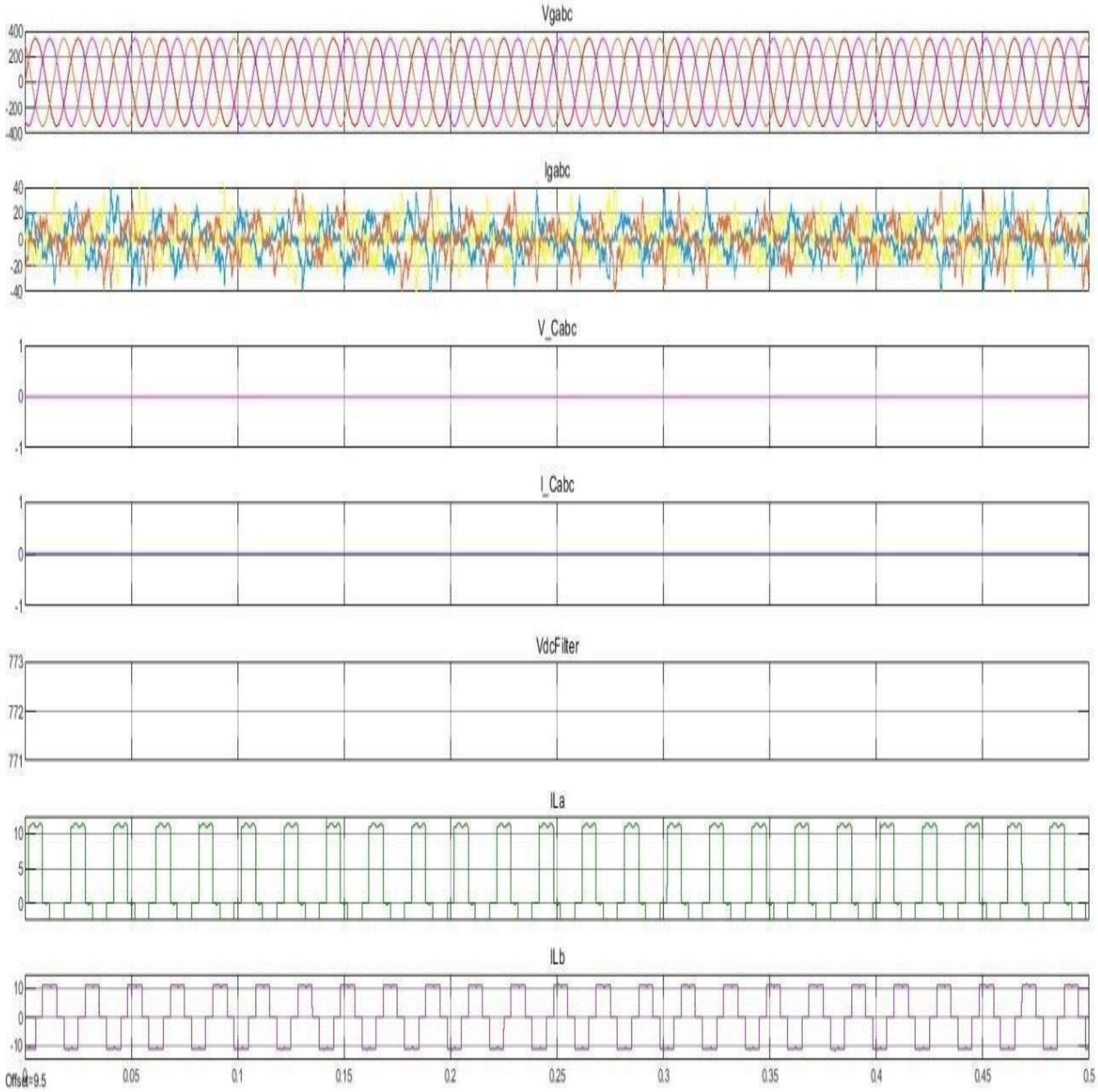

Fig. 13. Grid output waveforms of solar PV system with filter

2.2.3. DC Link voltage

DC link voltage is the voltage that is applied to the inverter input. A DC-DC converter is used to maintain dc link voltage of desired value. A high value capacitor is used to maintain the DC link voltage constant. An almost constant 700 V DC link is obtained from boost converter.

2.2.4. Inverter voltage and current

Inverter (VSI) produces a three-phase ac voltage output to supply the three-phase load at PCC point. A three-phase universal bridge utilizing IGBT switch is used in MATLAB simulation work to convert DC link voltage to three phase ac. Pulses for IGBT switches is produced by inverter control block. The three-phase balanced voltage and current supplied by inverter is shown in the Fig. 14. As VSI uses solid state switches which produces current harmonics that can be clearly shown in the Fig. 15.

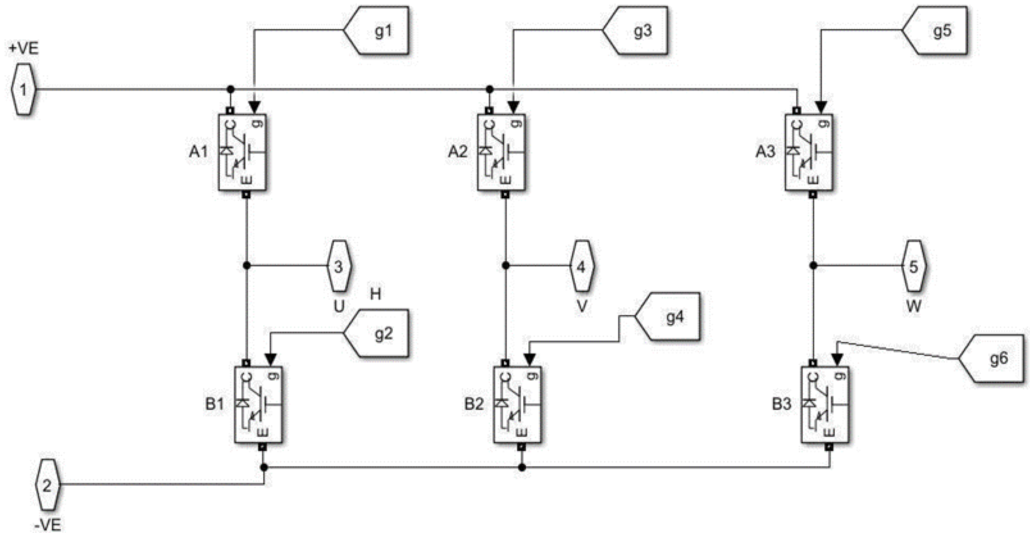

Fig. 14. MATLAB Simulink of Inverter

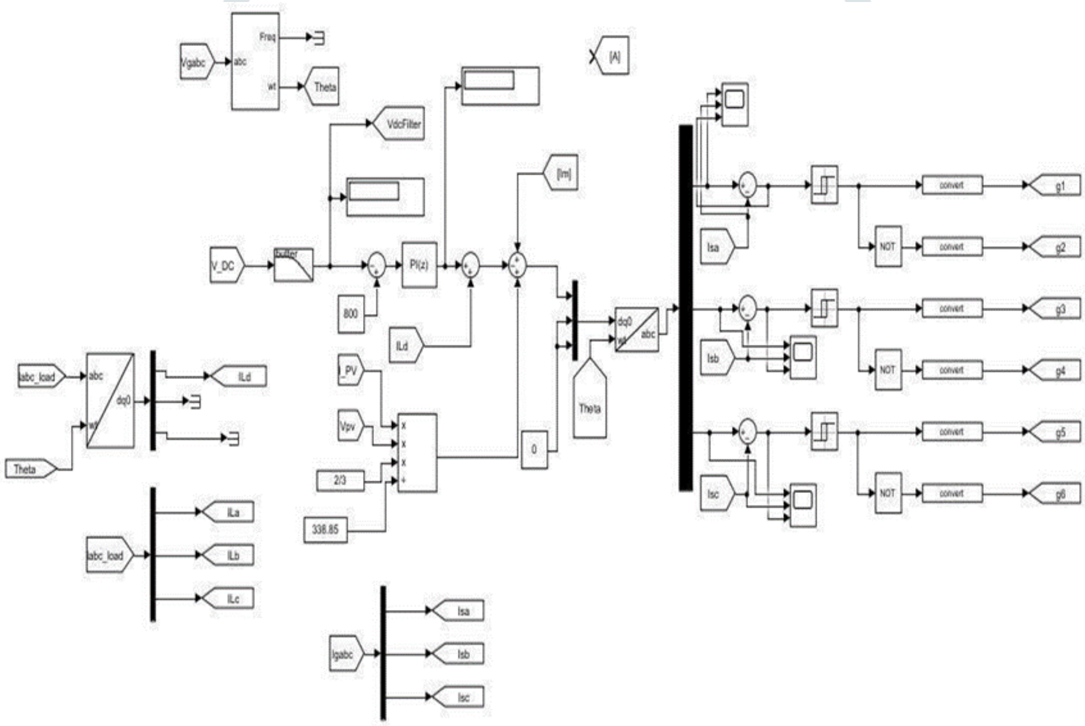

Fig. 15. MATLAB Simulink of Inverter controller

2.2.5. Power Supplied to Grid

The ratings of grid are shown in Fig. 16. The Simulink diagram of linear and non-linear loads is shown in Fig. 17 & 18. The output waveform of grid shows the Vgabc, Igabc, Iabc_load, Pg, Pl.

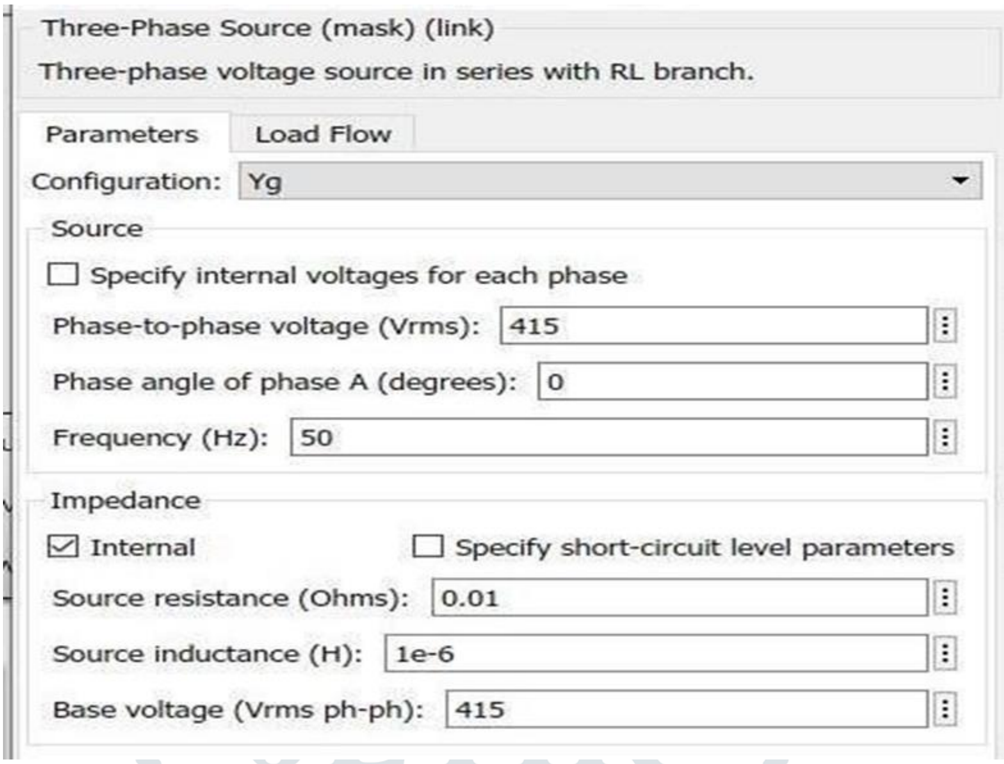

Fig. 16. Grid parameters

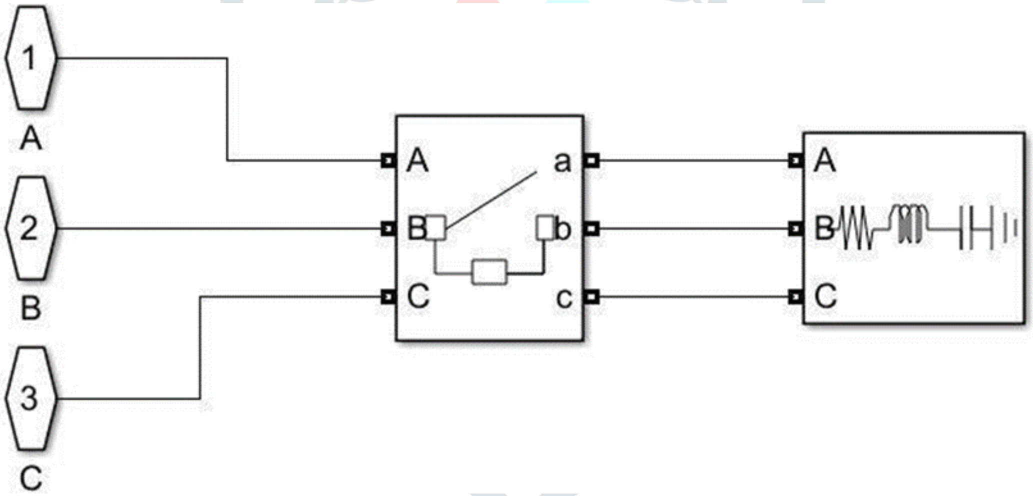

Fig. 17. MATLAB Simulink of Linear load.

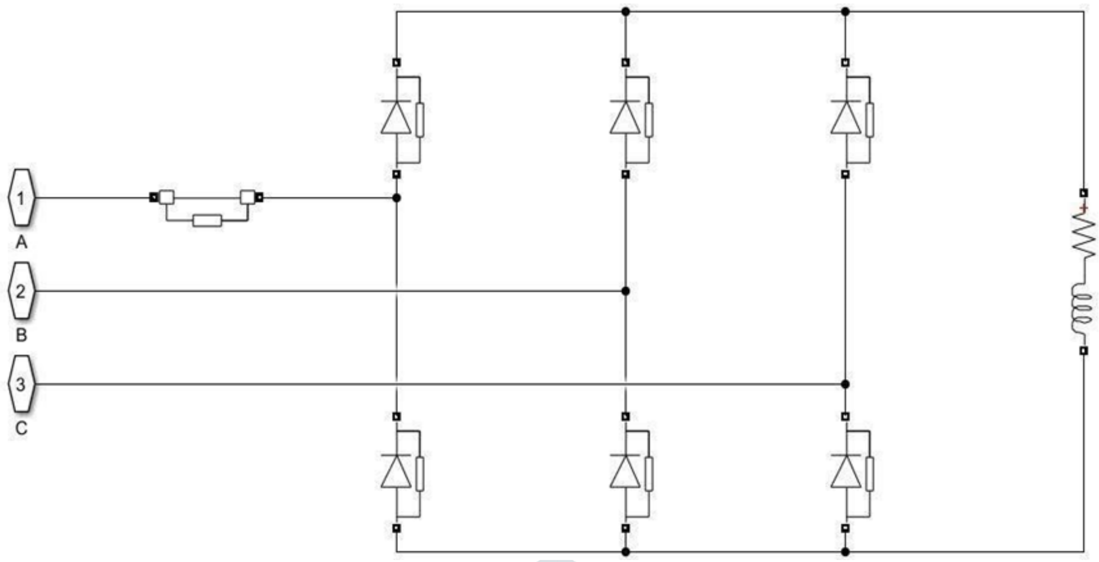

Fig. 18. Simulink of Non linear

2.2.6. Power quality analysis of system

Power quality of a grid connected solar PV system can be analyzed by the PCC point voltage analysis for different kinds of loads and for changing meteorological conditions, harmonic distortion in voltage at PCC point and harmonic distortion in current in the grid for different levels of percentage penetration.

2.2.7. Harmonic Analysis of Grid

As grid integration of solar PV system requires DC-DC Converter and three phases VSI which utilize many power electronics switches which in turn produced harmonics in the system. Hence, harmonic analysis is important for grid integrated system. However, a VSI is used as inverter and a synchronous reference frame theory is used to extract reference current for inverter control hence voltage generated is almost balanced while the current harmonics is very high in the system.

Now as the percentage penetration level of solar PV system increases in the grid the more and more current harmonics are introduced in the grid. Initially grid current is same as load current with harmonics 0.51% as penetration level increases up to 30% the current harmonics of grid also increases to 5.18% which is beyond standard permissible limit of 5%.

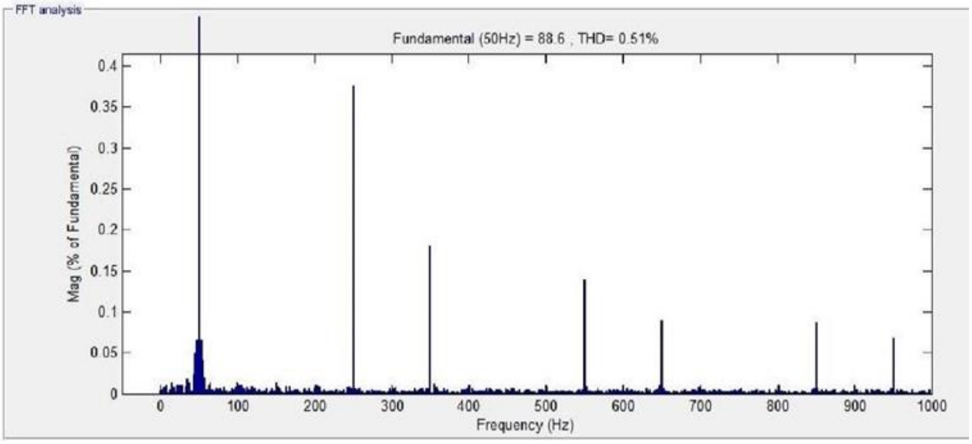

Fig. 19. THD of Load Current

The MATLAB simulated three phase grid connected solar PV system is discussed. Power, voltage and current produced by solar PV at constant and varying irradiance conditions, dc link voltage after applying P&O MPPT technique and active and reactive power supplied by inverter due to inverter control is presented and are satisfactory.

Also, power quality analysis of three phase grid connected system is presented when the percentage penetration of solar PV increased from 10% to 30% on the basis of harmonic distortion in the current of grid and voltage at the PCC point. The same comparison is given in the Table 1.

Table 1. Comparison of power quality at different percentage.

% Penetration of SPV	% Current THD of Grid	% Voltage THD Of PCC Point
0	0.5	0.2
10	3.52	1.5
15	4.33	1.4
20	4.54	1.31
25	4.78	1.27
30	5.18	1.22

3. CONCLUSION

The objective of this project- is to develop a three-phase grid connected solar PV system with different types of loads such as linear, non-linear and discontinuous. Also analyze the performance of this system to constant and changing irradiance levels and power quality analysis of the PCC point and then study the effect on grid current harmonic distortion when the percentage penetration of solar PV system in the grid system increases from 10% to 30%. Performance analysis of three phase grid connected system with P&O MPPT technique and inverter control scheme bases on synchronous reference frame theory is carried out. Further power quality three phase grid connected system is analyzed on the basis of variation of PCC point voltage at the discontinuous load and total harmonic distortion (THD) analysis of the grid current for increasing percentage penetration of Solar PV in the existing grid. As distribution grid is weak grid i.e. high R/X ratio PCC point voltage is affected by sudden load change or change in irradiance which directly affects the active power supplied by the Solar PV. Power efficiency is a key driving force due to the continual increase of energy consumption and costs. The present work can also be extended in future.

- The hardware can be developed for grid connected 3 phase Solar PV systems.
- After developing the hardware, power quality analysis of grid connected PV systems can be carried out.
- Further, the Solar PV system can also be integrated with a DSTATCOM for complete reactive power compensation.

Also, the grid integrated Solar PV systems are integrated with filters (passive or hybrid filters) to contain the harmonic level of existing grid to prescribed value as per power quality standards.

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