Simulation Based Three Phase Single Stage Grid connected Inverter Using Solar Photovoltaics

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Abstract. Since ages, the best alternative for fossil fuel generation is found from Renewable energy sources. One among them is the Solar energy which can produce solar power. Solar power can be taught as “Solar Electricity” and is the most practical, cleanest forms of Renewable Energy. Solar Power Systems otherwise called as PV systems can be of various types like off-grid and on-grid systems. This paper, focuses on Grid connected solar electric system. The paper aims at modelling high performance Three Phase Single Stage Grid Connected Inverter. So as to achieve maximum output from the photovoltaic array, MPPT Tracking is connected. The conversion from DC output of photovoltaic array is done to AC so that it is fed into the grid, a IGBT based inverter is used which converts from DC to AC power. A Simulation model is developed in MATLAB Simulink and results are presented in the paper.

Keywords: Solar Inverter, Grid connected, MPPT Controller, Solar PV array

1. INTRODUCTION

Electricity has become a portion of contemporary life and one cannot consider of a world deprived of it. The examples of lighting rooms, working fans, A/C, electric stoves and etc. are a proof that it’s a necessity in our day to day life. In Industries, large machines are worked with the help of electricity. However, People’s dependency on electricity is progressively challenging; as non-renewable energy source reserves decrease and the threat of environment change appears from time to time and the need for alternative energy source is unparalleled. Because of the above realities, world is heading near clean and environmental friendly non-conventional energy sources like solar, wind, geothermal energy etc. Solar power, i.e., electricity produced by means of power from the sun, is an eye-catching way to counterbalance our dependence on electricity produced by burning fossil fuels [2].

Basically, a Solar Electric System also known as Solar Power System is a system intended to supply functioning solar power by means of photovoltaics. This system can be of two types:

- Off-grid systems
- On-grid systems

Off-grid systems also known as Standalone Solar Electric Systems that are present at the locations where grid extension is not available due to high cost, for example in case of rural or remote areas. In this kind of scheme, it operates on charging the batteries by using the solar power. The battery which is powered is then used to run the appliances.

On-grid or Grid Connected Schemes are utmost used in urban areas. The DC power generated by the solar PV panels is not stored in the batteries instead they are converter to AC power using Inverter, which is then directly connected to the grid. Whenever there is excess power generation, it is fed to the grid and when the power is deficient at the consumer end it is taken from the grid.

In this paper, Three Phase Single-Stage Grid Connected Solar Inverter is offered. The schematic representation of the same is presented as shown in fig.1.

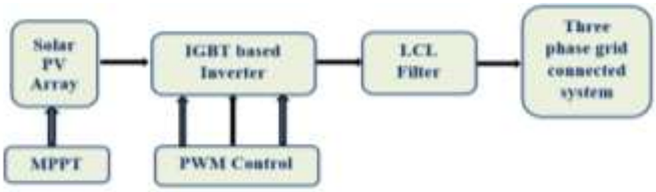


Fig.1: Schematic Representation of the proposed work

Fig.1 shows the schematic representation of Three Phase Single-Stage Grid Connected Inverter. Here, output of the solar panel is directly connected to solar inverter input. LCL filter is used to filter out harmonic currents in grid. MPPT is used as a reference for DC bus voltage controller. Feed forward term is added to the DC bus volatge controller[3]. The sepcifications of the system are as follows:
Rated power of the system = 100KW
Open circuit voltage of PV is = 907.5V
Switching frequency of the inverter = 10kHz
Value of Inductance = 500µH
Value of Capacitance = 100µF
Line to Line voltage = 400V, RMS, 50 Hz

2. SOLAR PV CHARACTERISTICS

Solar cells otherwise called as photovoltaic cells generate electricity when it is open to sunlight. Solar cells are comprised of Semiconducting materials. These materials direct electricity under definite conditions, so they act as neither insulators nor conductors. A solar cell is a p-n junction diode that produces the charge carriers when an applied photon has energy larger than the bandgap of semiconductor component element.

PV array is formed by connecting PV modules in series and parallel, where modules are formed in connecting cells in series. Every type of PV cell is distinctive and has its own separate characteristics.

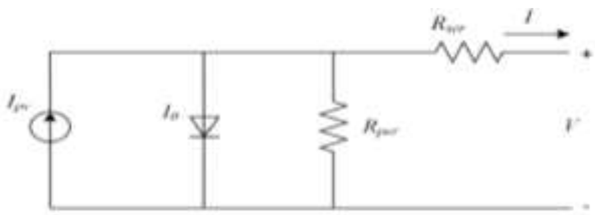
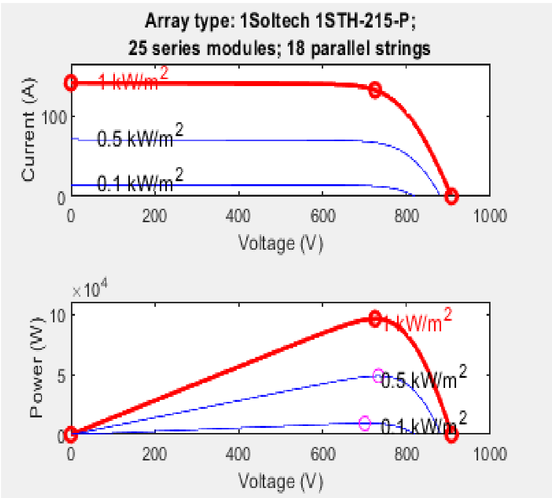


Fig.2: Corresponding circuit of a single cell

Fig.2 represents the equivalent circuit of a single cell. The current source is nothing but the current generated by the photovoltaic cell. Diode is a schottkey diode. The addition of net current generated by the solar cell is the current produced from current source and a diode. [7].

The I-V characteristics of a PV array taken from MATLAB/Simulink is given below:



PV cell is graphically denoted as current-voltage (I-V) curve. An I-V curve trails the PV cell's performance and highlights important features like V_{oc}, I_{sc} and P_{max}. A PV cell will continuously function along this curve. A power curve is utilized to catch the maximum power point. Power curve plots the voltage along its horizontal axis and power along the vertical axis. When this is superimposed on the I-V curve for the same cell, it is very clear where the maximum power point lies.

Table.1: Solar cell characteristics

SL.No.	Parameter	Ratings
1	Maximum power	213.15W
2	Cell Voltage at P_{max}	29V
3	Cell Current at P_{max}	7.35A
4	Short Circuit Current-SCC (I_{sc})	7.84A
5	Open Circuit Voltage-OCV (V_{oc})	36.3V
6	Temperature coefficient of V_{oc} (%/deg.C)	-0.36099
7	Temperature coefficient of I_{sc} (%/deg.C)	0.102

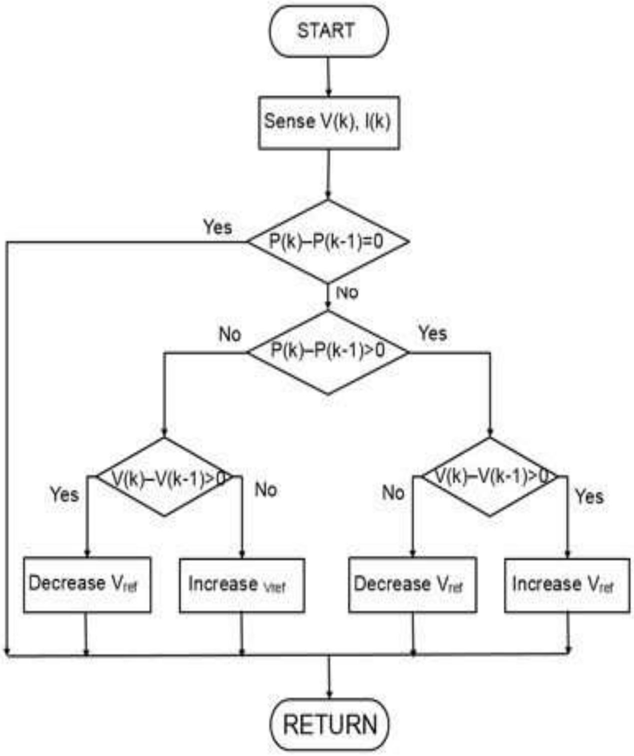
3. MPPT DESIGN

In Solar Grid connected system, Solar cell being a non-linear device cannot produce constant power always. Therefore, it is necessary to obtain maximum power output from the solar panel. For any Solar Panel, irradiance and temperature for any particular day keeps changing due to which solar power output also changes. It is important to trace the maximum power even during the varying conditions of temperature and irradiance. [6].

There are various types of algorithms and ways to implement MPPT. Some of them are P&O method, IC method and fuzzy logic controller method. In this work, P&O method is used. P&O controller adjusts the voltage by a small amount from the array and measures power, if the power increases, further adjustments in that direction are tried until power no longer increases. Here, we use PV voltage and current to implement in MPPT. The reference voltage is output of the MPPT. This reference voltage is compared with actual PV voltage to obtain the error. The error is then provided to PI Controller. The output of the PI controller will generate required duty ratio for PWM generation.

MPPT ALGORITHM

The MPPT Algorithms are designed for the Photovoltaic systems which can generate maximum power at any instant of varying conditions. There are basically two sensors used at the input side of MPPT for voltage and current measurement. The current, voltages established in the MPPT do have mathematical relations to justify the operation [1].



4. THREE PHASE INVERTER

The PV Inverters portray a key role in converting the power delivery from the PV arrays to the AC grid. Inverter is an electronic circuitry that converts from DC to AC for the preferred magnitude and frequency. Inverters can be line commutated or self-commutated inverters. In this work, single-stage inverter is used which has one treating stage – MPPT and grid current control. Inverter bridge is comprised of IGBT switches. Output of the inverter is connected to an LCL filter. LCL filter is used because its superior filtering performance [5].

The control algorithm used is synchronous reference frame theory. To implement the controller, first we need to sense the voltages Vabc – line to line voltages. These three voltages (abc) are then transformed to two phase alpha-beta voltages using park's transformation. Using alpha-beta voltages, PLL is implemented. Alpha-beta voltages are then converted to dq voltages using clark's transformation. This is used to sense current for controller implementation.

Currents of inverter (Iabc) is then transformed to alpha-beta domain using park's transformation and then to dq domain using clark's transformation.

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Id (Active current) and Iq (Reactive current) is deducted from the reference current to obtain the error. Error is fed to PI Controller to find voltages Ud and Uq. To monitor the three load voltages and currents Three-Phase V-I Measurement block is used.

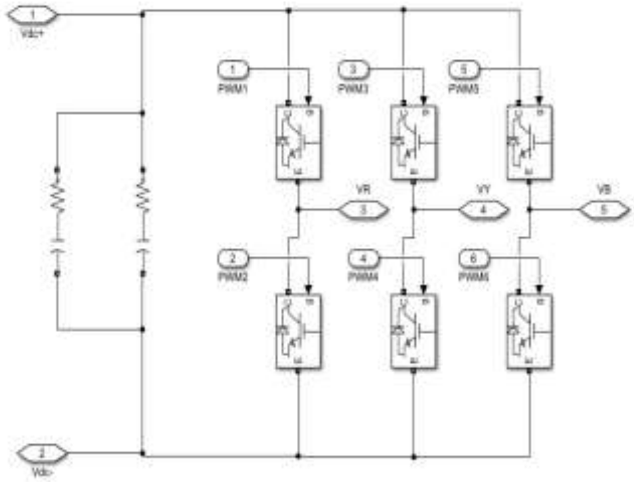

Fig.3: Three phase bridge Inverter

Fig.3 represents the MATLAB model of Three Phase Bridge Inverter used in the implementation. It has 6 IGBT switches with 6 input signal port for PWM signal. The swicthing frequnecy is 10KHz. Two Input Bus capacitor of 500µF each is connected in parallel. This entire circuit is created into a subsystem and to monitor the inverter current Three Phase V-I measurement block is connected.

Voltage and Current transformation blocks

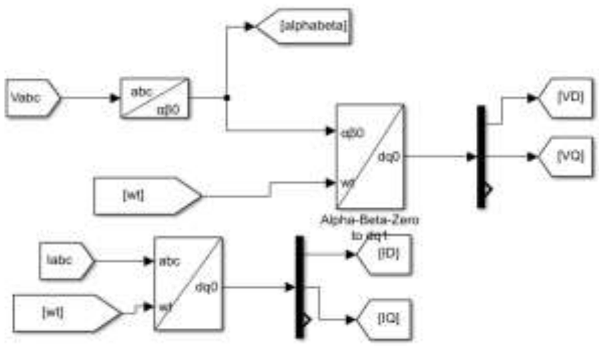

Fig.4: Voltage and Current transformation blocks

Fig.4 represents the voltage and current transformation block. Take input as V_{abc}, convert from abc to alpha-beta transformation, which is then converted from alpha-beta to dq transformation. Give input of ωt to alpha-beta to dq transformation which is the output of PLL. The same procedure is follwed for current transformation block.

Phase Locked Loop(PLL)

In order to match the phase of an input signal a feedback control system called PLL block is used. It automatically adjusts the phase of a locally produced signal. To monitor the three load voltages and currents Three-Phase V-I Measurement block is used.

Phase locked Loop works on the principle that it will generate an output signal from its own internal voltage control oscillator by taking a signal to which it locks. The PLL block monitors the frequency and produces a signal (ωt output) that is locked on the variable frequnecy system voltage.

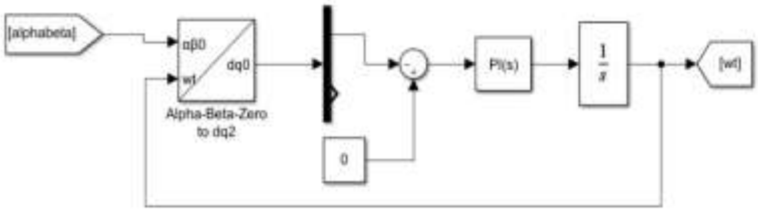

Fig.5: Phase locked loop Block, MATLAB

PWM Generation

Switching frequency of 10KHz triangular carrier signal for switching.

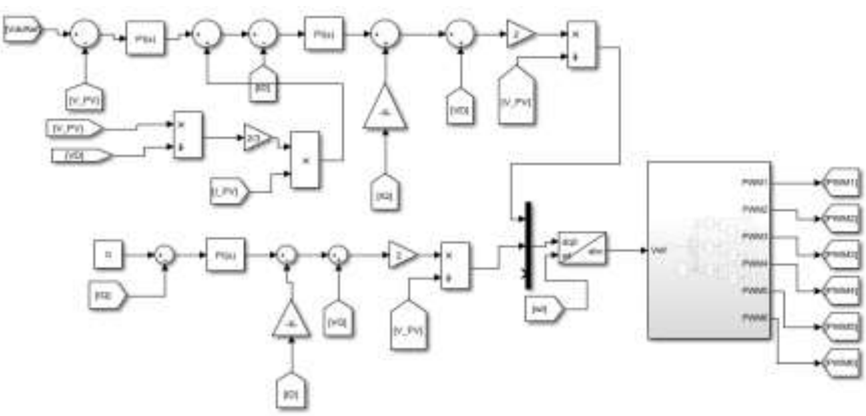

Fig.6: Block of PWM Generation

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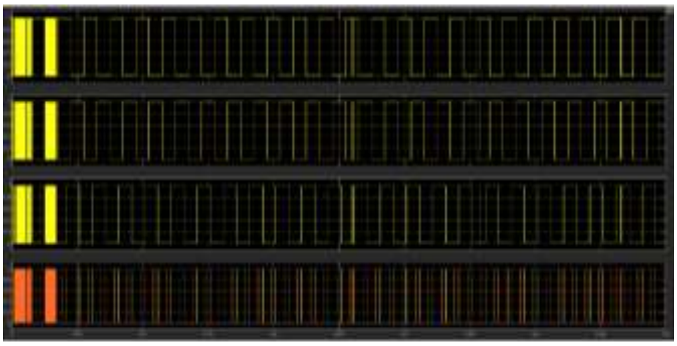

Fig.7: PWM Pulses for IGBT device

A PI control approach is utilized in case of inverter operation which is a classical approach in using proportional gain and integrator for adjusting the physical state of the system. The dq commanded voltages which are generated are converter into abc voltages using transformation process. To generate PWM Pulses dq to abc transformartion is used. The input to the dq frame is output of PLL i.e ωt and the input refrence signals taken from MPPT following through an PI controller.

Filter Design

Imagine a system without filter the current generated by the grid connected inverter contains lot of harmonics \, when such current is injected into the grid, the grid voltage hence causes lot of power quality issues in order to avoid these issues always keep a filter so that smooth cylindrical current without any harmonics is generated.

Steps to follow for filter design:

1) Selection of Switching frequency = 10KHz
2) Selection of resonant frequency

Resonant frequency = Switching frequency / 10

Therefore, f_{res} = 10KHz/10 = 1000Hz

3) Finding value of Capacitance

   $C = 0.05*S/ (V^2 * 2 * \pi * f) = 100.28\mu F$

4) Finding value of Inductance

   $L_{min} = 76.68\mu H$

Therefore, $L_1 = L_2 = L/2 = 38.34\mu H$ (Minimum value)

   L_{max} = 1Mh

Therefore, $L_1 = L_2 = L/2 = 500\mu H$ (Maximum value)

5. DIGITAL IMPLEMENTATION

The entire Circuit Modelling is simulated in MATLAB/SIMULINK. The reference signals to the PWM pulse generator is taken from the load AC Voltage which is intern utilized as required phase for generating sine waves. The obtained pulses are given to the three phase bridge inverter to obtain the AC output waveform. This output waveform is fed to the Three phase AC source. Scope blocks are connected to measure and see the respective output waveforms.

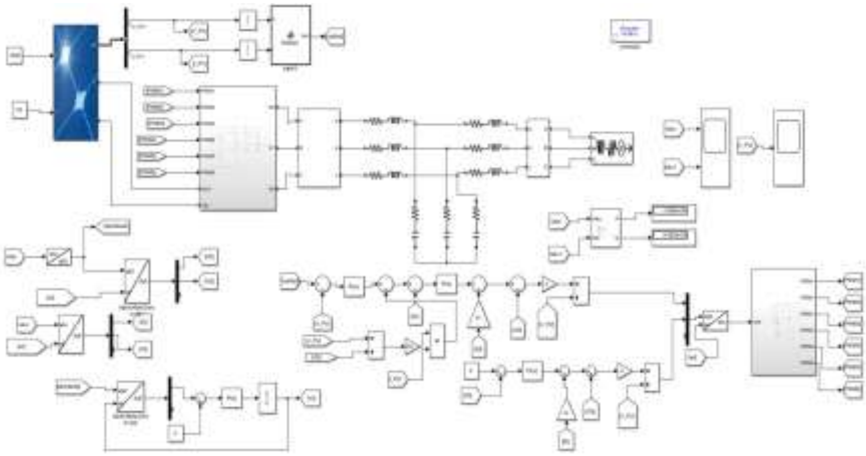

Fig.8: MATLAB/Simulink framework of the complete system

Fig.8 represents the complete system modelled in MATLAB/Simulink. Consisting of a PV array serving an inverter that feeds the utility grid (AC Voltage) via an LCL filter. The Inverter control is implemented using PI controller. When we run the simulation it is observed that as the irradiance level changes automatically inverter output current als changes. Since the PV manufacture has grown its impact on the AC grid system which is also growing automatically [4].

6. RESULTS

The whole framework is built in MATLAB Simulink model. The system parameters that are used in this work are presented in Table.2. as shown below.

Table.2: System parameters

SL.No.	Parameter	Ratings
1	Inverter Switching frequency	10Khz
2	Line to Line voltage (RMS)	400V
3	Inverter Side inductance	500µH
4	AC side inductance	500µH
5	Filter capacitance	100µF
6	Rated power	100KW

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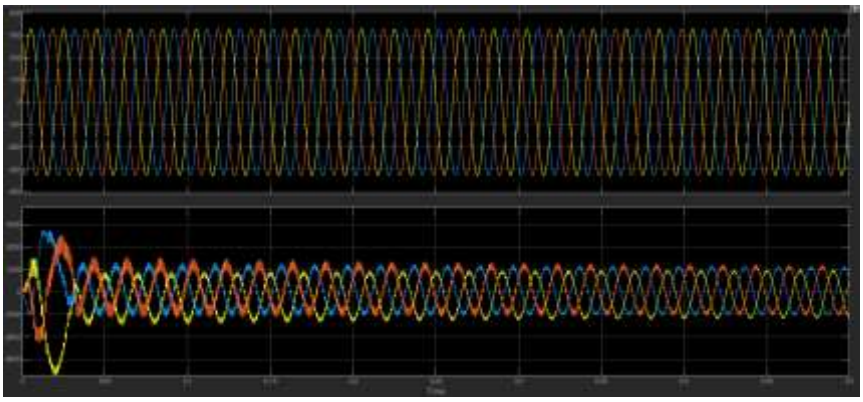

Fig.9: Voltage & Current output of the simulation model

The grid current and power has reached the MPPT point corresponding to 1000W/m^2 radiation.

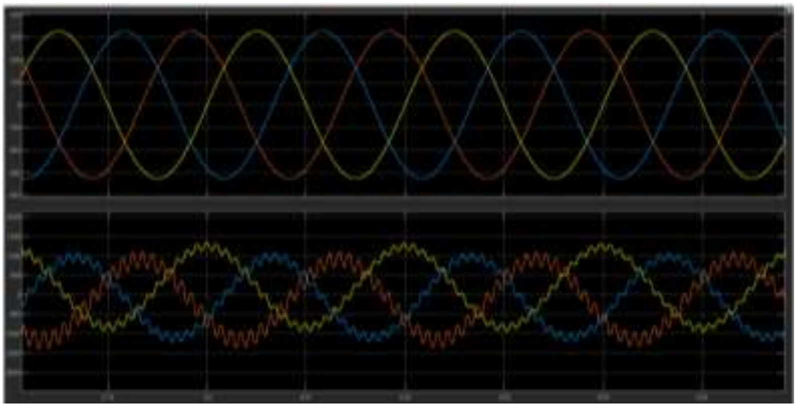

Fig.10: Output voltage and current of the simulation model

Phase to phase value of voltage = 400V.
Phase to ground value = 400*√2/√3 = 326V
The output voltage and current obtained is around 305V and 200A.
Therefore, Total output power = V*I = 305*200 = 61kW

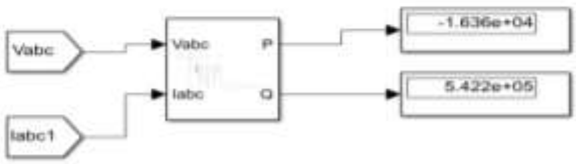

Fig.11: Sample Active and Reactive power output

7. CONCLUSION

In this work, the importance of Three phase Single-Stage grid connected PV systems has been emphasized. Basically, it presents the operation and control of a single-stage three phase grid connected inverter. Suitable for various fluctuating conditions of solar photovoltaic system. The complete system is virtually simulated in MATLAB/SIMULINK software. To trace the extreme power from solar PV array, MPPT algorithm is used. Active power is injected into the grid using a renewable energy system. Simulation results validate the performance of the proposed scheme.

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