Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

Matlab Modelling and Simulation of Single Stage Grid Tie Inverter

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***Abstract*— We have abundant solar energy as it is supplied by nature and it is thus free. For smart energy networks solar energy is appropriate with distributed power generation. Solar panels are currently on a fast reducing track. Residential solar panels are easy to install on rooftops or on the ground. As a PV array gives DC voltage as output and it should be converted to AC to feed micro grid. So an inversion is needed in between these two ends. Here we propose a single stage inverter with advantage of less switching loss. A MATLAB/Simulink model is developed and is used to study the characteristics of inverter for different load conditions.**

***Keywords*— Photovoltaic cells, PWM inverters, MATLAB/ Simulink, PV arrays**

I. INTRODUCTION

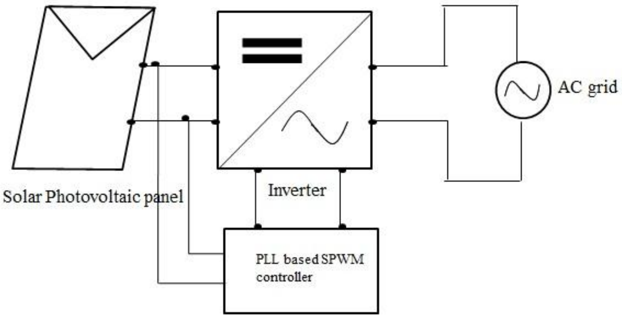
The global energy consumption is increasing at a rapid rate to improve the standard of living of all the humans. However, the primary sources of electric power that is the conventional fossil fuels which are so far present are on the verge of extinction. Also, the extensive use of fossil fuels and nuclear resources causes the serious environment pollution and safety problems. In addition to this, the present generating units and transmission lines are already loaded near to their rated maximum and it is much difficult to load them further. Due to above mentioned facts, world is heading towards environmentally clean and safe renewable energy sources such as PV, wind, fuel cells, etc. The PV generation is one of the most promising renewable energy sources, as it is safe; maintenance and pollution free. Solar-electric energy demand
is growing consistently, which is mainly due to the decreased cost of generation associated with it.

Solar panels can be used as a component of a larger photovoltaic system to generate and supply electricity in either commercial or residential applications. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module given the same rated output. For example, an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. All the loads which make use of electricity are known as electric loads. There are many types of electrical loads: household appliances such as microwaves and hair dryers, electronic equipment like stereo or computer equipment, as well as lighting, shop equipment and portable devices like cordless drills and cell phones. AC electricity is what operates common household appliances and shop tools. To power AC loads in an alternative energy system, we need either an engine generator which produces AC power or an inverter which changes DC power to AC.
In order to solve the power quality problems, the use of active power filter (APF) systems has rapidly increased. Many APF topologies and control algorithm for single-phase system are reported. But some additional costs are required for installation of APF systems. The cost of the Grid interactive PV system can be minimized by decreasing the number of power conversion stages and the number of components involved in each stage.

With the objective of reducing the cost and increasing the efficiency, a single stage, single-phase, grid-interactive inverter topology is proposed in this paper. In the presented work, the function of APF is added in the existing inverter of PV system by making suitable modification/improvement in the control methodology. Hence, this proposed interface does not need any additional hardware/power-circuit for enabling existing inverter to act as an APF also. This concept, thus, reduces the overall design cost of the system. In this project, we have used sinusoidal pulse width modulation (SPWM) technique to invert the DC voltage from the PV panel to AC voltage to feed the loads.

II. SYSTEM CONFIGURATION

The system being modeled is shown in Fig. 1. It consists of a PV array feeding a voltage source inverter (VSI) that feeds AC voltage to the utility grid and the local loads through an interconnecting inductance L. The power output of single-phase inverters oscillates at twice the line frequency, and thus, a large capacitor C is connected between the PV array and the PWM inverter. A smoothing inductor is also connected in series with local loads to avoid the spikes in the grid current. The modeling of various components of Fig. 1 is explained in the subsequent section.



Fig(1): Proposed topology for grid connected inverter

A. *Solar PV Characteristics:*

A PV cell is the building block of the PV array. Normally, PV cells are connected in series to give sufficient dc voltage; it results in a PV module [4]. The series-parallel connections of PV modules form a PV array. The commonly used simplified electrical equivalent circuit of a PV module is shown in Fig2,

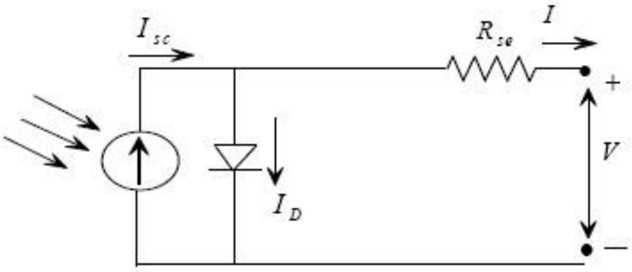


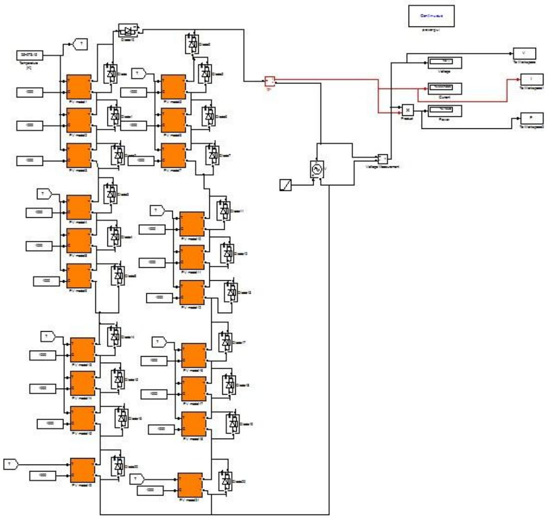
Fig (2): PV module equivalent circuit

This simplified circuit is consists of an ideal current source in parallel with anti-parallel diode and a series resistance Rse. From simplified equivalent circuit, output current I from a PV module is given as follows:

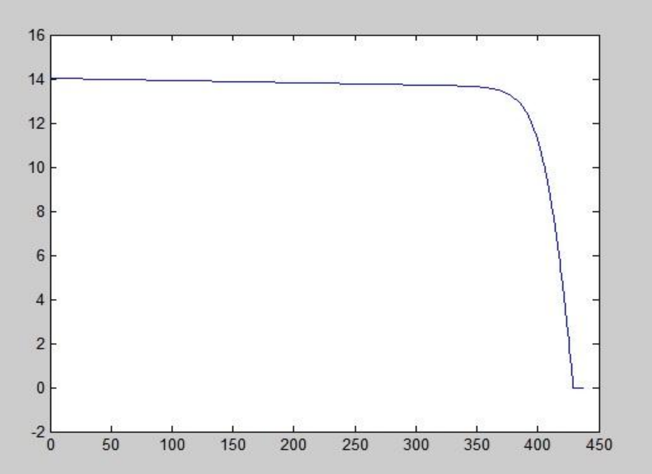
$$I = I_{sc} - I_D = I_{sc} - I_0\left[\exp\left(\frac{(V+IR_{se})q}{\eta mkT}\right)-1\right] \tag{1}$$

where, V is the terminal voltage of PV module in V, I0 is the diode saturation current in A, Isc is the short circuit current of a PV module in A and ID is the diode current in A under a given solar irradiation or insolation. q, η, k, T and m denote the electronic charge (1.6×10-19C), ideality factor of the antiparallel diode, Boltzmann’s constant (1.38×10-23 J/K), cell temperature in 0C and the number of cells in series in the module, respectively. The rating of a PV module is estimated by the maximum power produced by a module under standard test conditions (STC). STC corresponds to an insolation level of (S = 1.0 kW/m2) and a cell temperature of (T = 25ºC).

Using equation (1) and the values of various parameters under STC, the PV characteristics at a given insolation and temperature can be simulated. The Fig (3) and (4) shows the MATLAB/Simulink PV model and I-V characteristics of the PV array at STC.



Fig(3): MATLAB/Simulink PV Model



Fig(4): The i-v characteristics of a PV array

III. CONTROL OF PROPOSED GRID-INTERACTIVE PV SYSTEM

A. *Phase Locked Loop (PLL):*

The PLL (phase locked loop) block is a feedback control system that automatically adjusts the phase of a locally generated signal to match the phase of an input signal.

The Three-Phase V-I Measurement block is used to monitor the three load voltages and currents. Open its dialog box and see how this block allows to get the output three phase voltages and currents in per unit (pu).

The Discrete 3-Phase PLL block measures the frequency and generates a signal (wt output) locked on the variable frequency system voltage. The PLL drives two measurement blocks taking into account the variable frequency: one block computing the fundamental value of the positive-sequence load voltage and another one computing the load active and reactive powers. These two blocks and the PLL are initialized in order to start in steady state. The PLL and the two measurement blocks are available respectively in the Extras/Discrete Control Blocks and Extras/Discrete Measurements libraries.

The whole system, (power network, PLL and measurement blocks) is discretized at a 50 us sample time.

The display blocks are used to get the numeric data for different values like voltage, current, angle (wt), frequency active & reactive power.

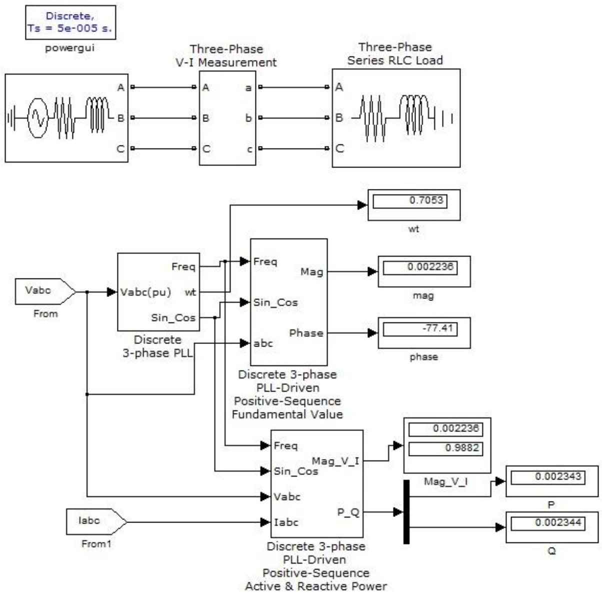


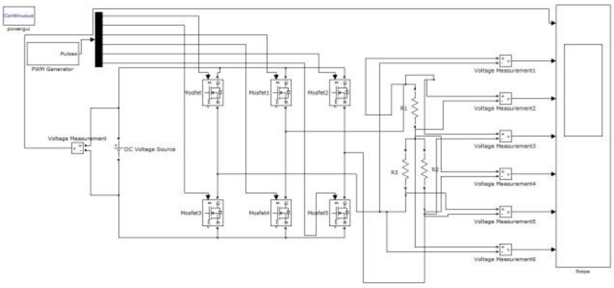
Fig (5): Phase Locked Loop (PLL) Model

B. SPWM Technique:

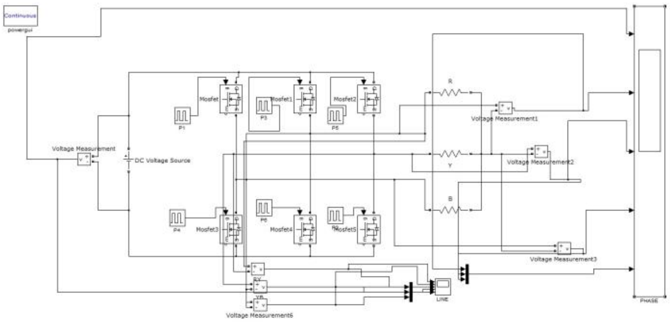
The SPWM modulation uses a carrier frequency of 1080 Hz. In a two-level voltage-sourced converter using ideal switches, the two pulses sent to the upper and lower IGBT of each arm could be complementary. However, in practical VSCs the turn-off of semiconductor switches is delayed because of the storage effect. Therefore, a time delay of a few microseconds (storage time + safety margin) is required to allow complete extinction of the IGBT which is switched off before switching on the other IGBT. Otherwise, a short circuit may occur on the DC bus.

In order to get an acceptable accuracy with a 1080 Hz switching frequency, a sample time Ts= 5.44 microseconds is used to discretize the circuit.

Figures (6) & (7) show the SPWM Simulink model working in 180^{O} and 120^{O} modes respectively.



Fig(6): Three phase SPWM inverter model (180O mode)



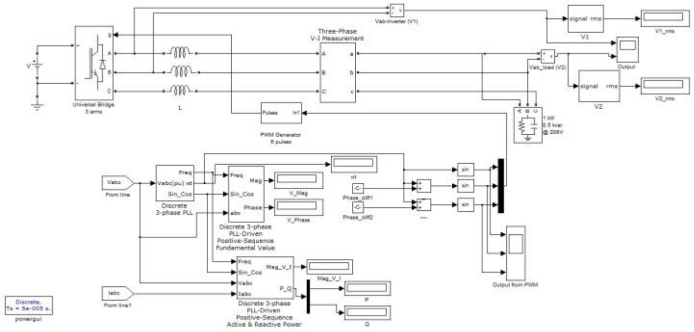
Fig(7): Three phase SPWM inverter model (120O mode)

There are many advantages of SPWM. Some of them are listed below:

1. The output voltage control is easier with PWM than other schemes and can be achieved without any additional components.
2. The lower order harmonics are either minimized or eliminated altogether.
3. The filtering requirements are minimized as lower order harmonics are eliminated and higher order harmonics are filtered easily.
4. It has very low power consumption.
5. The entire control circuit can be digitized which reduces the susceptibility of the circuit to interference.

C. System Modelling Via MATLAB/Simulink

The load AC voltage is used to calculate the required phase (wt) for generating the sine waves which are given as reference signals to the PWM pulse generator. These signals are compared with carrier waveform to generate the pulses. These pulses are fed to the three level bridge inverter to get the AC output waveform. This output waveform is fed to the utility grid. Scope blocks are used so as to observe the respective output waveforms. Fig (8) represents the MATLAB/Simulink Model with Closed Loop Control ensuring active power flow from source to load side.



Fig(8): MATLAB/Simulink Model with Closed Loop Control

D. Results

The model of proposed single stage grid-tie inverter is simulated in MATLAB to show its performance. Fig (9) and (10) shows the output waveform obtained from PWM inverter working in 180^{O} and 120^{O} mode respectively. In this PWM inverter a dc voltage of 50 V is used. In 180^{O} mode, for each thyristor, conduction time is 180^{O} whereas in 120^{O} mode, conduction mode for each thyristor is 120^{O}. The output waveforms are obtained for 20 ohms star connected load in both the cases. In 180^{O} mode, all the phase voltages V_R, V_Y, V_B are observed to be continuous whereas in 120^{O} mode, all the phase voltages are observed to be discontinuous with a lag of 60^O. This 60^O angle is allotted for commutation of thyristors.

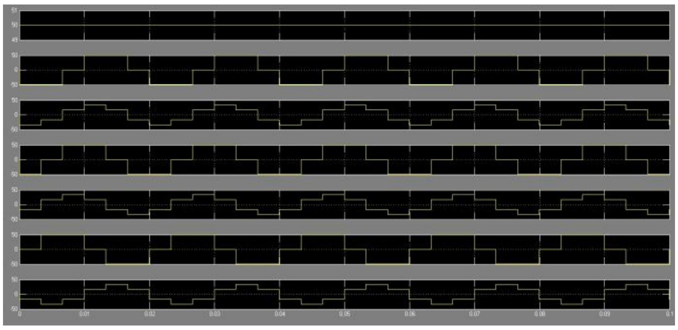


Fig (9): PWM inverter (180 degree mode)

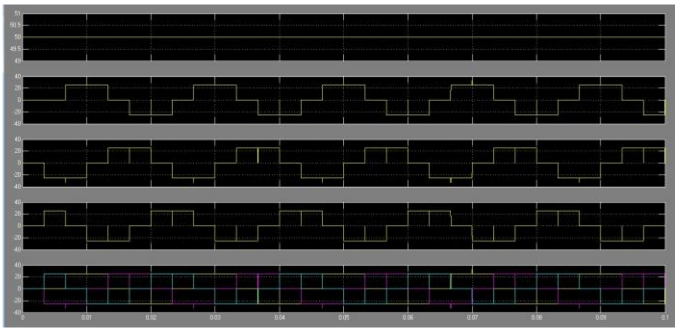


Fig (10): PWM inverter (120 degree mode)

The three phase sinusoidal waveforms generated using the phase generated from PLL is shown in fig (11). In this PLL model, the line voltages are measured from the load side. The three phase 120^O apart sinusoidal waveforms are generated using the phase angle calculated using PLL.

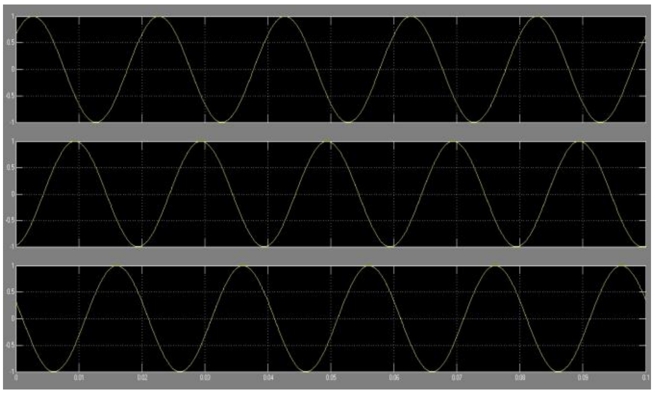


Fig (11): Sinusoidal waveform fed to the PWM inverter

The overall response of the Simulink model simulated with closed loop control is shown in fig (12). In the MATLAB/Simulink model dc input voltage of 200 V is used for carrying out the simulations. Thus, the expected peak value of AC output waveform is obtained as 200 V.

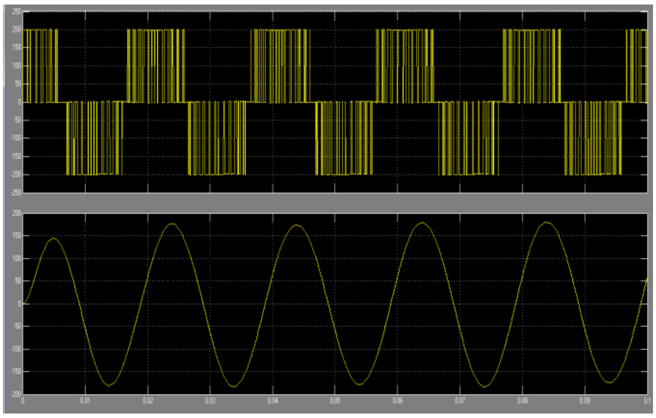


Fig (12): Output Waveform of simulated model

IV. CONCLUSION

This paper presents a behavioral model and control of a single-stage grid-tie inverter suitable for changing voltage conditions and varying load demand. The overall system is simulated in MATLAB/Simulink through PLL based SPWM technique utilizing a DC supply. The proposed system is capable of injecting active power to the utility grid while a controller is to be designed for compensating load reactive power and harmonics under distorted grid voltage condition. After compensation, the grid current is sinusoidal and in-phase with grid voltage.

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