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DOUBLE STAGE SINGLE PHASE GRID – TIE INVERTER USING MPPT TECHNIQUE

[1]Sri Harsha B, [2]Christy Manoraj J S,

[1]PG Scholar, [2]Professor,

[1]Department of Electrical and Electronics Engineering,

[1]Government College of Engineering, Salem, Tamil Nadu, India

Abstract: Owing to increased pollution and greenhouse gas emissions, the renewable energy is becoming predominant. This paper is steered with an objective to implement a Grid Connected PV system through a Distributed Energy (DE) resource system. The Roof – top solar PV system is the highly concentrated resource in this work. As the commercially available solar cells have low efficiency, MPPT technique with various control algorithms are introduced to track the maximum power point. Perturb and Observe (P&O) algorithm is implemented for the MPPT in which the voltage is slightly perturbed in the direction of the increasing power to the maximum power point. Inverter employed here is a single phase single stage grid – tie inverter which converts DC to AC, also ensures that the PV system is operated at the maximum power point. Unipolar pulse width modulation is used for providing pulses to the gate terminals of the power semiconductor switches used in grid tie inverter. Low pass filters are commissioned to reduce the high frequency harmonics. Grid integration with the PV module is achieved by implementing a Phase Locked Loop (PLL) circuit. The LCL filter at the inverter's output is used to reduce the harmonics from the voltage and current which is fed to the grid. Proportional Integral (PI) Controller serves the task of controlling and tuning the controllers and circuits involved as they require a significant degree of control.

***Index Terms* - Distributed Energy, Grid – tie inverter, Maximum Power Point Tracking, Perturb and Observe, Phase Locked Loop.**

I. INTRODUCTION

Solar-grid integration is a technique developed for weighty perforation of Photovoltaic (PV) power into the utility grid. This is portrayed as an important technology as the integration of standardized PV systems into the grids optimize the energy balance, improves the economics of the PV system, reduces operational costs, and provides added value to the consumer as well as the utility. In most nations, solar-grid integration is an emerging common practice; as there is a blooming demand for the use of alternative clean energy against fossil fuel. Solar-grid synchronization technology includes advanced inverters technology, anti-islanding technology, grid-plant protection technology, solar-grid forecasting technology and smart grids technology.

The double stage single phase grid tie inverter using MPPT technique is designed and developed on a simulation platform MATLAB Simulink. The paper is carried out with an intention to avail the abundant solar power available in this universe. Solar panels of required power ratings are erected on roof tops for the efficient capture of the solar energy. This process of collecting power from the nearby renewable sources are called Distribution Generation.

Since the power out from the solar and other renewable resources are intermittent, it is highly impossible to draw power all the time. In order to compensate the above problems, certain MPPT techniques are implemented to retrieve maximum available power from the solar panel for the efficient operation of the system.

This paper is all about a real time project centered on roof top solar PV system for which Perturb and Observe (P&O) algorithm is implemented. The power output from the solar PV is connected to an inverter whose power out is fed into the grid. Hence, the inverter is known as Grid - tie inverter. The affiliation between PV array and inverter is bridged using a DC link. The DC link is used to reduce high frequency noise and performs the task of active power supply to the grid.

The grid – tie inverter used here is a single phase full bridge inverter constructed using four power semiconductor switching devices like IGBT. The control signals to these switches are provided by Unipolar pulse width Modulation. At the output side, in order to match the phase of the inverter with that of the grid, a technique called Phase Locked Loop is hired. This PLL technique locks the Phase of the voltage and hence frequency is locked. If this condition is attained, the power flow takes place from inverter to grid.

II. MATERIALS AND METHODS

2.1 Grid Synchronization Techniques

Grid synchronization of single-phase grid-connected converters lie in the precise detection of the grid voltage and it's ascribes in order to tune an internal oscillator to mitigate the oscillatory dynamics imposed by the grid. The important attributes for interfacing renewable energies into the grid are the amplitude and the phase-angle of the fundamental frequency component of the grid voltage. However, other harmonic component's detection can be anticipating for implementing additional functionalities with in the grid-connected distributed generators, such as power conditioning, resonance damping or grid impedance detection.

These grid synchronization techniques bear particular similarities to the harmonic detection methods used in power systems and is categorized into two main groups, namely the frequency-domain and the time-domain detection methods.

The frequency-domain detection methods are generally based on discrete implementation of the Fourier analysis. The Fourier series, the discrete Fourier transform (DFT) and the recursive discrete Fourier transform (RDFT) are some of the possible grid synchronization techniques in single-phase systems. According to frequency analysis, the sample frequency of the signal should be an integer multiple of the fundamental grid frequency.

The time-domain detection methods are based on certain nature of adaptive loop which enables an internal oscillator based on the input signal. phase-locked loop (PLL) the most prominent synchronization techniques in engineering application is portrayed. By using some kind of quadrature signal generator (QSG), the PLL is integrated with the low frequency (50/60 Hz) conventional grid. At last, the frequency-locked loop (FLL) is presented as an effectual synchronization technique to be implemented in a grid-connected power converter, mainly when the grid is disturbed by transients due to grid faults.

The most common and widely used grid synchronization techniques include grid synchronization using Fourier analysis, using Phase Locked Loop, Synchronous Reference Frame [SRF] PLL, Double Synchronous Reference Frame [DSRF] PLL, Unbalanced Harmonic Based [UHD] PLL, Zero Crossing Detector.

2.2 Grid Synchronization using Phase Locked Loop

A control system capable of generating an output signal whose phase is correlated to the phase of an input signal is called Phase Locked Loop (PLL. The simplest PLL consists of an electronic circuit comprises of a variable frequency oscillator and a phase detector in a feedback loop. A periodic signal generated by the internal signal oscillator is compared by the Phase detector with the phase of that signal to the phase of the input periodic signal, thereby adjusting the oscillator to keep the phases matched.

When the input and output phases are maintained in lock step it determines that the frequencies in both input and output stages are kept the same. Consequently, a phase-locked loop can track an input frequency, or it can bring about a frequency that is a product of the input frequency which is done in additional with synchronizing signals.

These properties are used for computer clock synchronization, demodulation, and frequency synthesis. The block of the PLL [figure 1.] is provided here for appropriate demonstration.

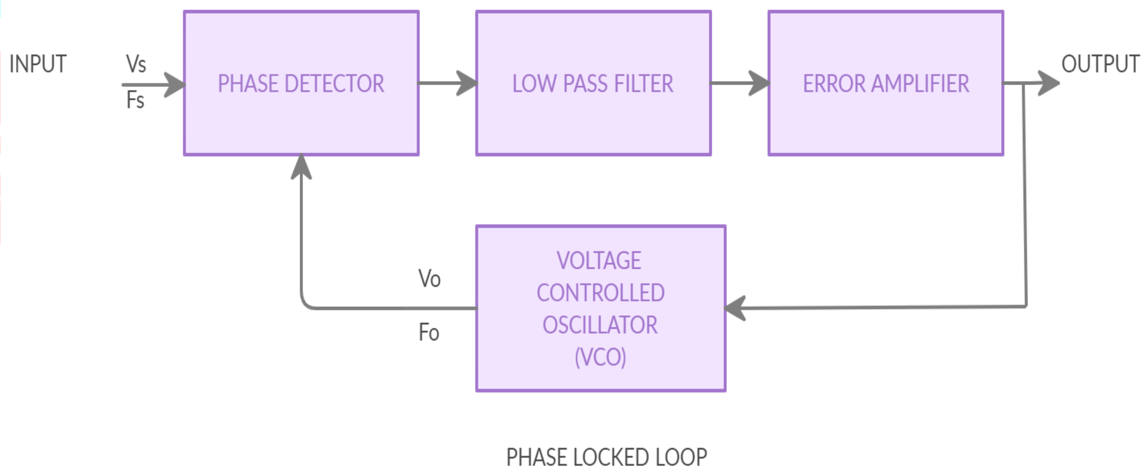

figure 1. phase locked loop

A phase locked loop, PLL, is principally a kind of servo loop. A PLL performs its actions on a radio frequency signal, and hence all the basic criteria for loop stability and other parameters remain the same. The input signal V_i of input frequency f_i is sent through a phase detector. A phase detector block in PLL is nothing but a comparator that compares the input frequency f_i with that of the feedback frequency f_o.

The phase detector lends an output error voltage ($V_{er} = f_i + f_o$), which is nothing but a DC voltage. This DC voltage is then provided to an LPF for filtering. The high frequency noises are abruptly removed by the LPF and it produces a DC voltage, (V_{er} = f_i -f_o) which is steady in nature. The dynamic characteristics of the PLL is again represented by the V_f. The steady DC level is then passed to a VCO. The output frequency of the VCO (f_o) is directly proportional to the input signal.

The PLL is a significantly helpful circuit that's often majorly employed in radio or wireless applications. in sight of its quality, the PLL finds place in several wireless, radio, and general electronic things from mobile phones to broadcast radios, televisions to Wi-Fi routers, picture show radios to skilled communications systems and a lot more.

A basic phase locked loop, PLL, consists of three basic elements. They are,

- **PHASE COMPARATOR / DETECTOR:** In this block, the phase of the two signals are compared and a voltage according to the phase difference between the two signals is generated.
- **VOLTAGE CONTROLLED OSCILLATOR, VCO:** The radio frequency signals are normally generated by this block and is the output of the loop. Its loop frequency can be controlled over the operational frequency band.

- **LOOP FILTER:** It filters out the signal from the phase comparator in the PLL.

It removes the components from the signals to which the phase is differentiated from the VCO line. Most of the characteristics of the loop including the loop stability, speed of lock, etc. is governed by this loop filter.

III. DESIGN OF LCL FILTER

Power output from the inverter consists of current with harmonics. This current when connected to the grid may cause the grid voltage to deteriorate and leads to power quality issues. In order to confront the harmonics, an LCL filter is employed between output side of the inverter and the input side of the grid. Due to its superior performance, it is widely used in grid synchronization. The design of capacitor is based on the reactive power absorbed at the rated conditions. The design of inverter side inductor is based on the current ripple. From which the value of grid side inductor can be calculated. The schematic representation of the LCL filter [Figure 2.] is provided.

Since the power output from the grid tie inverter is a stepped sine wave, in order to smoothen the stepped sine, wave to normal sine wave, the LCL filter is used.

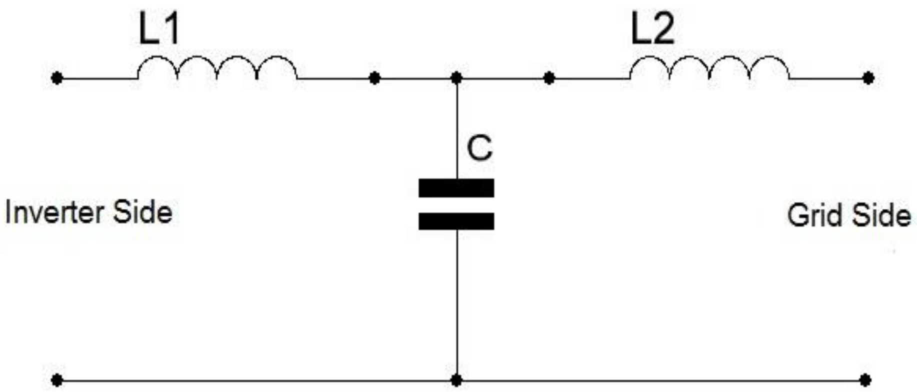

figure 2. lcl filter

The design of LCL filter includes the design of both inverter and grid side inductors and a capacitor. The function of LCL filter is used to smooth the square wave output of the grid tie inverter to a pure sinusoidal wave.

3.1 Design of Capacitor

The design of capacitor is mainly based on the reactive power absorbed at the rated conditions. Based on the condition that, the reactive power (Q) absorbed by the capacitor is limited to 5% of the rated power (S).

$$Q = \frac{V^2}{(1/(2*pi*f*c))} \quad (1)$$

$$5\%\ of\ S = V^2 * 2 * pi * f * c \quad (2)$$

$$C = \frac{0.05*S}{V^2*2*pi*f} \quad (3)$$

By applying the parameter values, $V_{dc} = 400V$, V_{GRID} = 230V, 50Hz, $P_O = 2KVA, F_s = 10kHz, I_{rip}$ = 20%. The value of C is obtained as 6.0175 µF.

3.2 Design of Inductor

The design of inductor includes the design of inverter side inductor (L1) and grid side inductor (L2). The value of inverter side inductor (L1) is based on the maximum permissible current ripple. The current ripple should be limited to 20% of the rated current.

$$L1 = \frac{V_{DC}}{4*f_{sw}*\Delta I_{PPMAX}} \quad (4)$$

$$L1 = \frac{400}{4*10000*8.69*1.414*0.2} \quad (5)$$

$$L1 = 4.06mH \quad (6)$$

Where, L1 is the value of the inverter side inductor.

The total inductance (L1 + L2) is selected based on the maximum voltage drop across the inductor.

$$V_{L1+L2} = I * X_{L1+L2} \quad (7)$$

According to the condition, the Maximum drop is limited to 10% of rated voltage.

$$V_{L1+L2} = I * 2 * pi * f * (L1 + L2) \quad (8)$$

$$10\%\ of\ V = \mathrm{I * 2 * pi * f * (L1 + L2)} \quad (9)$$

$$L1 + L2 = \frac{10\%\ of\ V}{\left(\frac{S}{V}\right)*2*pi*f} \quad (10)$$

$$L1 + L2 = \frac{0.1*V^2}{2000*2*pi*50} = 8.41mH \quad (11)$$

By substituting the value of L1 in L1 + L2, the value of L2 is obtained as 4.35mH.

To operate the filter within the safe region, the resonant frequency of the filter is set between two frequency limit. The frequency limits include Grid frequency (f_g) and switching frequency (F_s).

$$10\, f_g < f_{res} < 0.5\, F_s$$

$$10*50\, f_g < f_{res} < 0.5*10\, F_s$$

$$500 < f_{res} < 5000$$

In order to operate the filter in the desired region, the above frequency limits have to be met. This LCL filter is mainly used for smoothing the output of the Voltage source inverter. It has some advantageous features when compared to other filter topologies. They are, higher attenuation rate, effective cost reduction, overall weight and size of the components are minimized and decent performance can be claimed with accurate and compact values of inductors and capacitors. This filter filters out the harmonics produced by the inverter and hence finds place between the inverter and the grid.

IV. SIMULATION OF DOUBLE STAGE SINGLE PHASE GRID – TIE INVERTER USING MPPT TECHNIQUE

As the power output of the solar and other renewable resources are intermittent, it is highly impossible to draw power all the time. In order to compensate the above problems, certain MPPT techniques are implemented to retrieve maximum available power from the solar panel for the efficient operation of the system.

This paper centered on roof top solar PV system for which Perturb and Observe (P&O) algorithm is implemented. The output of the solar PV is connected to an inverter whose power output is fed into the grid. Hence, the inverter is known as Grid - tie inverter.

The interface between PV array and inverter is bridged using a DC link. The DC link is used to reduce high frequency noise and performs the task of active power supply to the grid.

The grid – tie inverter used here is a single phase full bridge inverter constructed using four power semiconductor switching devices like IGBT. The gate signals to these switches are provided by Unipolar pulse width Modulation. At the output side, in order to match the phase of the inverter with grid, a technique called Phase Locked Loop is employed. This PLL technique locks the Phase of the voltage and hence frequency is locked. If this condition is attained, the power flow takes place from inverter to grid.

4.1 Block Diagram Representation

A Grid – tie inverter using IGBT switches of suitable rating is employed as a power interface between Solar PV system and the Grid maintains voltage at the Point of Common Coupling (PCC).

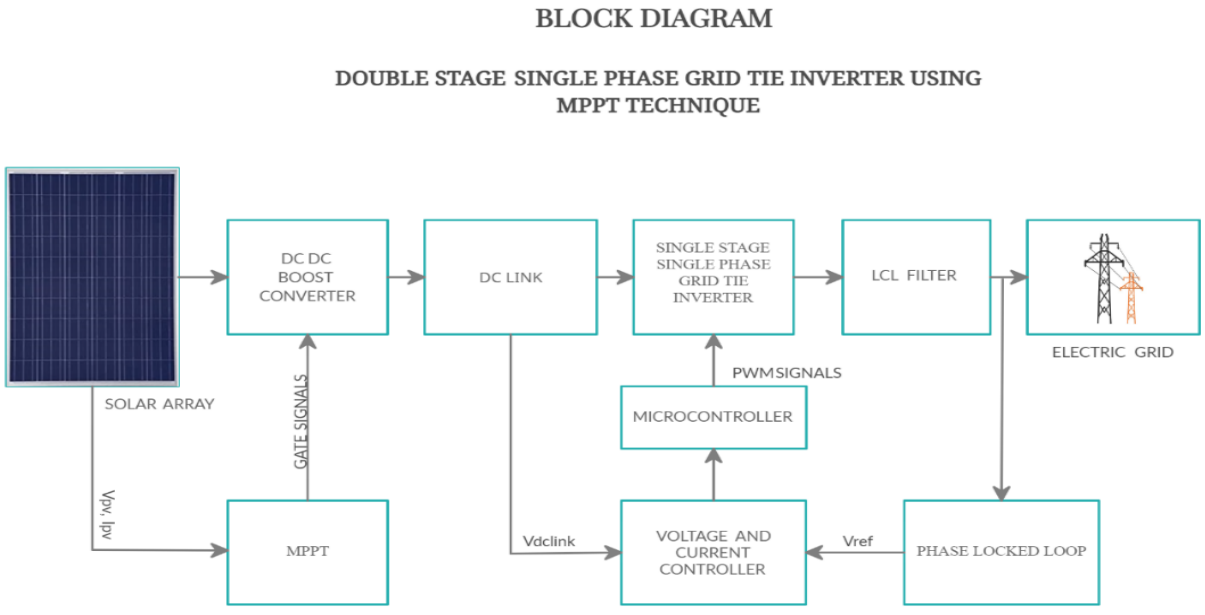

figure 3. block diagram representation

It receives the DC input from the array and transforms it to the AC output required by the grid. Phase Locked Loop is assigned to synchronize the voltage and frequency of the inverter with the grid. Maximum Power Point Tracking [MPPT] is used to ensure that the gate pulses are provided to the inverter for proper export of electricity into the grid. The control signals are provided to the inverter through a Microcontroller.

In most of the distributed energy sources like Solar, the power quality can be poor due to their intermittent nature. This intermittent supply in excess cannot be fed directly to the conventional grid as it can collapse the grid. Thus, an adaptive technique called Grid Synchronization is brought to form. A process by which an internal reference signal generated by the control algorithm of a grid tied inverter is brought in line with a particular grid variable such as Voltage, Frequency, Phase angle and Phase Sequence. Here, the fundamental component of grid voltage is synchronized.

4.2 DC DC Boost Converter

A boost converter is powered by suitable DC sources like DC generators, conventional batteries, solar PV systems etc. When the magnitude of one DC voltage is varied to a different DC voltage then it is called DC to DC conversion. Principally, a DC to DC converter with an output voltage greater than the source voltage is called as a boost converter. It is also referred to as a step-up chopper as it raises the source voltage.

The voltage source at the input side is connected to an inductor. The semiconductor device which operates as a switch is connected across the source. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel.

The inductor near the input source leads to a constant input current, and hence the Boost converter is the constant current input source. The load's is a constant voltage source. The power semiconductor switches are triggered by using Pulse Width Modulation(PWM). PWM can be time-based or frequency based. Time-based Modulation is mostly used for DC-DC converters. In this type of PWM modulation, the frequency is maintained constant.

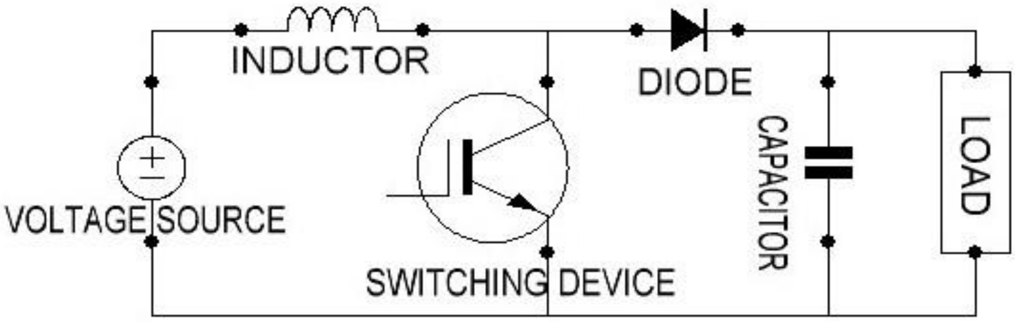

figure 4. schematic of boost converter

4.3 DC Link

In order to provide isolation and to suppress the ripple, grid connected PV systems require DC link capacitor. The switching losses of the inverter are provided by this DC link. Principally, Capacitor stores potential energy in the electrostatic fields. So, when there is a reduction in the source, it is capable of driving the load and vice versa. In between the source and load, it plays the role of both regulator and stabilizer. When its value is increased, it can store the energy for a longer time period to deliver energy to the load.

Primarily, a DC link capacitor maintains a DC voltage with small ripples. In case of transients, it serves as an energy storage element to supply real power. Under Steady state conditions, the real power supplied by the source equals the real power required by the demand. When the load condition changes, the real power balance between the source and load is disturbed. This real power compensation is done by DC link capacitor.

4.4 Grid – Tie Inverter

Typically, a photovoltaic array generates DC power, whereas most of the electrical appliances operate on AC power. Hence, a power electronic circuitry which converts DC to AC called Inverter is developed.

An electrical device capable of converting DC input supply to symmetric AC voltage of standard magnitude and frequency at the output side is portrayed as inverters. Generally referred to as DC to AC converter. An ideal inverter input and output can be represented either in a sinusoidal and non-sinusoidal waveform. Inverters are classified into two types according to the type of load being used i.e., single-phase inverters, and three-phase inverters.

Single-phase inverters are further classified into two types of half-bridge inverter and full-bridge inverter. Based on the input source, they are classified as Voltage Source Inverter [VSI] and Current Source Inverter [CSI].

A Unipolar Pulse Width Modulation [UPWM] technique is used to provide gating signals to the power semiconductor switches present within the full bridge inverter.

The output from the single phase full bridge inverter generates a square wave AC output voltage when provided with a DC input by adjusting the triggering based on the appropriate switching sequence, where the output voltage generated is of the order +Vdc, -Vdc, or 0.

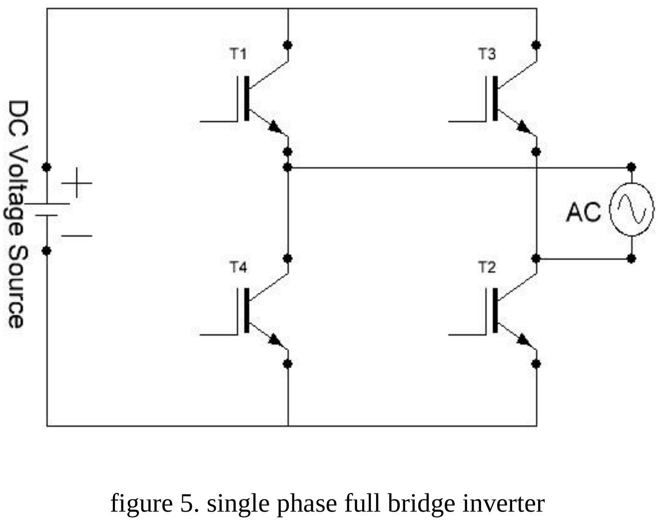

figure 5. single phase full bridge inverter

4.5 Maximum Power Point Tracking

The efficiency of a solar cell is low. So, in order to enlarge the efficiency, the voltage and current from the Solar PV systems should be maintained evenly throughout the day of operation. Maximum Power Point Tracking (MPPT) is one among the procedures. From a fluctuating source, the above mentioned course of action is adopted for procuring the maximum power for effective operation. In order to maintain the maximum power available during the course of action, various algorithms are employed. With the help of algorithms, the duty cycle of the converters can be varied. The algorithm used here is Perturb and observe [P&O] algorithm. Because of its simplicity in operation, P&O is most widely used.

4.6 Perturb and Observe[P&O] algorithm

This method is similar to that of the Hill Climbing technique, where the Voltage or duty cycle is perturbed in the direction to get the appropriate reference voltage values and the corresponding system variations are found. The obtained reference voltage values determine the value of direction of next perturbation. Thus, by continuous incrementing and decrementing, the Maximum Power Point is obtained for effective operation.

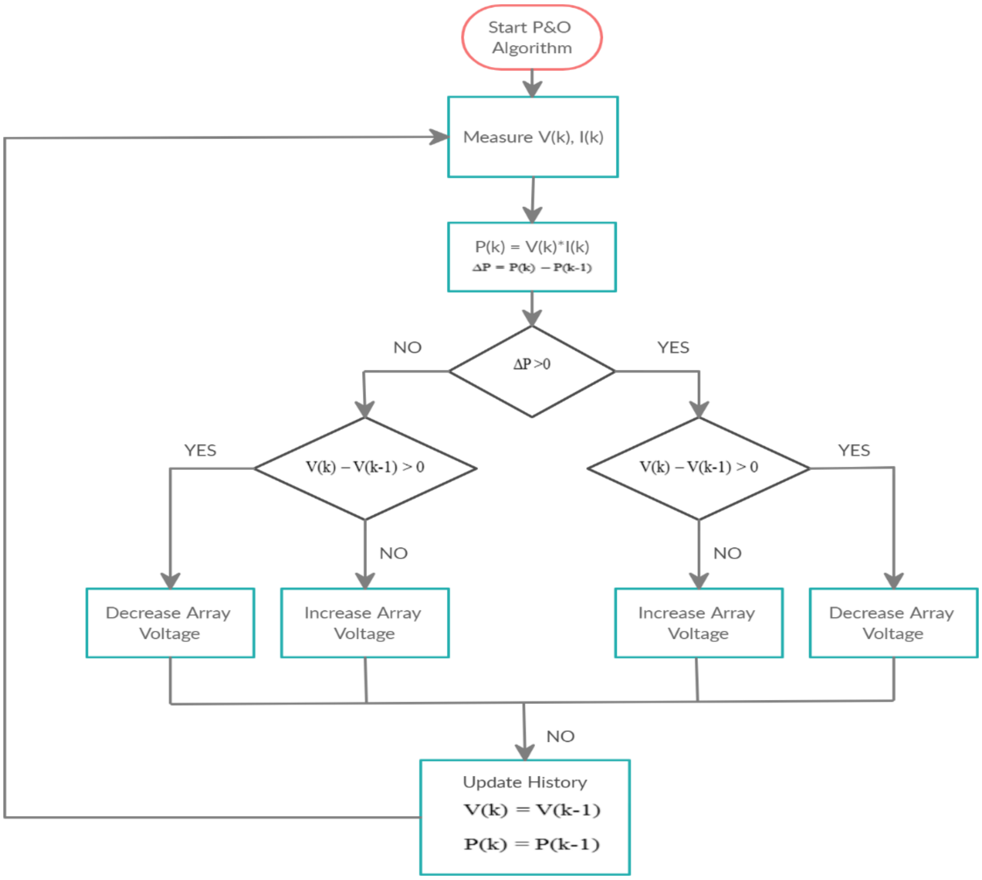

figure 6. perturb and observe (p&o) algorithm

4.7 Simulation model and Resultant output waveform

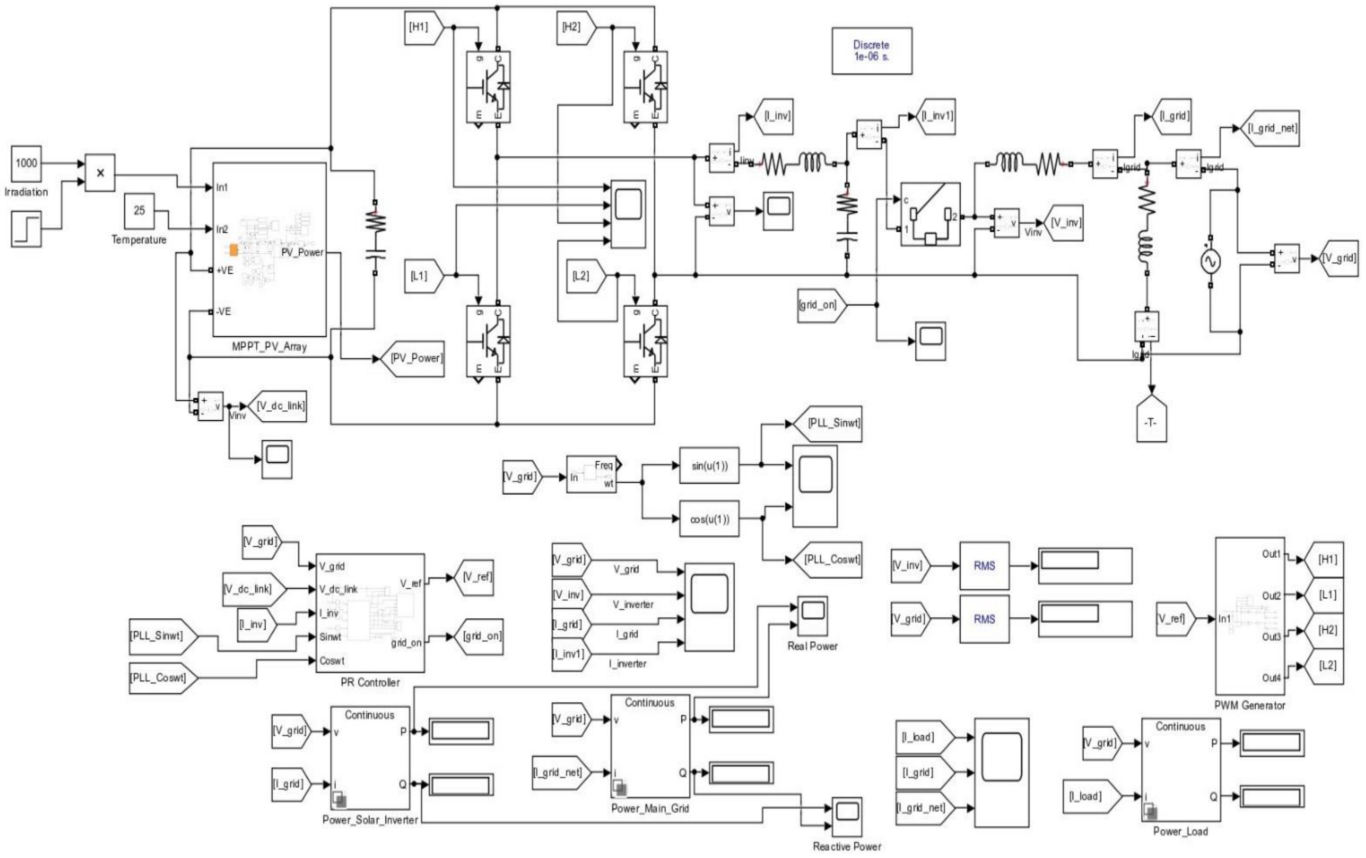

figure 7. simulation model

The simulation model and operation of Single stage single phase grid – tie inverter using MPPT technique is discussed here. Initially, a single phase single stage grid – tie inverter is constructed using four power semiconductor switching devices like IGBT. The DC power input to the inverter is obtained from 27 solar panels each of rating 18.5V and 100Kw capacity with an open circuit voltage of 420V in both series and parallel strings are created. It is capable of providing the necessary input to the inverter. As the solar power is not regular, the controllability of the PV system is difficult.

The following were the resultant output waveforms obtained by simulation. Figure 8. represents the value of output voltage obtained at the boost converter which is exactly near 400 V and it's the desired value required for operation.

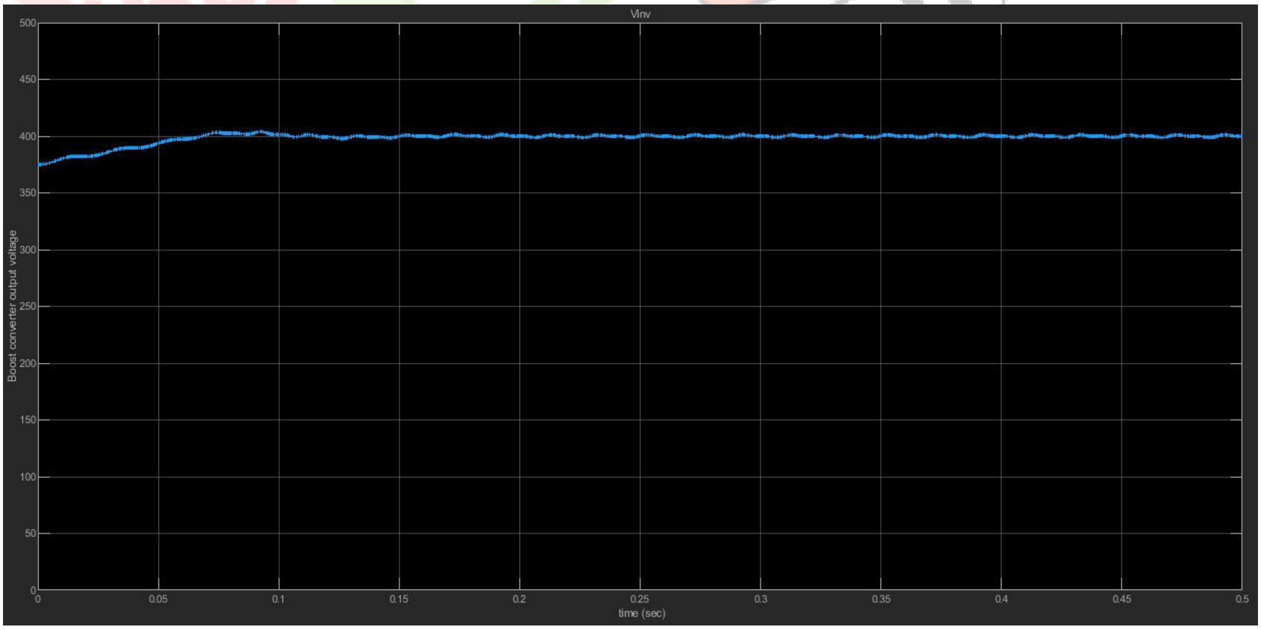

figure 8. output voltage of the boost converter

Figure 9. describes the waveform obtained at the MPPT technique from which the values of voltage, current and power at the MPPT stage is displayed.

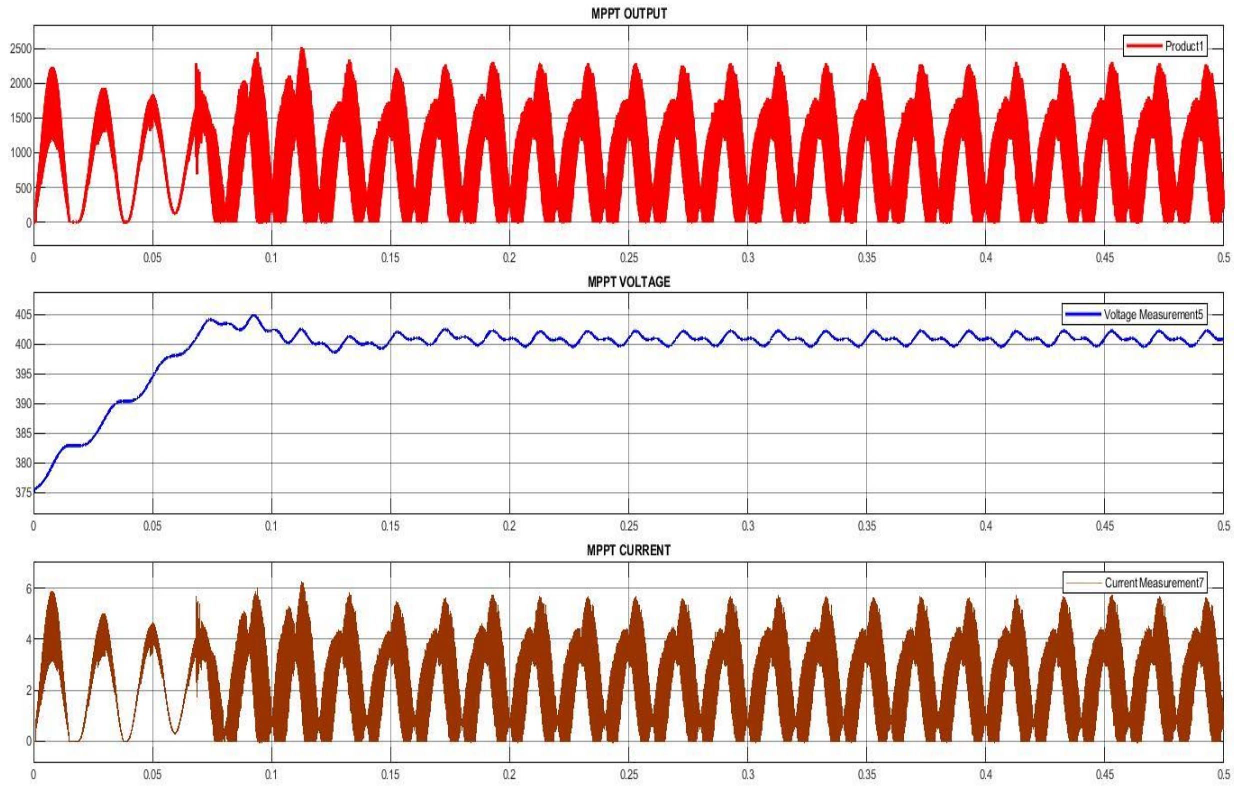

figure 9. maximum power point tracking output voltage, current and power

Figure 10. determines the current values obtained from the waveforms representing the inverter current, grid current and load current.

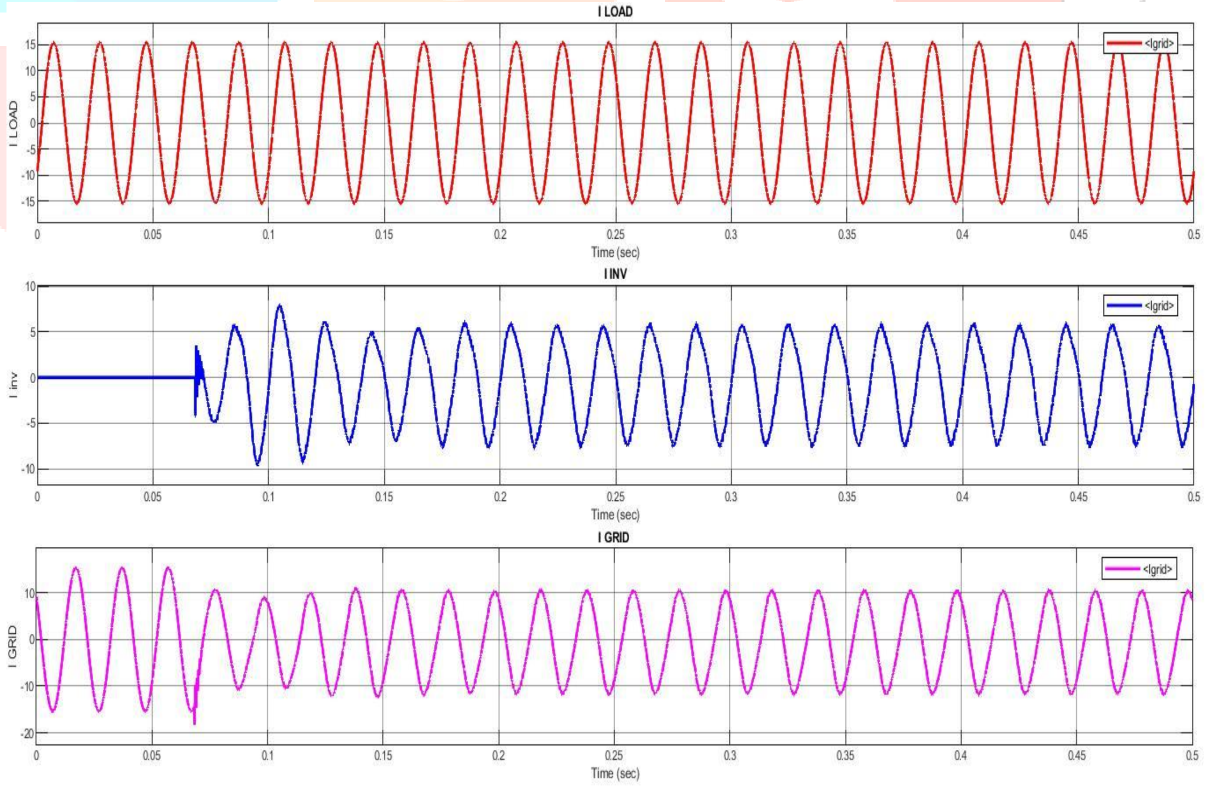

figure 10. load current, inverter current, grid current

Figure 11. represents the magnitude of Output voltage from PR controller, Grid Voltage, Reference Voltage.

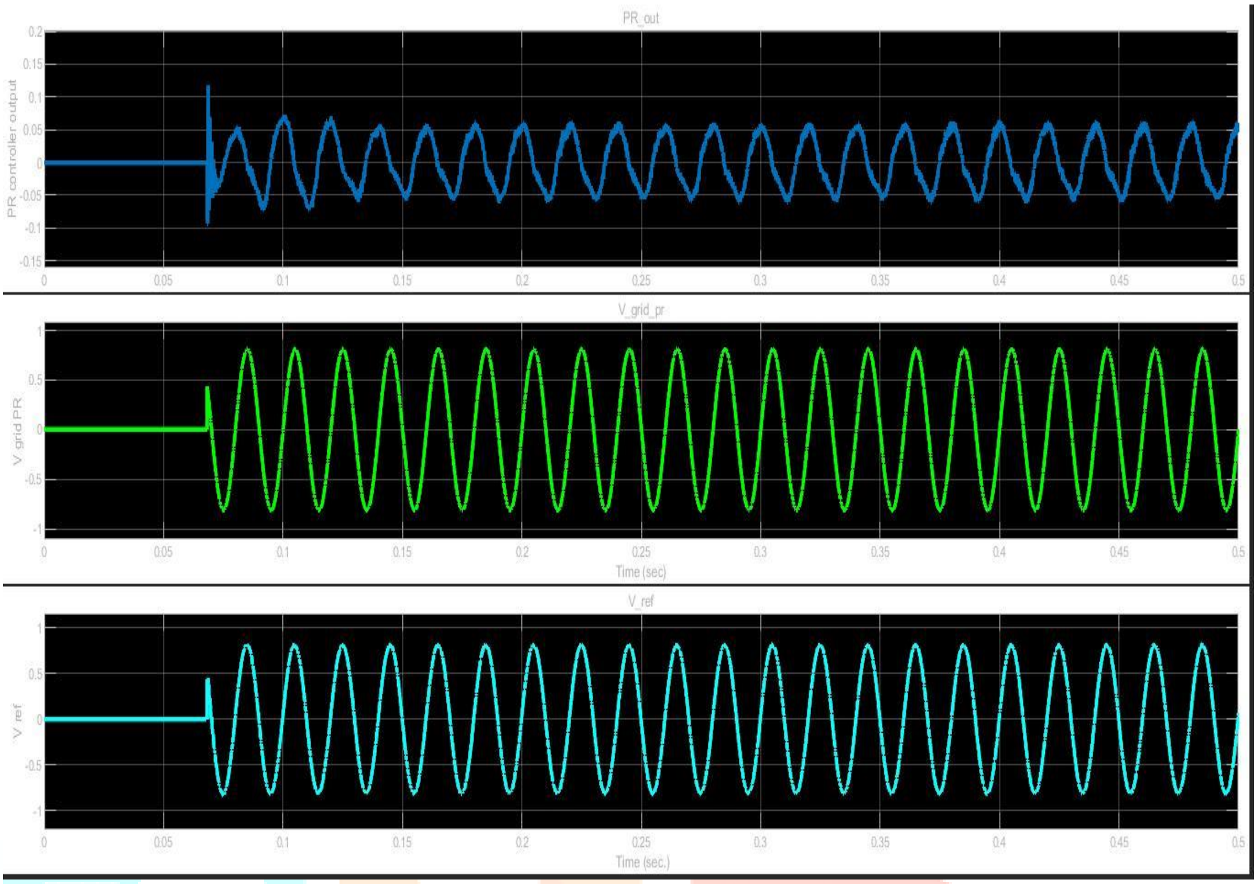

figure 11. output voltage from proportional resonant controller, grid voltage, reference voltage

Figure 12. shows the value of the output obtained at the PLL.

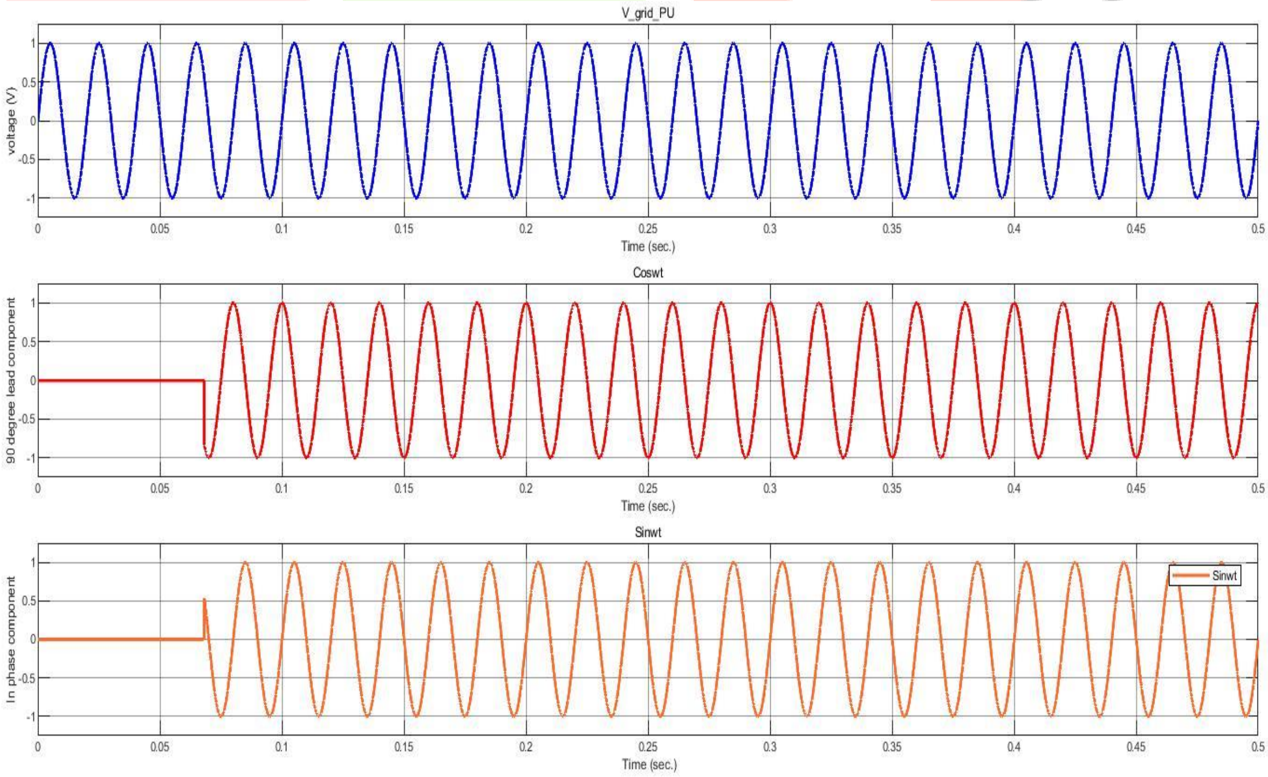

figure 12. output of the phase locked loop

Figure 13. and Figure 14. displays the magnitude of both the real and reactive power injected into the grid.

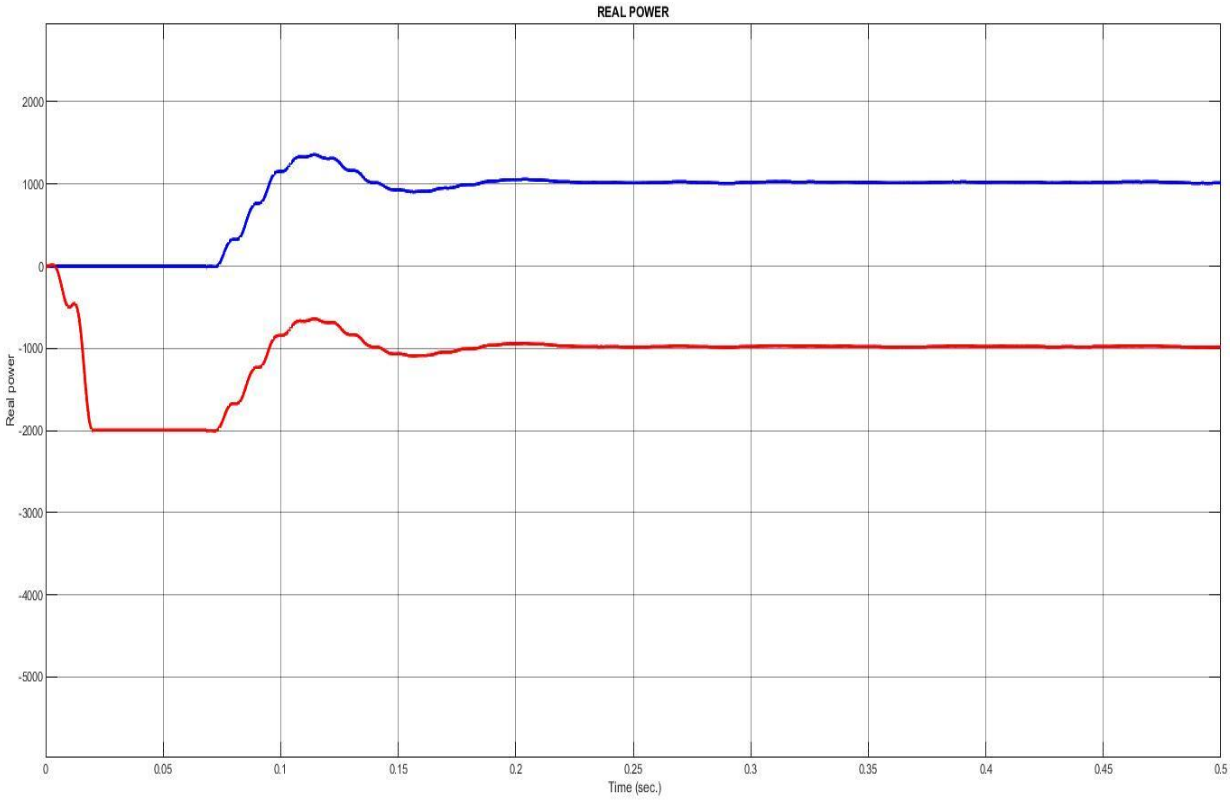

figure 13 real power

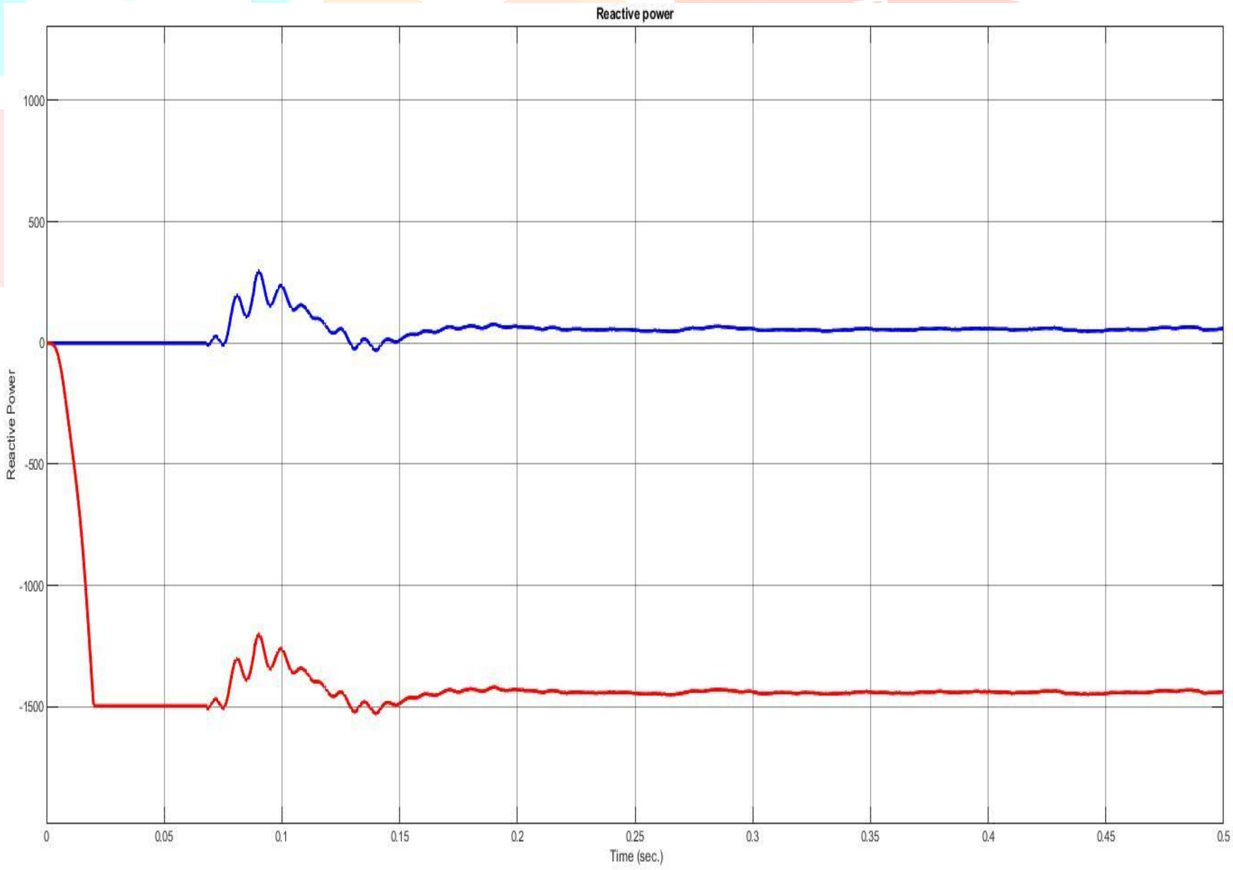

figure 14 reactive power

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VI. CONCLUSIONS

Developed with an intention to reduce the dependence on conventional energy sources, this paper put forth a technique, thereby the power from the distributed generation systems are pumped to the conventional grids for encouraging enhanced reliability of operation on the renewable energy sources and to create awareness regarding depletion in the level of raw materials required for the conventional electricity generation. In order to meet this goal, grid synchronization has to be met, which is done here. A base trim inverter, single phase full bridge inverter is employed here to serve the role of a grid – tie inverter. Phase locked loop, a grid synchronization technique is assigned to lock the phase and frequency of the inverter with the grid. Few advantages of this work includes, the number of power interfaces for power conversion are reduced to one, thereby reducing the system complexity. The Unipolar sinusoidal pulse width modulation technique is used to reduce the harmonics. Among several MPPT techniques, P&O algorithm is used to track maximum available power from the PV system, thus increasing the efficiency of operation of the inverter. This Paper is mainly focused on the simulation part. The number of power interfaces used for power conversion are reduced to one, thereby reducing the system complexity. With the limited available resources, this work was carried on a single phase power supply. The same will be done in three phase power supply in the near future. In order to meet the power quality issues, this work will be upgraded with some protective features in the upcoming days. Various inverter topologies, advanced power semiconducting switches, pulse width modulation and grid synchronization techniques can be implemented to enhance the theme.

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