**Project Stage - II Report**

On

**GRID CONNECTED PV PANEL WITH A dq CONTROLLED INVERTER**

*Submitted in partial fulfilment of the requirements for the award of the degree of*

# BACHELOR OF TECHNOLOGY

in

# ELECTRICAL AND ELECTRONICS ENGINEERING

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**(Approved by AICTE, New Delhi and Affiliated to JNTUH, Hyderabad) Accredited by NBA - EEE, ECE, CSE & IT and NAAC with ‘A’ Grade Bachupally, Hyderabad – 500090**

# 2022-2023

**DECLARATION**

We hereby declare that the work described in this report, entitled **“GRID CONNECTED PV PANEL WITH A dq CONTROLLED INVERTER”** which is being submitted by us in partial fulfilment for the award of the degree of **Bachelor of Technology** in the department of **Electrical and Electronics Engineering** at **BVRIT HYDERABAD College of Engineering for Women,** affiliated to **Jawaharlal Nehru Technological University Hyderabad**, Kukatpally, Hyderabad-500085 is the result of original work carried out by us under the guidance of Ms. **K. Amritha, Associate Professor, EEE.**

This work has not been submitted for any Degree /Diploma of this or any other institute to the best of our knowledge and belief.

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Certificate

*This is to certify that Project Work (Stage - II) report, entitled* **“GRID CONNECTED PV PANEL WITH A dq CONTROLLED INVERTER”** *is a bonafide work carried out by* ***Ms.***

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*The results embodied in this work have not been submitted to any other University or Institute for the award of any degree.*

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**ABSTRACT**

The Sun is an extremely powerful energy source, and [sunlight](https://www.britannica.com/science/sunlight-solar-radiation) is by far the largest source of energy received by [Earth.](https://www.britannica.com/place/Earth) Photovoltaic (PV) panels, also known as [solar panels,](https://www.greenmatch.co.uk/solar-energy/solar-panels) capture the sun’s energy and convert it into electricity**.** Solar panels produce direct current (DC) electricity. Maximum Power Point Tracking (MPPT) is an algorithm that is included in charge controllers used for extracting maximum available power from PV module. The voltage at which PV module can produce maximum power is called maximum power point (or peak power voltage). Maximum power varies with solar radiation, ambient temperature, and solar cell temperature.

With varied weather conditions, the PV system should continuously operate, with great efficiency level near/at the maximum power point (MPP) of the solar panel. Maximum power can be transferred from solar cell PV module to the connected load by using DC/DC Boost converter (step up) as the output of solar panel is low. The MPPT is based on the perturb and observe algorithm. Inverter is used to convert DC to alternating current (AC), which the electrical grid uses. The energy fed to the grid from PV panel is to be maintained at constant voltage and constant frequency. To maintain these values constant Direct Quadrature (dq) method is used. Then this AC can be fed into commercial electrical grid or can be directly supplied to the consumer.

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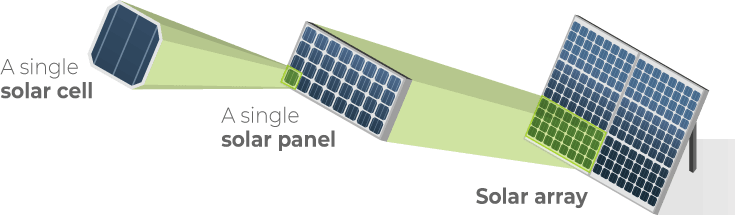
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# CHAPTER 1 INTRODUCTION

Solar energy, [radiation](https://www.britannica.com/science/solar-radiation) from the [Sun](https://www.britannica.com/place/Sun) capable of producing [heat](https://www.britannica.com/science/heat), causing [chemical](https://www.britannica.com/science/chemical-reaction) [reactions,](https://www.britannica.com/science/chemical-reaction) or generating [electricity.](https://www.britannica.com/science/electricity) The total amount of solar energy incident on Earth is vastly in excess of the world’s current and anticipated energy requirements. If suitably harnessed, this highly [diffused](https://www.britannica.com/dictionary/diffused) source has the potential to satisfy all future energy needs. In the 21st century solar energy is expected to become increasingly attractive as a [renewable energy](https://www.britannica.com/science/renewable-energy) source because of its inexhaustible supply and its non-polluting character, in stark contrast to the finite [fossil fuels](https://www.britannica.com/science/fossil-fuel) [coal,](https://www.britannica.com/science/coal-fossil-fuel) [petroleum,](https://www.britannica.com/science/petroleum) and [natural gas.](https://www.britannica.com/science/natural-gas)

PV in solar panels means ‘[photovoltaic](https://www.greenmatch.co.uk/solar-energy/photovoltaics)’, because the panels consist of small [photovoltaic](https://www.greenmatch.co.uk/solar-energy/solar-panels/photovoltaic-cells) [cells](https://www.greenmatch.co.uk/solar-energy/solar-panels/photovoltaic-cells) that are connected together. PV cells are made of semiconducting material — silicon being the most used. PV cells are usually very small but when combined to form solar panels and solar arrays, they can be very efficient. When the sun shines over the cells, an electric field is created. The stronger the sun, the more electric energy is produced. Nevertheless, the cells do not need direct sunlight to work, and they can still produce electricity on a cloudy day.



**Fig.1.1 Solar Array**

Solar panel produces DC output and it changes by the contingent on the irradiances and the temperature. By using MPPT algorithm, maximum power of solar panel can be found and given to the boost converter. Due to the low output voltage of the PV cells and high current, Boost Converter is used to step-up the voltage to match with the grid voltage. Inverter is used to convert DC to AC. In DC, electricity is maintained at constant voltage in one direction. In AC, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Inverters are just one example of a class of devices called [power electronics](https://www.energy.gov/eere/solar/solar-power-electronic-devices) that regulate the flow of electrical power. The LCL filter effectively smooths the inverter current output, and the filtered harmonic-free current to supply to the grid. Sinusoidal Pulse width Modulation (SPWM) is used to switch the Insulated gate bipolar transistor (IGBT) which is used in the construction of inverter bridge.

The energy fed to grid should maintain constant voltage and constant frequency for this dq method is used. To control active and reactive power of inverter dq method is used. The method uses the dq synchronous reference frame transformation for three-phase converters. This method transforms an orthogonal pair consisting of the inverter output current and a time shifted version of this current from a stationary frame to a rotating frame synchronous to the fundamental output frequency. The steady state current components in this rotating dq frame are DC values and thus PI control methods can be used with zero error. The dq method is a promising numerical technique that produces accurate solutions with less computational effort.

## OBJECTIVE OF THE PROJECT:

* + - Simulation and Modelling of DC-DC Boost Converter.
    - Design and MATLAB simulation of a 3-phase grid-connected inverter using dq method.

## PROBLEM STATEMENT:

Solar panels produce DC power. This DC should be converted to AC before injecting it to the grid. Solar panel output depends upon the irradiance and temperature, which may change throughout the day. Irrespective of the output of the solar panel, energy fed to the grid from the inverter should have constant voltage and frequency.

## ORGANIZATION OF THE PROJECT:

The organization of the Project is as follows:

**Chapter- 1:** Describes the introduction to Boost Converter, MPPT, Inverter with dq control method.

**Chapter- 2:** Describes the Literature Survey for the proposed system.

**Chapter- 3:** Describes Maximum Power Point Tracking.

**Chapter- 4:** Describes the Methodology, modes of operations of boost converter.

**Chapter- 5:** Discusses the design aspects of circuit components and the block diagrams and implementation of the Simulink model of the proposed system.

**Chapter- 6:** Discusses the Result of solar panel output voltage and output current, and boost converter output voltage and dq controlled inverter output.

**Chapter- 7**: Describes the Conclusion of the project. **Chapter -8:** Describes the Future Scope of the project. **Chapter -9:** List of references is shown in this chapter.

# CHAPTER 2 LITERATURE SURVEY

* Ref [1] refers to a mathematical modelling of three-phase grid-connected inverter system including output LCL filter and closed loop control using complex vector notation. The control scheme used is synchronous frame PI control on complex space vector of grid current in synchronous dq reference frame. Effect of controller's tuning parameters is investigated using complex vector root locus and complex vector frequency response function of closed loop system according to different tuning

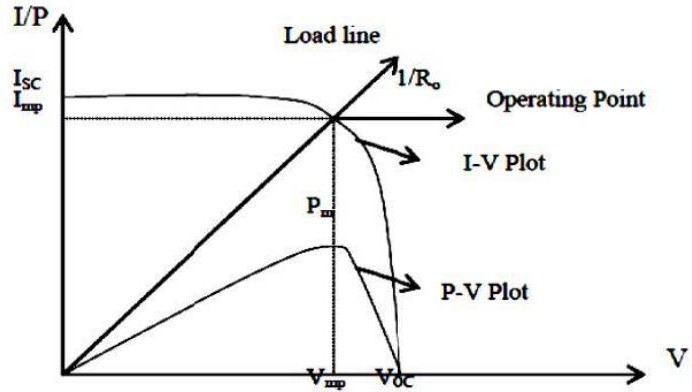
parameters.

* Ref [2] refer to a detailed comparative survey of four maximum power tracking techniques Perturb and Observe (P&O), Incremental Conductance (InC), fuzzy logic- based tracking technique and a less known, method using only the photovoltaic current measurement. The drawback of the three studied methods is P&O, InC and one sensor algorithm, is that at steady state the operating point oscillate around the maximum power point, giving rise to the waste of the output panel's available energy.
* Ref [3] refers to information of the design of closed loop Boost converter using PI Controller.
* Ref [4] refers to modified dq control strategy that improves the dynamic response of the grid-connected inverter compared to the conventional approach.
* Ref [5] refers to the design of DC/DC boost converter physical model. Circuit diagram as well as the principle of work and features of components selection for the purpose of design are presented. The recommendations to the problems related to design and assembly of boost converter and its components are given.
* Ref [6] refers to validates an algorithm for Maximum Power Point Tracking using Perturb and Observe technique. The algorithm starts by setting the computed maximum power (PMAX) to an initial value (usually zero). Next the actual PV voltage and current are measured at specific intervals and the instantaneous value of PV power. Hence the final value of PMAX will be the point at which maximum power can be delivered to the load.
* Ref [7] refers to dq impedance reshaping method of power-controlled GCIs to eliminate the negative effect of Phase-locked loop (PLL) on low-frequency stability. The dq impedance models of the grid-connected inverter (GCIs) under current and power control modes are first established using complex vector and complex transfer function theory. On its basis, the negative effects of PLL on current control loop and power control loop are theoretically derived. A grid voltage feedforward loop is then designed in the control system of the power-controlled GCIs, where the parameters of the feed- forward loop are calculated.
* Ref [8] refers to MPPT is a technique used in power electronic circuits to extract maximum energy from the PV Systems. In the recent decades, PV power generation has become more important due its many benefits such as needs a few maintenance and environmental advantages and fuel free. However, there are two major barriers for the use of PV systems, low energy conversion efficiency and high initial cost. To improve the energy efficiency, it is important to work PV system always at its maximum power point.
* Ref [9] refers to the latest research articles of the last decade, several authors have increased their interest in the topological design of DC/AC inverters applied to photovoltaic plants. It is an exponential rate of new articles. Therefore, a deep investigation of the trends and limitations of the new topologies of DC/AC inverters is developed, which will improve the performance and efficiency of solar plants. Finally, the research concludes the four most important failure modes that still present permanent unavailability or considerable efficiency losses in current designs, as well as the most important topologies from 2019 to 2020, with the description of efficiency and limitations from the point of view of the electronic layout.
* Ref [10] refers to the compact-size analog maximum power point tracking (AMPPT) technique is proposed in this paper for high power efficiency in the PV system. Combining existing MPPT approaches, we present a fast and accurate tracking performance. Here, a wide-range current multiplier, which tracks the MPPT in the solar power system, is implemented to detect the power slope condition of the solar panel. Experimental results show that the proposed technique can rapidly track the MPP with a high tracking accuracy of 97.3%. Furthermore, the proposed system can connect to the grid-connected inverter to supply ac power.
* Ref [11] refers to a new version of perturb and observe tracking algorithm for maximum power extraction from the solar photovoltaic panel, which has self-predictive and decision taking ability. The working principle of self-predictive perturb and observe (SPP&O) algorithm is based on three consecutive operating points on the power- voltage characteristic. Out of three points, first two points very smartly detects the dynamic condition, as well as in normal condition, quickly searches the MPP region. Moreover, by using a circular analogy, all points decide the optimal operating position for next iteration, which is responsible for quick MPP tracking as well as improved dynamic performance. Here, in every new iteration, the step-size is reduced by 90% from the previous step-size, which provides an oscillation free steady-state performance.
* Ref [12] refers to modern world there is burgeoning demand for energy to power every piece of technology. Due to this, the non- renewable energy resources are reaching the point of depletion sooner than expected. Thus, researchers around the globe are searching for an alternative of fossil fuel and trying to find a sustaining energy source. There has been many recent development and innovation in the field of solar energy utilization. A method has been proposed for the maximum utilization of solar energy for home lighting applications. Firstly, sun tracking solar panels are to be used for harnessing as much solar energy as possible. This assures the maximum solar power gets stored in the PV cell. The PV cell gives DC output which can be stored in a battery, preferably lithium polymer battery and can be used to power home lighting appliances.
* Ref [13] refers to a LCR (longitudinally coupled resonator) filter design requires a complex non-linear optimization procedure. The effectiveness of such a procedure depends both on the performance of the optimization algorithm, and on the underlying model of the device. This paper describes a general procedure for optimizing LCR filter responses by applying non-linear programming techniques directly to a green function device model. A simplified green function analysis procedure has been developed that is extremely accurate and is also efficient enough to be used directly in optimization.
* Ref [14] refers to Boost Converter based on Photovoltaic Energy System. The PV system are growing because of large, protected, important, exhaustible and available resource for the future energy supply. The solar output power is dependent on the intensity of the solar cell temperature and radiation of the solar cells. Though PV power generation system implements an efficient utilization of the solar energy, but the conversion energy of the solar cell is very low. Therefore, MPPT is employed in the PV system to make the most of the result as an output power, regardless of the power, temperature & irradiation circumstances & of load electrical characteristics.
* Ref [15] refers Control of three-phase grid-connected LCL-filtered inverters with adaptability to non-ideal grid. The voltage imbalance, distortion, and frequency volatility of the three-phase grid voltage are examples of less-than-ideal grid circumstances. Under non-ideal grid conditions, three-phase grid also contains negative, zero, and harmonic components in addition to positive sequence components. The negative sequence produced a signal that oscillated twice as fast as the grid frequency on the d-axis, which regrettably led to an error in the phase-locked loop.
* Ref [16] refers to Design, simulation & performance evaluation of three phase grid connected PV panel. Solar energy is more in demand these days thanks to recent developments in PV panels. We must connect solar energy to the grid in order to fully commercialise and use it. The design and simulation of a two-stage converter system for integrating solar panels with the grid are the topics of this research. It is made up of a PV panel, a boost dc-dc converter to increase the voltage of the PV panel, a VSI to convert dc to ac, and lastly the grid.
* Ref [17] describes LCL filter design and control for grid-connected PWM converter. To attenuate switching harmonics on grid side with an LCL filter, cost effectiveness must be considered to select filter parameters. It proposes a filter design method based on a computer simulation tool.
* Ref [18] introduces a harmonic model of LCL filter in grid-connected operation, then researched the variable relationship among LCL filter's parameter and resonance frequency and high-frequency ripple attenuation. Based on the analysis a reasonable design method was brought out in order to achieve optimal effect under the precondition of saving inductance magnetic core of LCL filter, at the same time guaranteeing the resonance frequency of LCL filter was not too small lest restrict current controller resign.
* Ref [19] refers the issue of MPPT which has been addressed in different ways in the literature but, especially for low-cost implementations, the perturb and observe (P&O) maximum power point tracking algorithm is the most commonly used method due to its ease of implementation.
* Ref [20] refers perturbation and observation (P&O) method to track the maximum power point of PV system. Based on the mathematical model of PV system, this method tracks the maximum power point by regulating the output voltage after measuring the changes of output power.
* Ref [21] describes an enhanced Maximum Power Point Tracking (MPPT) of Photovoltaic (PV) systems by means of Model Predictive Control (MPC) techniques. The PV array can feed power to the load through a DC/DC converter boosting the output voltage. Due to stochastic behavior of solar energy, MPPT control technique of PV arrays is required to operate at maximum power point. Extracting the maximum power from PV systems has been widely investigated within the literature. This discribes enhancement of the Incremental Conductance (INC) method through a fixed step predictive control under measured fast solar radiation variation. The proposed predictive control to achieve Maximum Power Point (MPP) speeds up the control loop since it predicts error before the switching signal is applied to the selected high gain multilevel DC-DC converter.
* Ref [22] deals with implementing an internal model control strategy for Maximum Power Point Tracking (MPPT) of a standalone solar Photo Voltaic (PV) system in order to enhance its efficiency.
* Ref [23] proposes modified dq control strategy that improves the dynamic response of the grid-connected inverter compared to the conventional approach. The transient time in traditional approach is 10 times slower than in the modified inverter with the same regulator parameters.
* Ref [24] presents the DQ modeling method to eliminate the switching action to achieve time-invariant model. The power system studied is the AC distribution system. The small-signal model of the power system is obtained by using a linearization technique.
* Ref [25] refers the different types of voltage source inverters. The voltage source inverters are the main component of the variable frequency drives(VFD). In the medium voltage variable speed drive market, the various techniques have progressed with constituents, design, and reliability.

**CHAPTER 3**

**MAXIMUM POWER POINT TRACKING (MPPT)**

The solar panel efficiency is indeed lower. In order to improve its effectiveness and match the source, A right approach must be used in order to load something properly, which is the MPPT method. Using this method, maximum power point tracking from a changing source can be obtained. The PV system's I-V curve is nonlinear and has trouble supplying power to the attached load. This is accomplished by using an MPPT protocol and a boost configuration converter with a variable duty cycle. To find the maximum output power from the solar panel MPPT algorithm is used.



**Fig.3.1 Maximum power point output**

The point tracked where Imp & Vmp bump into the extreme power point as shown in figure. This point demonstrates the thorough going power existing by the PV cell. As the load line crosses the very point accurately, then after the extreme power is being transmitted to the attached load.

## MPPT TECHNIQUES:

There are numerous techniques used for tracking the maximum power as follows:

* + - Constant voltage method
    - Incremental conductance method
    - Open Voltage method
    - Perturb and Observe method

## Constant Voltage Method:

The simplest MPPT control strategy is the Constant Voltage (CV) algorithm. The operating point of the PV array is kept near the MPP by regulating the array voltage and matching it to a fixed reference voltage equal to the VMPP of the characteristic PV module. The CV approach makes the assumptions that insulation and temperature fluctuations on the array are negligible and that the constant reference voltage provides a good approximation of the genuine MPP. As a result, the operational point is never exactly at the MPP, and different data must be used for various geographical areas. The CV technique doesn't require any input. However, in order to configure the duty-cycle of the dc/dc converter via PI regulator, measurement of the PV array voltage, or VPV, is required.

## Incremental Conductance Method:

The Incremental Conductance (IC) algorithm is based on the finding that the equation (*d*Ipv/*d*Vpv) +(Ipv/Vpv) =0 holds at the MPP, where IPV and VPV are the current and voltage of the PV array, respectively. (*d*Ipv/*d*Vpv) +(Ipv/Vpv) =0 when the operating point in the P-V plane is to the right of the MPP. In contrast, (*d*Ipv/*d*Vpv) +(Ipv/Vpv)>0 when the operating point is to the left of the MPP. Thus, the instantaneous conductance Ipv/Vpv and incremental conductance dIpv/dVpv can be compared to follow the MPP. As a result, the quantity's sign, (*d*Ipv/*d*Vpv)+(Ipv/Vpv), reflects the MPP's proper direction of perturbation. If dIpv does not change once MPP is reached, PV array operation is maintained at this time and perturbation is terminated. In this case, the algorithm decrements or increments the PV array voltage VPV to track a new MPP.

## Open Voltage Method:

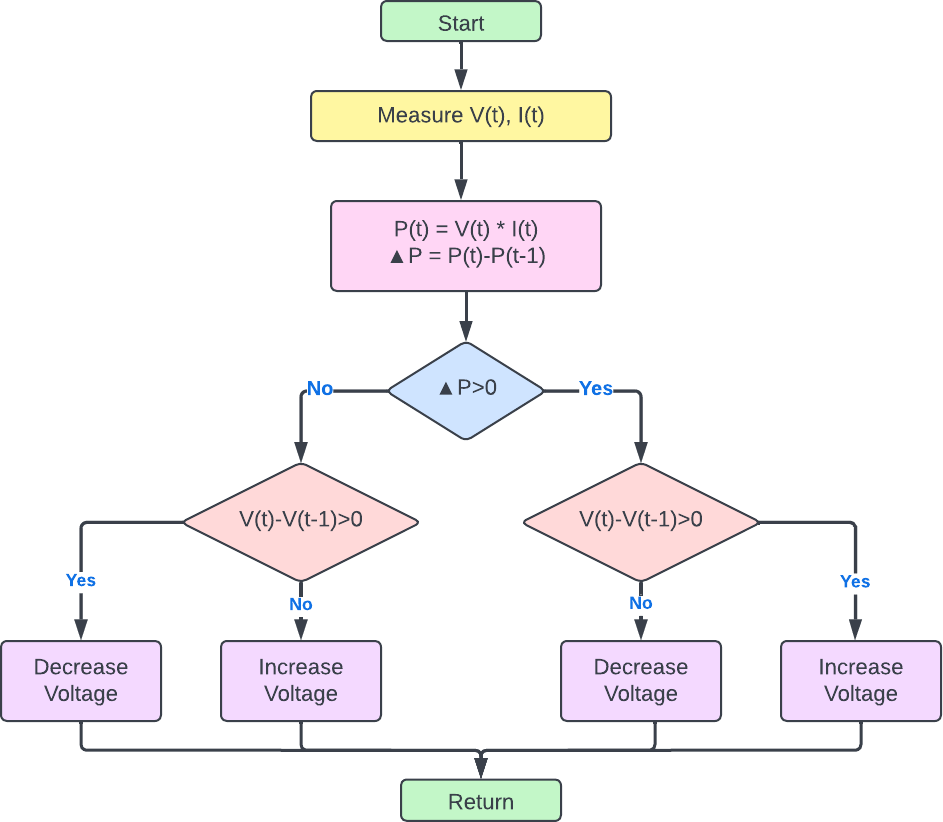
The Open Voltage (OV) method is based on the observation that the voltage of the maximum power point VMPP is always close to a fixed percentage of the open-circuit voltage Vov. Production spread, temperature, and solar insulation levels change the position of the maximum power point within a 2% tolerance band. This technique uses 76% of Vov as value of the operating voltage Vop (at which the maximum output power can be obtained), in general, this value is very close to VMPP. This control algorithm requires measurements of the voltage Vov when the circuit is opened. Here again it is necessary to introduce a static switch into the PV system; for the OV method, the switch must be connected in series to open the circuit. When IPV=0 no power is supplied by the PV system and consequently no energy is generated. Also, in this method measurement of the PV array voltage VPV is required for the PI regulator.

## Perturb and Observe Method:

The P&O algorithms operates periodically by 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 (*d*P/*d*VPV>0), the control system moves the PV array operating point 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. A common problem in P&O algorithms is that the array terminal voltage is perturbed in every MPPT cycle; therefore, when the MPP is reached, the output power oscillates around the maximum, resulting in power loss in the PV system.

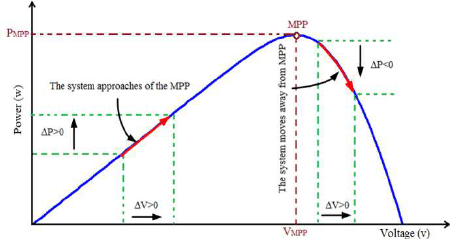
This is especially true in constant or slowly-varying atmospheric conditions but also under rapidly changing atmospheric conditions. In the classic P&O technique (P&Oa), the perturbations of the PV operating point have a fixed magnitude. In the optimized P&O technique (P&Ob), an average of several samples of the array power is used to dynamically adjust the magnitude of the perturbation of the PV operating point. In the three-point weight comparison method (P&Oc), the perturbation direction is decided by comparing the PV output power on three points of the P-V curve.

These three points are the current operation point A, a point B perturbed from point A, and a point C doubly perturbed in the opposite direction from point B. All the three algorithms require the measurement of the PV array voltage VPV and of the PV array current IPV.



**Fig.3.2 Perturb and Observe MPPT algorithm flowchart**

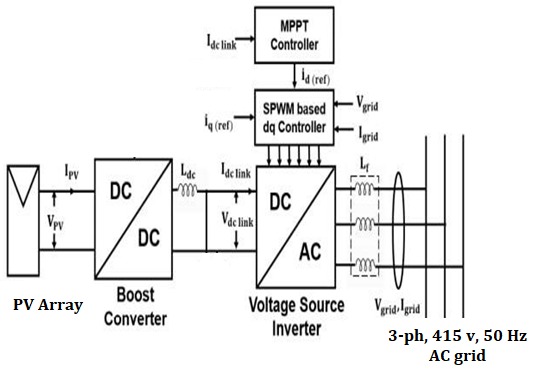
The small increment ΔV is in the PV system of the operating system is perturbed, which results change in ΔP. If the ΔP will be positive, the same directional operating voltage needs to be perturbed for the increment. On the other hand, as the ΔP will be negative, the obtained operating point system should move left to a MPP and said direction of functioning voltages essentially be opposite to the direction of increment.



**Fig.3.3 PV characteristics for P&O method**

# CHAPTER 4 METHODLOGY

MPPT is an algorithm implemented to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load. From the MPPT method, the maximum output power of the solar panel can be found. Perturb and Observe MPPT algorithm is used to extract maximum power from the PV array. Boost converter is used to step-up the voltage of solar panel. To convert DC to AC inverter should be used. Inverter is designed based on dq control. The dq control, is the reference frame transformation module for transforming the current and voltage parameters of the utility grid to a reference frame rotating synchronously. The dq Method is a promising numerical technique that produces accurate solutions with less computational effort.

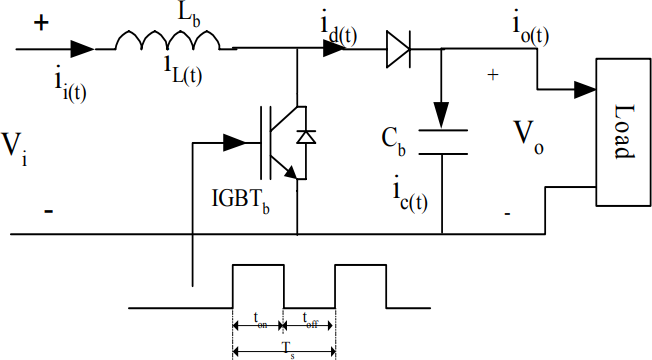


**Fig.4 .1 Block diagram of the grid connected PV panel with a dq controlled inverter**

## BOOST CONVERTER:

* + 1. **Operating Principle:**

The operation of the boost converter is based on the principle of storing energy in an inductor. The voltage drop across an inductor is proportional to the change in the electric current flowing through the device. The circuit arrangement operates in such a way that it helps in maintaining a regulated and increased dc output at the load. circuit diagram for a typical boost converter is shown in the figure below.



**Fig.4.2 Boost Converter Circuit**

In this circuit, the solid-state device such as power IGBT which operates as a switch is connected across the source. A diode is used as a second switch. The diode is connected to the capacitor and the load. The capacitor and load are connected in parallel as shown in the above circuit diagram. The inductor is connected in series with the supply voltage source which leads to a constant input current. So, the boost converter acts as a constant current input source and loads act as a constant voltage source.

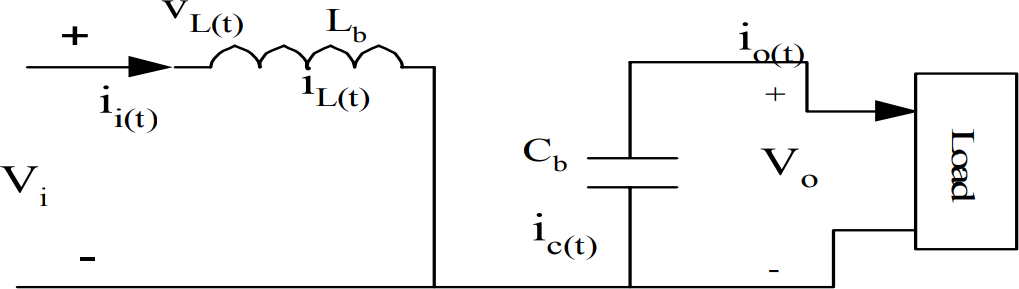
The controlled switch S is turned on and off by using PWM (Pulse Width Modulation). PWM can be time-based or frequency based. Time-based Modulation is mostly used for Boost Converter because it is simple to construct and use. The frequency remains constant in this type of PWM modulation.

There are two modes of operation of the Boost converter. They are:

* + - 1. Mode I: Switch is ON and Diode is OFF
      2. Mode II: Switch is OFF and Diode is ON

## Mode I: Switch is ON and Diode is OFF:

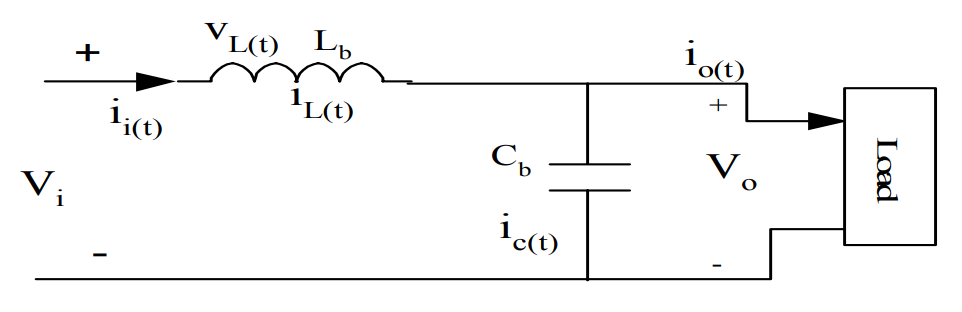
In this mode of operation, switch is in closed condition i.e., ON state, and diode is in open condition i.e., OFF state. Thus, switch allows the flow of current through it. All the current will flow through the closed path including inductor, switch, and back to the dc input source. The circuit diagram for this mode is shown in the figure below.



**Fig.4.3 Switch is ON and Diode is OFF**

Here, the polarity of the inductor will be according to the direction of the flow of current. In this mode of operation, the diode D is in reverse biased condition so that diode does not allow the flow of current through it to the circuit. In this condition, the voltage across the switch S will appear across the load resistance and hence output voltage.

## Mode II: Switch is OFF and Diode is ON:

In this mode of operation, switch is in open condition i.e., OFF state and diode is in closed condition i.e., ON state. Thus, switch diode allows the flow of current through it, whereas switching blocks the current flow through it. The circuit diagram for this mode is shown in the figure below.

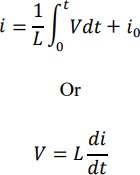
*Fig. Switch is OFF and Diode is ON*

**Fig.4.4 Switch is OFF and Diode is ON**

The inductor in the circuit store energy in the form of the magnetic field, the inductor acting as the source when the switch S is open. Hence diode becomes closed. In this mode of operation, the inductor releases the energy stored in the previous mode when switch was closed. During releasing of energy stored in the inductor, the polarity of the inductor gets reversed which causes the diode to come in forward biased condition. So, it allows the flow of current in the circuit through diode. The way of current flow is shown in the above figure.

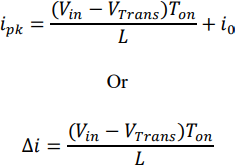
The released energy is ultimately dissipated in the load resistance which helps to maintain the flow of current in the same direction through the load and also steps up the output voltage. The current through the inductor is of decreasing nature and will die out after the point in time.

The voltage-current relation for the inductor L is:

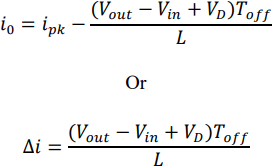


For a constant rectangular pulse:

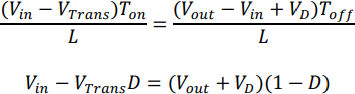
When the transistor M1 is switched:



And when the transistor is switched off the current is:



Here VD is the voltage drop across the diode Dm, and *V*trans is the voltage drop across the transistor M1. By equating through delta i, we can solve for Vout:





Neglecting the voltage drops across the diode and the transistor:



So, the output voltage is related directly to the duty cycle. The main challenge when designing a converter is the sort of inductor to be used. From above equations, the inductance is inversely proportional to the ripple current. So, to reduce the ripple, a larger inductor should be used.

## Component Calculations:

* **Load Resistance: **

## Duty Cycle:



* **Capacitor:**

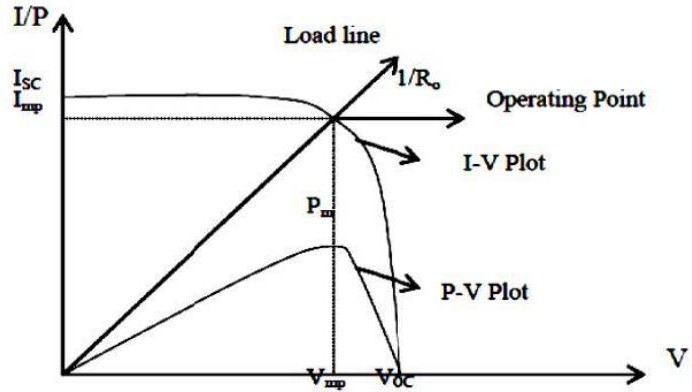


* **Inductor:**



**4.2 MPPT:**

The solar panel efficiency is indeed lower. In order to improve its effectiveness and match the source, A right approach must be used in order to load something properly, which is the MPPT method. Using this method, maximum power point tracking from a changing source can be obtained. The PV system's I-V curve is nonlinear and has trouble supplying power to the attached load. This is accomplished by using an MPPT protocol and a boost configuration converter with a variable duty cycle. To find the maximum output power from the solar panel MPPT algorithm is used.



**Fig.3.1 Maximum power point output**

The point tracked where Imp & Vmp bump into the extreme power point as shown in figure. This point demonstrates the thorough going power existing by the PV cell. As the load line crosses the very point accurately, then after the extreme power is being transmitted to the attached load.

**4.3 INVERTER:**

An inverter is a device of power electronics used to convert fixed DC into regulated AC. An inverter is a static device. During a power outage, the inverter converts DC electricity from the batteries into AC power. IGBT, MOSFET, and GTO power semiconductor switching devices, which have the ability to self-commutate are used in inverters. Low DC voltage cannot be utilized in a household appliance in specific conditions, such as when the DC voltage is low. Therefore, whenever a solar power panel is used, an inverter can be used.

**4.2.1 Types of Inverters:**

* **Single-phase Inverters:**

**Single phase inverters** are classified into two types namely half-bridge inverter and full bridge inverter.

* **Half-bridge Inverter:**

An essential part of the full bridge inverter is the half-bridge inverter. It can be constructed with two switches and two capacitors, each of which has an output voltage equal to Vdc2. Additionally, the switches balance one another; if one switch is turned on, another one turns off automatically.

* **Full-bridge inverter:**

Direct current to alternating current is converted via a complete bridge inverter circuit. By flipping the appropriate switches open and shut in the proper series, it can be accomplished. Different working states for this kind of inverter depend on closed switches.

* **Three Phase Inverter:**

An input DC is converted to a 3-phase output AC using a three-phase inverter. Its three arms are typically deflected at an angle of 120 degrees to create a three-phase AC supply. The 50% of the ratio inverter control as well as controlling can occur after every T/6 of the time T. The switches that are employed in the inverter work best together.

* 1. **Direct Quadrature Control:**

In comparison to the standard approach, ref [15] provides a modified dq control strategy that improves the dynamic response of the grid-connected inverter. The concept is discussed and validated using simulation results. dq-control is another name for synchronized reference frame management. It converts grid voltage and current into a frame that rotates synchronously with the grid voltage vector by Park Transformation so that three-phase time-varying signals are converted into DC signals.

A voltage vector can be divided into a positive-sequence component revolving counterclockwise and a negative-sequence component rotating clockwise using the symmetrical component theory. (zero-sequence is ignored). Negative sequence components will be registered as AC signals oscillating at twice the fundamental frequency if a set of unbalanced signals is transformed into a positive sequence reference frame, and vice versa if a positive sequence reference frame is created from negative sequence components. Due to this coupling between the two synchronous reference frames, PI controllers are unable to function well when the system is unbalanced. This transformation is achieved by use of the Clarke and Park transformation methods, which convert the abc to αβ and αβ to dq. This transformation produces DC components of the measured parameters, which are easily processed through filtering and control procedures. The output creates control instructions for the active current that controls active power and, upon request, enables the reactive power coefficient to be set to zero. The reactive power reference Q should be imposed on the controller architecture if reactive power control is also desired for this system. The dq control structure is made up of PI controllers, due to their satisfactory reaction for regulating the DC parameters. The transfer function of a PI-based controller in dq coordinates is presented.

# CHAPTER 5 IMPLEMENTATION

## DESCRIPTION OF COMPONENTS:

* + 1. **Simulink:**

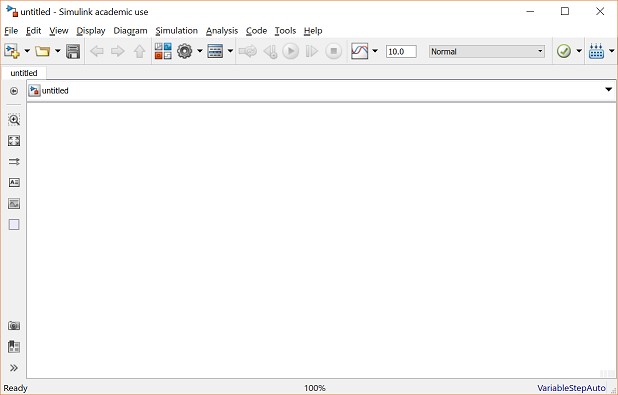
Simulink is a simulation and model-based design environment for dynamic and embedded systems, integrated with MATLAB. Simulink, also developed by MathWorks, is a data flow graphical programming language tool for modelling, simulating, and analysing multi- domain dynamic systems. It is basically a graphical block diagramming tool with customizable set of block libraries.

It allows user to incorporate MATLAB algorithms into models as well as export the simulation results into MATLAB for further analysis.

Simulink supports −

* + - * System-level design
      * Simulation
      * Automatic code generation
      * Testing and verification of embedded systems

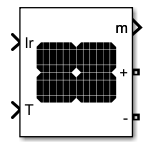
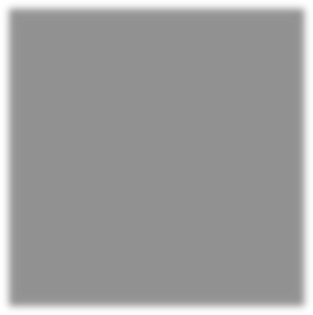
There are several other add-on products provided by MathWorks and third-party hardware and software products that are available for use with Simulink. Simulink is capable of systematic verification and validation of models through modelling style checking, requirements traceability and model coverage analysis. Simulink Design Verifier allows user to identify design errors and to generate test case scenarios for model checking.



**Fig.5.1 Simulink window**

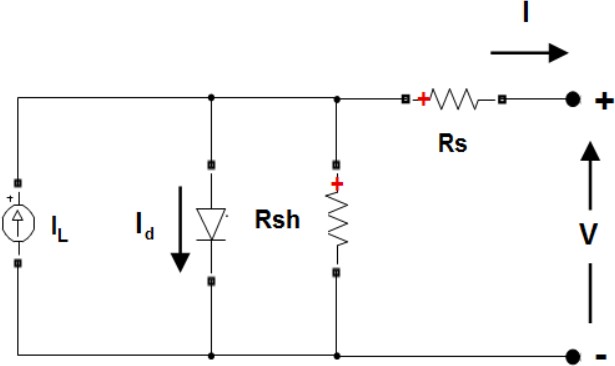
## PV Array block:

The PV Array block implements an array of photovoltaic PV modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series.

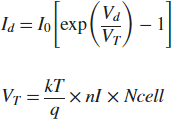


**Fig.5.2 PV Array**

The PV Array block is a five-parameter model using a light-generated current source (IL), diode, series resistance (Rs), and shunt resistance (Rsh) to represent the irradiance- and temperature-dependent I-V characteristics of the modules.



**Fig.5.3 PV Array Circuit**

The diode I-V characteristics for a single module are defined by the equations

## Input:

* **Ir** - Control signal defining that irradiance applied to solar panels, specified as a scalar in the range [0, 1000], in W/m2.
* **T -** Control signal defining temperature of cells, specified as a scalar, in degrees Celsius. The input can be a finite negative, zero, or positive value.

## Output:

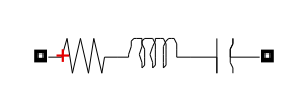
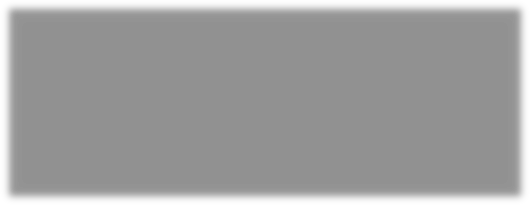
* **m** - Measurements, returned as a five-element vector.

|  |  |  |
| --- | --- | --- |
| **S.No.** | **Parameter** | **Value** |
| 1 | Parallel Strings | 47 |
| 2 | Series-connected modules per string | 10 |
| 3 | Open circuit Voltage | 36.3 |
| 4 | Short circuit Current | 7.84 |

**Table.1. Parameter Values given to PV Array**

## RLC Branch:

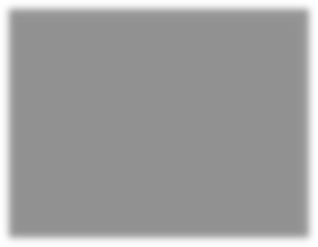
The Series RLC Branch block implements a single resistor, inductor, or capacitor, or a series combination of these. Branch type parameter can be used to select elements you want to include in the branch. Negative values are allowed for resistance, inductance, and capacitance.



**Fig.5.4 RLC Branch**

## IGBT:

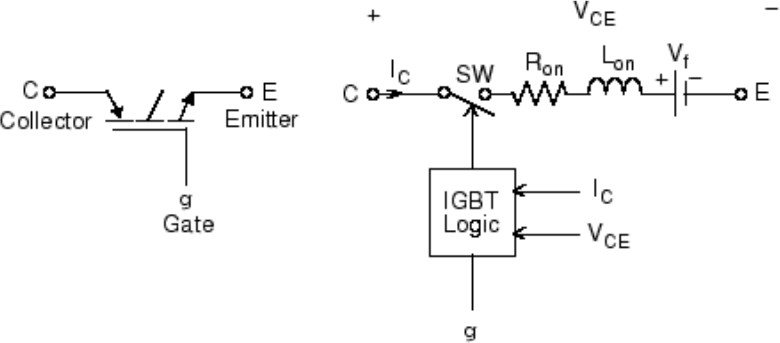
IGBT means Implement insulated gate bipolar transistor.



**Fig.5.5 IGBT**

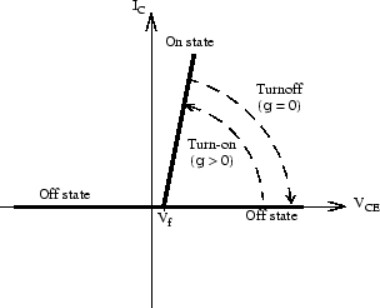
The IGBT block implements a semiconductor device controllable by the gate signal.

The IGBT is simulated as a series combination of a resistor Ron, inductor Lon, and a DC voltage source Vf in series with a switch controlled by a logical signal (g > 0 or g = 0).



**Fig.5.6 IGBT Circuit**

The IGBT block contains a series Rs-Cs snubber circuit, which is connected in parallel with the IGBT



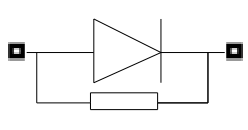
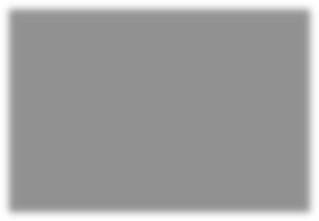
**Fig.5.7 On & Off states representation of IGBT**

The IGBT turns on when the collector-emitter voltage is positive and greater than Vf and a positive signal is applied at the gate input (g > 0). It turns off when the collector-emitter voltage is positive and a 0 signal is applied at the gate input (g = 0).

## Diode:

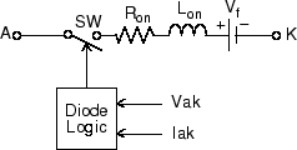
The diode is a semiconductor device that is controlled by its own voltage Vak and current Iak. When a diode is forward biased (Vak > 0), it starts to conduct with a small forward voltage

Vf across it. It turns off when the current flow into the device becomes 0. When the diode is reverse biased (Vak < 0), it stays in the off state.



**Fig.5.8 Diode**

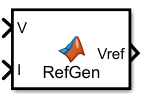
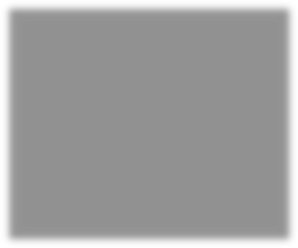
The Diode block is simulated by a resistor, an inductor, and a DC voltage source connected in series with a switch. The switch operation is controlled by the voltage Vak and the current Iak.



**Fig.5.9 Diode Circuit**

## MATLAB Function:

MATLAB Function blocks enable you to define custom functions in Simulink models by using the MATLAB language. MATLAB Function blocks support C/C++ code generation from Simulink Coder and Embedded Coder.



**Fig.5.10 MATLAB Function**

## Code:

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

Vrefmin = 0;

Vrefinit = 300;

deltaVref = 1;

persistent Vold Pold Vrefold; dataType = 'double';

if isempty(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;

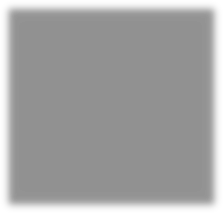
end

Vrefold = Vref; Vold = V;

Pold = P;

## PI Controller:

The PID Controller block implemented as PI controller. The block is identical to the [Discrete PID Controller](https://www.mathworks.com/help/simulink/slref/discretepidcontroller.html) block with the Time domain parameter set to Continuous-time.

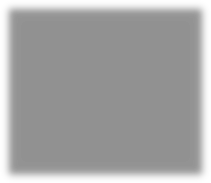


**Fig.5.11 PI Controller**

The block output is a weighted sum of the input signal, the integral of the input signal, and the derivative of the input signal. The weights are the proportional, integral, and derivative gain The Repeating Sequence block outputs a periodic scalar signal having a waveform that you specify using the Time values and Output values parameters. The Time values parameter specifies a vector of output times. The Output values parameter specifies a vector of signal amplitudes at the corresponding output times. Together, the two parameters specify a sampling of the output waveform at points measured from the beginning of the interval over which the waveform repeats (the period of the signal) types and structures. The controller used in the Simulink model is PI Controller in Continuous- Time domain.

## Sum:

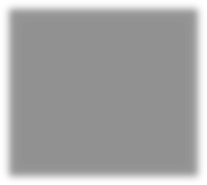
The Sum block performs addition or subtraction on its inputs. The Add, Subtract, Sum of Elements, and Sum blocks are identical blocks. This block can add or subtract scalar, vector, or matrix inputs. It can also collapse the elements of a signal and perform a summation. The Sum block first converts the input data type to its accumulator data type, then performs the specified operations.



**Fig.5.12 Sum**

## Repeating Sequence:

The Repeating Sequence block outputs a periodic scalar signal having a waveform that user specifies using the Time values and Output values parameters. The Time values parameter specifies a vector of output times.

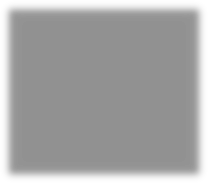


**Fig.5.13 Repeating Sequence**

The Output values parameter specifies a vector of signal amplitudes at the corresponding output times. Together, the two parameters specify a sampling of the output waveform at points measured from the beginning of the interval over which the waveform repeats. Time Values given for the model is [0 0.0002].

## Relational Operator:

The Relational Operator block performs the specified relational operation on the input. The value user chooses for the Relational operator parameter determines whether the block accepts one or two input signals.



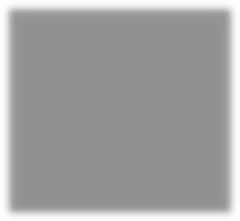
**Fig.5.14 Relational Operator**

|  |  |
| --- | --- |
| **Operation** | **Description** |
| == | True if the first input is equal to the second input |
| ~= | True if the first input is not equal to the second input |
| < | True if the first input is less than the second input |
| <= | True if the first input is less than or equal to the second input |
| >= | True if the first input is greater than or equal to the second input |
| > | True if the first input is greater than the second input |

**Table.2. Different Relational Operators**

## Unit Delay:

The Unit Delay block holds and delays its input by the sample period you specify. When placed in an iterator subsystem, it holds and delays its input by one iteration. This block is equivalent to the z-1 discrete-time operator. The block accepts one input and generates one output. Each signal can be scalar or vector. If the input is a vector, the block holds and delays all elements of the vector by the same sample period. A setting of -1 means the block inherits the Sample time.

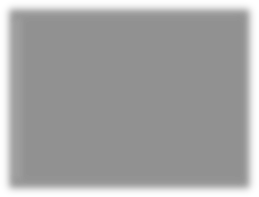


**Fig.5.15 Unit Delay**

## Goto:

The Goto block passes its input to its corresponding From blocks. The input can be a real- or complex-valued signal or vector of any data type. From and Goto blocks allow you to pass a signal from one block to another without connecting them.

A Goto block can pass its input signal to more than one From block, although a From block can receive a signal from only one Goto block. The input to that Goto block is passed to the From blocks associated with it as though the blocks were physically connected.



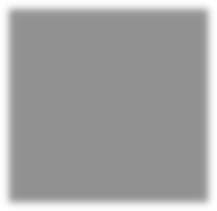
**Fig.5.16 Goto**

The tags used in the simulation model are:

* + - * **VPV:** Output Voltage of PV panel
      * **IPV:** Output Current of PV Panel
      * **PWM:** Pulse width Modulation given to IGBT for Switching purpose

## From:

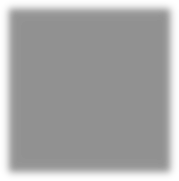
The From block accepts a signal from a corresponding Goto block, then passes it as output. The data type of the output is the same as that of the input from the Goto block. From and Goto blocks allow user to pass a signal from one block to another without connecting them. To associate a Goto block with a From block, enter the Goto block tag in the Goto Tag parameter.



**Fig.5.17 From**

## Bus Selector:

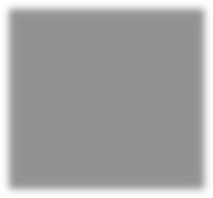
The Bus Selector block outputs the elements you select from the input bus. The block can output the selected elements separately or in a new virtual bus.



**Fig.5.18 Bus Selector**

## Scope:

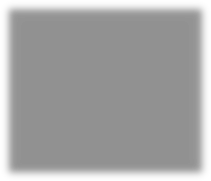
The Simulink Scope block displays the Time domain signals. The Scope allows you to adjust the amount of time and the range of input values displayed.



**Fig.5.19 Scope**

## Voltage Measurement:

The Voltage Measurement block measures the instantaneous voltage between two electric nodes. The output provides a Simulink signal that can be used by other Simulink blocks.

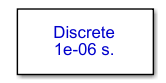
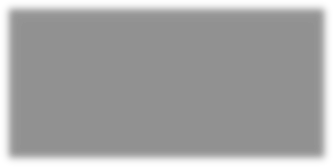


**Fig.5.20 Voltage Measurement**

## Powergui:

The powergui block allows you to choose one of these methods to solve your circuit:

* + - * Continuous, which uses a variable-step solver from Simulink
      * Discretization of the electrical system for a solution at fixed time steps
      * Continuous or discrete phasor solution



**Fig.5.21 Powergui**

The powergui block also opens tools for steady-state and simulation results analysis and for advanced parameter design. You need the powergui block to simulate any Simulink model containing Simscape Electrical Specialized Power Systems blocks. It stores the equivalent Simulink circuit that represents the state-space equations of the model.

## Three Phase Source:

## The Three-Phase Source block implements a balanced three-phase voltage source with an internal R-L impedance. The block connects the three voltage sources in Y with a neutral connection that you can internally ground or make it accessible.

## Three-Phase Source block

**Fig.5.22 Three Phase Source**

## Three Phase V-I Measurement:

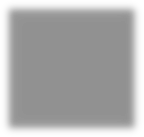
## The Three-Phase V-I Measurement block is used to measure instantaneous three-phase voltages and currents in a circuit. When connected in series with three-phase elements, it returns the three phase-to-ground or phase-to-phase peak voltages and currents.

## Three-Phase V-I Measurement block

**Fig.5.23 Three Phase V-I Measurement**

## Product Block:

The Product block outputs the result of multiplying two inputs: two scalars, a scalar and a non-scalar, or two nonscalars that have the same dimensions.



**Fig.5.24 Product Block**

## abc to Alpha-Beta-Zero:

## The abc to Alpha-Beta-Zero block performs a Clarke transform on a three-phase abc signal.

## abc to Alpha-Beta-Zero, Alpha-Beta-Zero to abc block

**Fig.5.25 abc to Alpha-Beta-Zero Block**

## Alpha-Beta-Zero to dq0:

## The Alpha-Beta-Zero to dq0 block performs a transformation of αβ0 Clarke components in a fixed reference frame to dq0 Park components in a rotating reference frame.

## Alpha-Beta-Zero to dq0, dq0 to Alpha-Beta-Zero block

**Fig.5.26 Alpha-Beta-Zero to dq0 Block**

## dq0 to abc:

## The dq0 to abc block uses an inverse Park transformation to transform a dq0 rotating reference frame to a three-phase (abc) signal. The angular position of the rotating frame is given by the input wt, in rad.

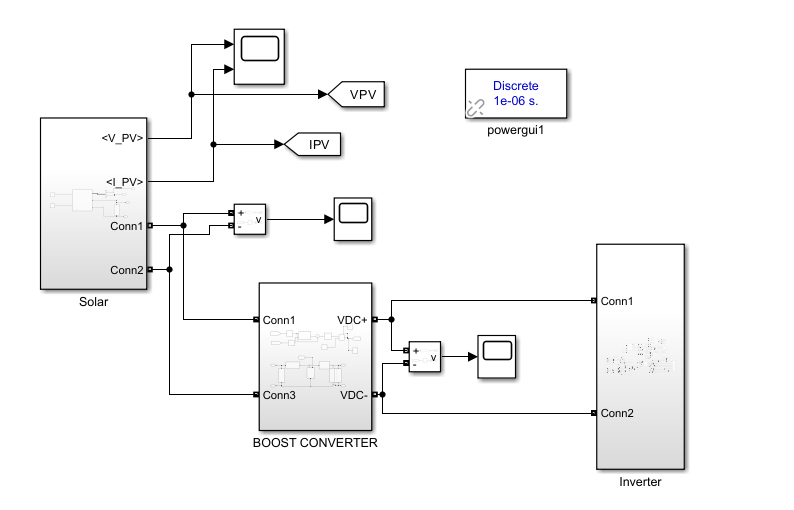
## 

**Fig.5.27 dq0 to abc Block**

## 

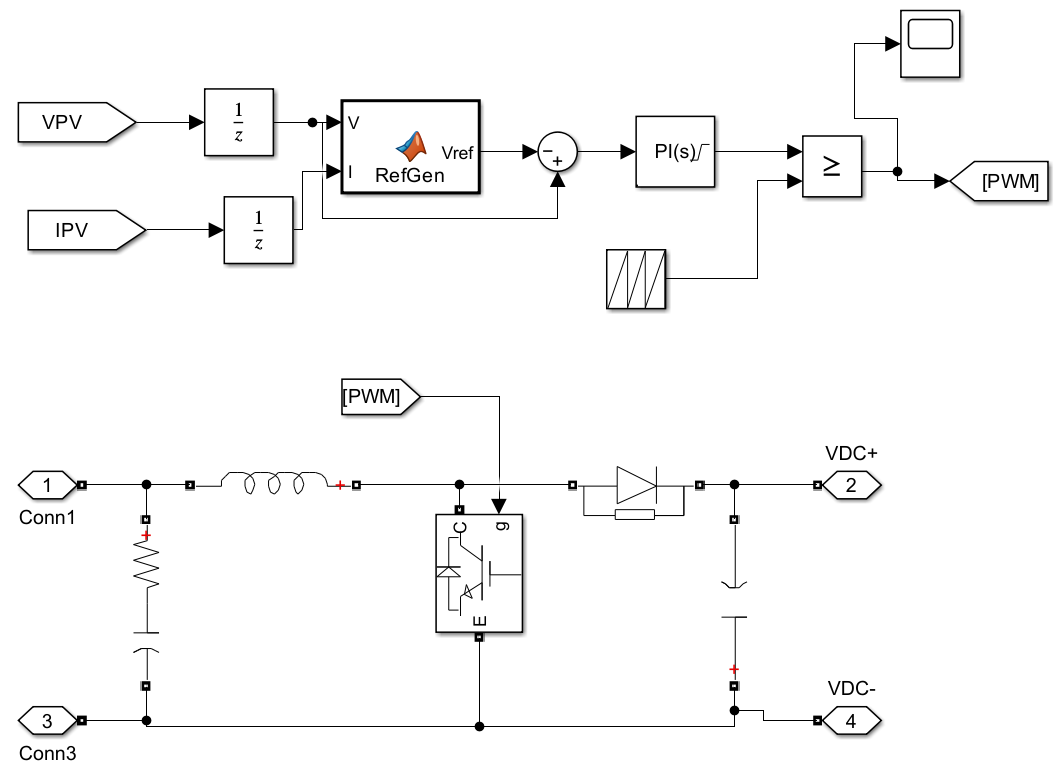
## 

## MATLAB/SIMULINK MODEL:



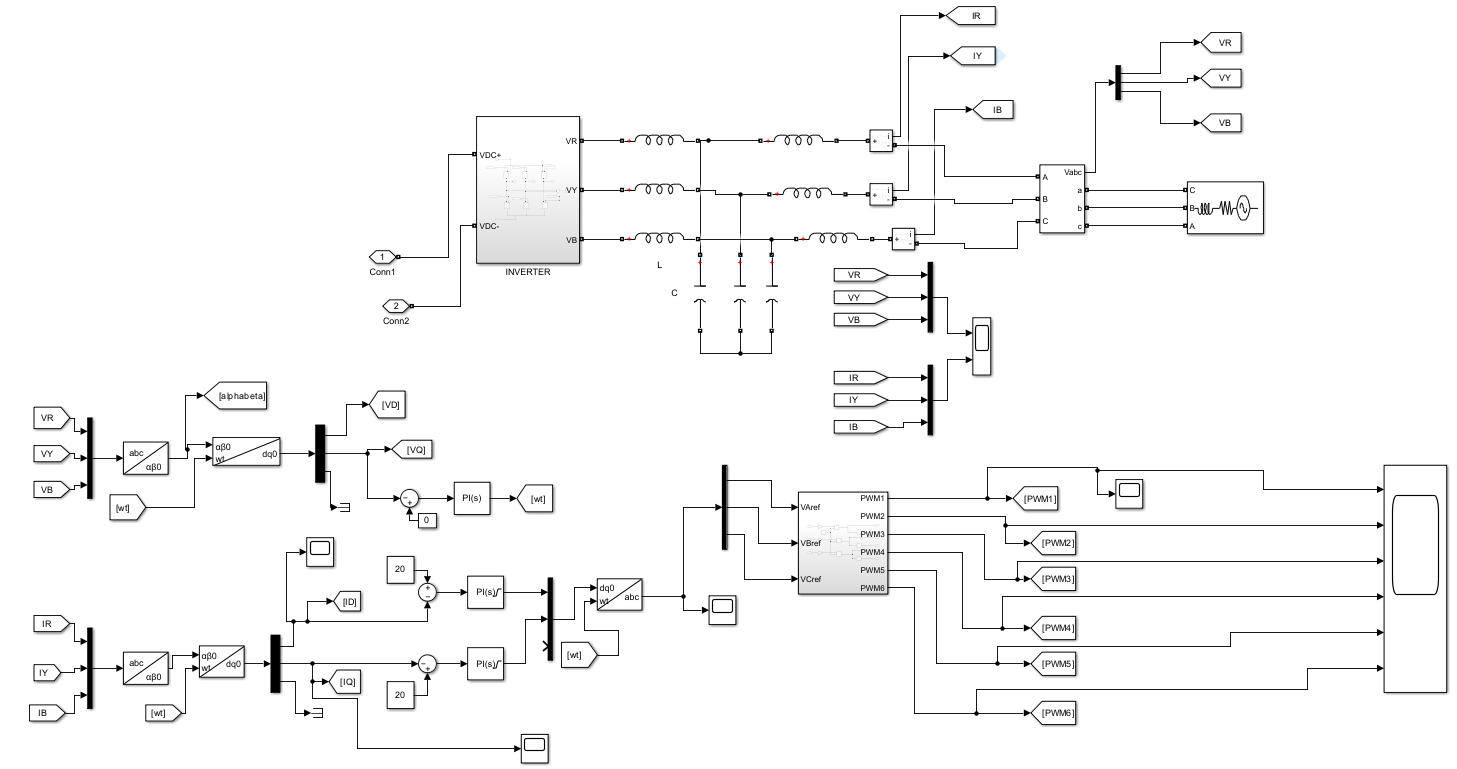
**Fig.5.28 Design and development of grid connected PV panel with a dq controlled inverter**

**5.2.1 BOOST CONVERTER MODEL:**



**Fig.5.29 Design and development of Boost converter**

**5.2.2 dq CONTROLLED INVERETR:**

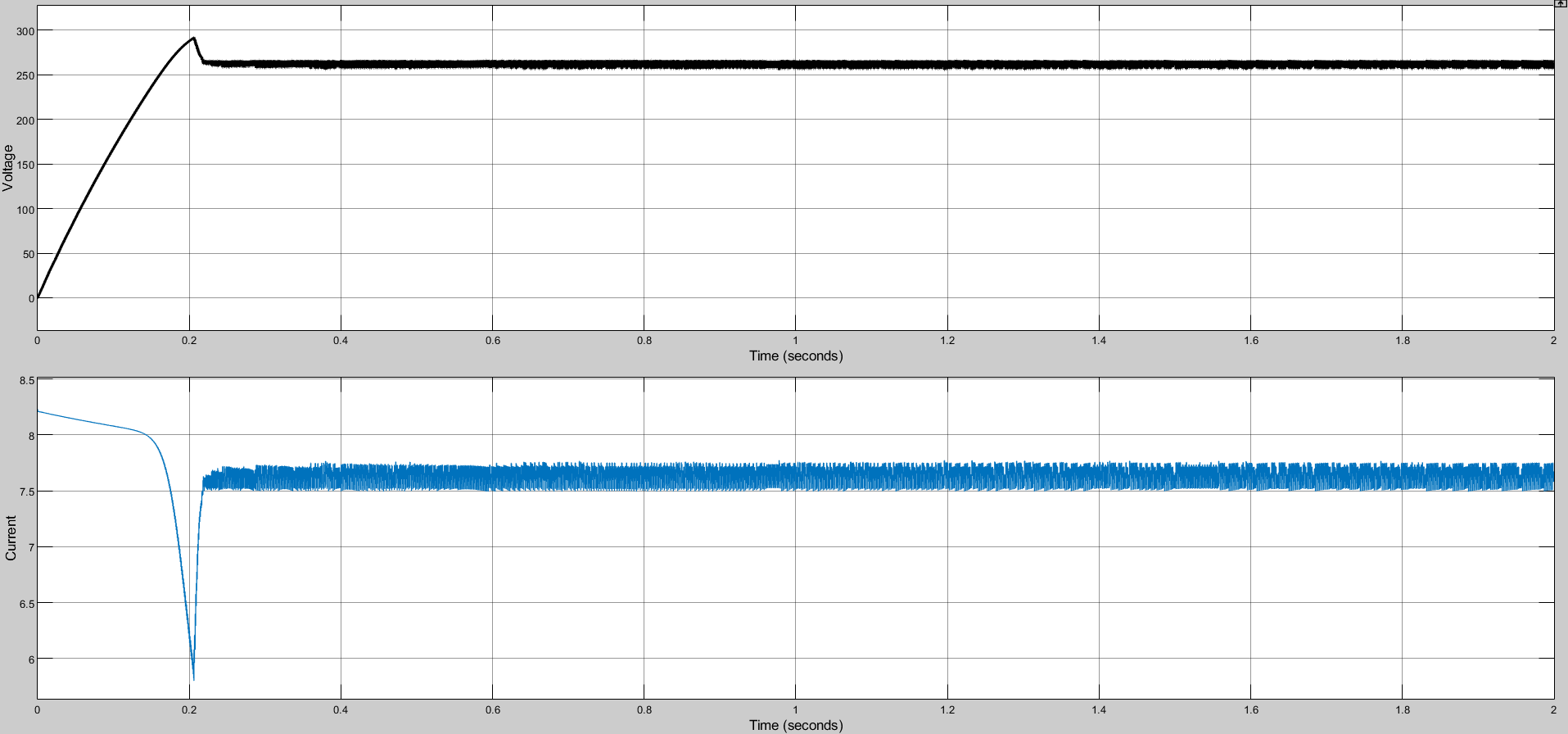


**Fig.5.30 Design and development of dq controlled inverter**

**CHAPTER 6 RESULT**

## SOLAR PANEL OUTPUT VOLTAGE AND CURRENT:

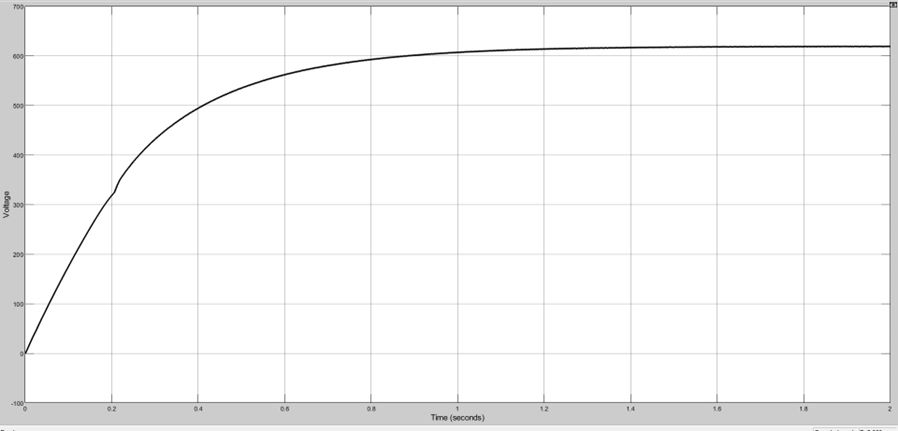
The first graph is the output voltage of the solar panel. The second graph is the output current of the solar panel. The input given to the solar panel is 1000 irradiance at 25 degree C temperature.



**Fig.6.1 Solar panel output of voltage and current.**

## BOOST CONVERTER OUTPUT VOLTAGE:

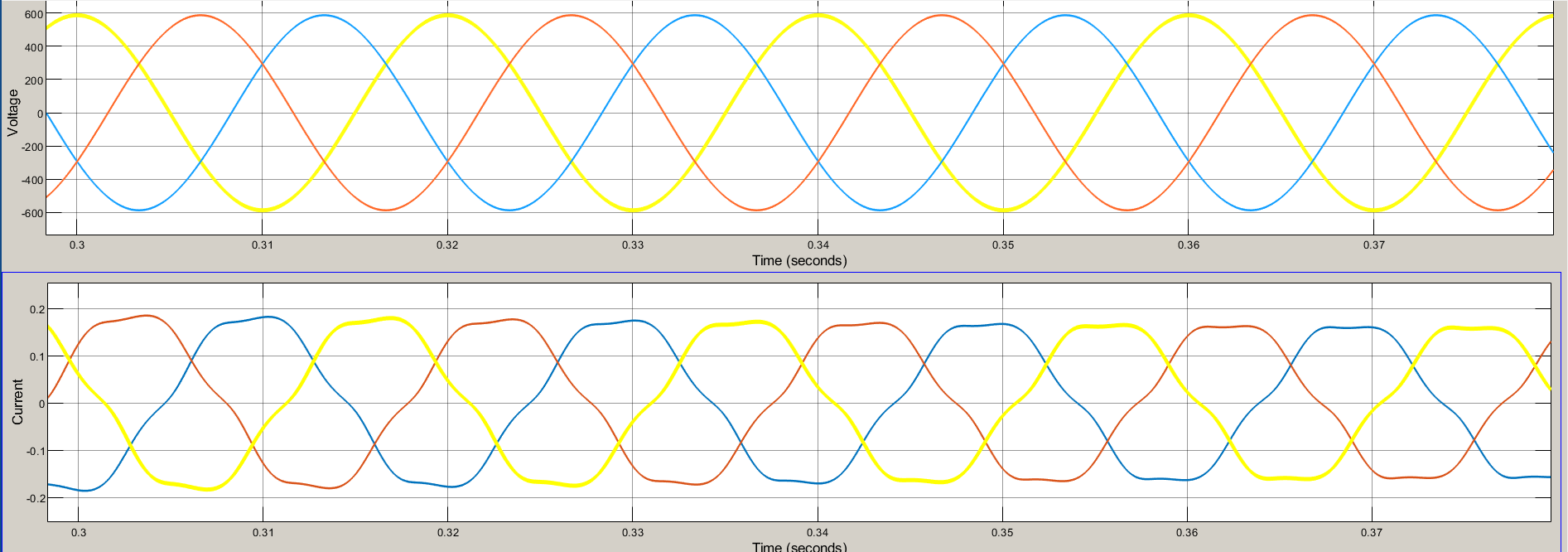
This is the output of the boost converter here the output voltage of the solar is step up to higher value. The graph showing the higher value of the voltage.



**Fig.6.2 Boost converter output voltage**

## dq CONTROLLED INVERTER OUTPUT:

## This is the output of the dq controlled inverter the current and voltage are shown accordingly.

****

**Fig.6.3 dq controlled Inverter Output**

# CHAPTER 7 CONCLUSION

This study presents a three-phase grid-connected inverter using the dq approach. For high-fidelity simulation, key components like PV panels, a boost converter, an inverter, and the utility grid are physically modelled in this model. The maximum output of the power is extracted. Boost converter is used to step up the voltage. Solar panels produce DC power. This DC should be converted to AC before injecting it to the grid. Inverter converts DC into AC. dq method is used in inverter. To improve the dynamic response of the grid connected inverter the dq control method is used.

# CHAPTER 8 FUTURE SCOPE

* Instead of dq method robust method can be used.
* The Robust method is more advanced and optimized compared to dq method. In order to improve the robust stability of the grid-connected inverter of photovoltaic power generation while connected to a weak power-grid, the robust model of grid-connected inverter under weak power-grid is used, and the influence mechanism of power-grid impedance and voltage distortion on the stability and current quality of grid-connected inverter is analyzed. On this basis, an adaptive robust H∞ control method is proposed, in which there is no need to online measure the power-grid impedance, and the control parameters do not change with the change of the power-grid impedance. Then, the calculation method of each reference quantity and the design method of control parameters are introduced.

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