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**REACTIVE POWER COMPENSATION IN SOLAR PV SYSTEM
WITH POWER QUALITY ANALYSIS**

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MASTER OF TECHNOLOGY

IN

POWER SYSTEM

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DECLARATION

I hereby certify that the work which is presented in the Major Project – II entitled “Reactive Power Compensation In Solar PV System with Power Quality Analysis” in fulfillment of the requirement for the award of the Degree of Master of Technology in Power System and submitted to the Department of Electrical Engineering, Delhi Technological University, Delhi is an authentic record of my own, carried out during a period from January to September 2020, under the supervision of Dr. M. Rizwan.

The matter presented in this report has not been submitted by me for the award for any other degree of this or any other Institute/University.



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Place: Delhi

Date: Nov 02, 2020



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ABSTRACT

Electricity is a basic need in all developing and developed countries, all kinds of industries, agriculture, commercial buildings, households etc. required electricity to function effectively and efficiently, thus electric energy is important to every country for its development and country growth. The major sources of energy are based on fossil fuels but they are limited, so nowadays we are moving towards renewable energy sources like solar, wind, tidal, biogas, hydro etc. Thermal power plants are widely used in mostly parts of the country, basically thermal power plant based on coal, however, due to limited availability of fossil fuel and emission of greenhouse gases makes it necessary to regulate the use of fossil fuels and develop the renewable energy sources which are sustainable and environment friendly. Renewable energy sources like hydro, wind and solar have become standard for electrical energy sources these days, nowadays there are loads of experimentation work happening in the field of renewable energy to further improve their productivity and efficiency. In the present years in all over the world power is generated through the photovoltaic system have grown rapidly. The grid connected PV solar systems have become popular across the globe and have great scope to cater major portion of electrical energy demand in future. Grid connected PV solar farm has the capability to transfer the solar energy to the grid and further improve the power quality of the system at the point of common coupling.

The equivalent electrical model of the PV cell is studied to understand the PV characteristics and its dependence on solar irradiation and the temperature. Design and development of a boost converter for MPPT in the PV system are discussed and modelled. Model of “grid connected photovoltaic solar system” using boost converter is developed and simulation results are presented and discussed for dynamic solar irradiation, temperature and load conditions.

This dissertation work “reactive power compensation in solar PV system with power quality analysis”, focuses on the electrical modelling of PV cell, conventional MPPT technique “perturb and observe” and reference current generated for the hysteresis current control using conventional SRFT and unit template current control techniques are studied. The simulated results of SRFT and unit template current control techniques are compared with different environmental and load conditions taking into account.

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LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
HCC	Hysteresis Current Controller
IGBT	Insulated Gate Bipolar Transistor
INC	Incremental Conductance
MPPT	Maximum power point tracking
PCC	Point of Common Coupling
PV	Photovoltaic
P&O	Perturb and Observe
SRFT	Synchronous Reference Frame Theory
THD	Total Harmonic Distortions
VSI	Voltage Source Inverter

LIST OF SYMBOLS

a	Diode Ideality Factor
C_{dc}	DC-link Capacitor
D	Duty Cycle
e	Prediction Error
f_{sw}	Switching Frequency
I_L	Load current
I_s	Sensed grid current
I_s^*	Reference grid current
k	Boltzmann's Constant
L_b	Boost Inductor
L_{lr}	Interfacing Inductor
L_s	Source Inductor
Q	Charge
R_s	Series Resistance
R_{sh}	Shunt Resistance
V_{dc}	DC-link Voltage
V_s	AC grid voltage
V_t	Voltage Template

CHAPTER 1

INTRODUCTION

1.1: General

Electricity is a basic need for everyone in their professional as well as in non-professional work. In all kinds of commercial buildings, industries, agriculture, households, hospitals, etc. electricity is essential, thus reliable and continuous electricity supply is important to every country for its development and growth. Nowadays we are mostly dependent on electronics and electrical equipment. Increasing in population, industries, and urbanisation demand for electricity in the world is increasing rapidly.

In the world several sources of electrical energy are available such as hydroelectric plant, wind power plant, nuclear power plant, solar power plant, thermal power plant, etc. mostly fossil fuel-based power plant is being used, and thermal power plant based on the fossil fuel using coal as a major source of electrical energy for the whole world till now. However, fossil fuel is limited and continuous combustion of these fuels does harmful effects on the environment and human life. It is therefore essential to regulate the use of fossil fuel and develop environment friendly and sustainable sources to generate electricity.

1.2: Renewable Energy

There are several renewable energy sources available worldwide like solar energy, wind energy, hydro energy, tidal energy, geothermal energy, etc. Sun is an infinite source of energy that makes it everlasting to be used for energy demands, reduction in electricity consumption rates, diverse applications and low maintenance cost. Nowadays most of the solar-based projects use photovoltaic systems to extract solar energy. This photovoltaic (PV) is a semiconductor device based on the principle, when solar irradiation hits the surface the ionisation process starts due to which solar energy is converted into electrical energy. There is a lot of research and development in the field of photovoltaic has done and still an ongoing process to reduce their size, cost, and improvisation of conversion efficiency of the PV. The continuous increasing in the efficiency and reduction in the cost of the PV are being used in many aspects for the conversion of solar energy into electrical energy like satellite, space-craft, solar pump for heating water, supplying the load demand, etc[1].

1.3: Photovoltaic Power Generating System

PV power generating system is used in numerous modes and operations, fundamentally categorised as grid integrated PV solar system and stand-alone, for residential use on rooftop, agriculture, industrial and commercial purposes. PV cells are used in small as well as in large power applications like calculators and wristwatch, photovoltaic cells are also widely used in configuration of module/array. The PV system is categorised on behalf of their working and application as shown in Figure 1.1.

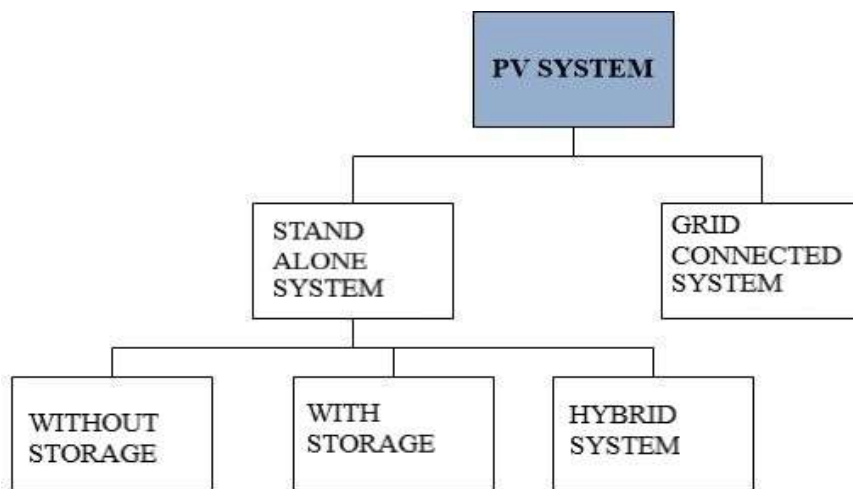


Figure 1.1: General categorization of the PV system

The stand-alone photovoltaic solar system is best suitable in the rural areas where supplying power through the grid is difficult and not a attainable solution. The stand-alone system can be used with or without power storage devices and also with hybrid system according to the need of the application. however without power storage capacity utilization of stand-alone system for the general-purpose application is difficult during the night and wet weather conditions. There are mainly five fundamental applications of the PV system; these are hybrid systems, grid connected centralized, grid connected decentralized off-grid domestic and off-grid non-domestic systems.

PV solar system is instigated in hybrid system with the cogeneration system and the wind turbine plant. PV system based on diesel engine is expanding and is used for electricity feeding in telecom network stations and provides reliable and cost effective system. It is being used in developing countries usually like in India where uses of

telecom systems and information systems like the internet and mobiles are growing rapidly.

In the last decade for electrical energy system, most of the PV solar system is a decentralized power unit i.e. electrical grid is directly connected to the PV solar system. The centralized power unit is cost-effective, economical and reliable because it does not need power storage devices due to cost per watt reduction. Power electronics interface circuit from the output of solar PV is required before connecting it to the grid or residential load because the output of the PV solar is DC and thus in order to connect it to the AC grid or load, DC-AC converter is needed. Grid interconnection system uses voltage source inverter (VSI) or current sources inverter (CSI) but CSI is not a feasible option for PV solar system to connect it with the grid at high and medium power, medium voltage level because of increase in the switching losses as compared to voltage source inverter (VSI) under similar operating conditions (grid parameter, rating and switching frequency)[2]. Therefore, VSI inverters are preferred over CSI for high and medium power, three-phase ac grid with medium voltage systems.

1.4: Power Quality

Quality of power is important along with the availability of electricity. The term of power quality clears from name that the quality of power that consumers and utility have received free from the harmonics. Power available at consumer terminal is characterized as the frequency of output voltage, magnitude and amount of harmonics in voltage and current. Power supply in industries, commercial buildings, household, agriculture etc. and mostly installed machinery is designed to operate at balance three-phase sinusoidal voltage at rated magnitude and frequency. Also on the other side, every utility would also want to transmit the balanced three-phase current free from the harmonics and contains fundamental components. In order to minimise loss in the network fundamental components at unity power factor is necessary, however at distribution load varies so balanced three-phase load currents are not guaranteed, also there are variety of loads with different reactive power demand that draws harmonic current from the distribution network, Therefore sudden changes in the load demand voltage sag and swell, the notch in supply voltage, all these issues arises in quality of power, so in order to deal with these problems FACTS devices like static compensator (STATCOM), static var compensator (SVC), unified power flow controller (UPFC) can be used according to the suitability[3].

1.5: Grid Connected Photovoltaic System

Grid connected PV system uses hysteresis current control (HCC), voltage source inverter (VSI) for the integration of the solar PV system to the grid. It can also be used as a system to work against the power quality issues like reactive power compensation, load unbalanced condition, load harmonics compensation[4].The grid connected photovoltaic system can be directly connected to the DC-link capacitor or DC-link can be connected using boost converter (for high DC voltage demands) before feeding it to the inverter and then power can be transferred to the three phase grid. In converters MPPT control techniques can be used to extract the maximum power from the PV system and transfer it to the three phase grid and simultaneously mitigate power quality problems, also by using these techniques it is able to improve the efficiency of the PV solar system. The VSI feeds the solar energy to the grid and able to provide reactive power compensation, harmonics elimination at point of common coupling (PCC)[5]. In order to extract the maximum power point, conventional control techniques are available such as perturb and observe algorithm (P&O), Incremental conductance techniques (INC), fractional current control, fractional voltage control, etc. and also artificial neural network (ANN), fuzzy logic control and other AI techniques [6].

In Figure 1.2 shows the basic block diagram of the grid interconnected PV solar system. The output of the PV solar voltage and the current is sensed by the current and the voltage sensor and compared with the previously defined value that gives the signal to the IGBT of DC-DC boost-converter, the output of the boost-converter is DC power which is fed to the voltage source inverter (VSI). The Three-Phase VSI converts DC power into the AC power and feeds it to the three phase grid, for the synchronization with grid various control techniques are used to match the grid voltage and the frequency at the point of common coupling. There are several control techniques available for the controlling of the VSI like synchronous reference frame theory (SRFT), power balance theory, instantaneous reactive power theory (IRPT), conductance based current algorithm etc[7].

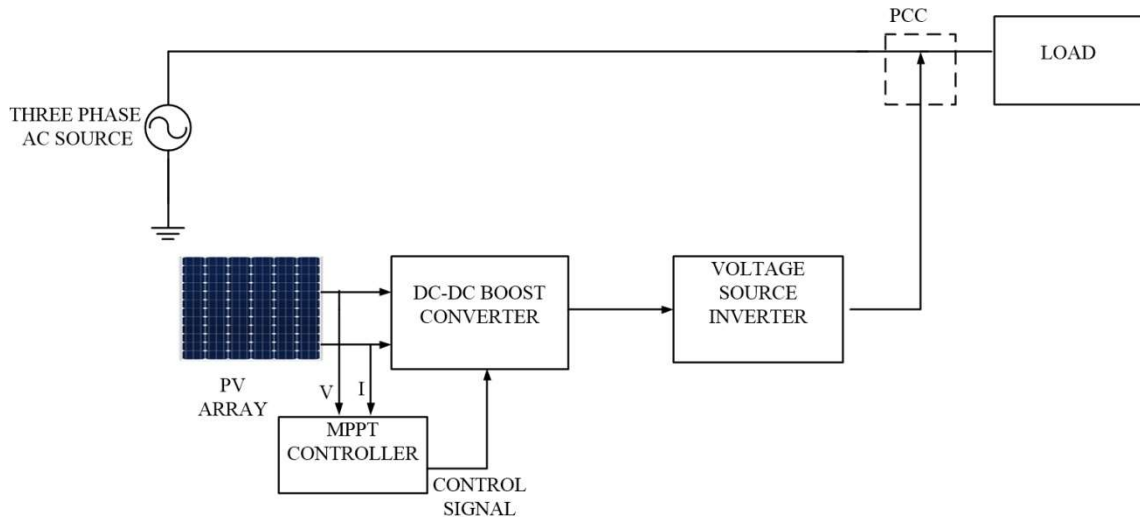


Figure 1.2: Block diagram of grid connected PV solar system

The PV grid connected system VSI controlled through enclosed loops. Provision for possible face sinusoidal current in to the grid is main motive of the control of the VSI. Regulation of current is done using inner current control loop. Voltage reference for the inverter is obtained using PI controller with the use of inner current control loop. The Clark's and Park's transformation method is used to obtain the synchronously rotating d-q frame with the grid and PI controller to maintain DC-link voltage constant with the d-q reference framed signals, abc to d-q transformation converts the AC signal into decoupled signal. To ensure the track for reference adequately with implementation and easy design PI controllers are employed on constant signals in dq reference frames [8].

1.6: Outline of Dissertation

This dissertation work consists of six chapters.

Chapter 1: First chapter focuses on the necessity of renewable energy, especially solar energy. Significance, advantage and how it's becoming an important part for the society and world, power quality, and grid-connected PV solar system.

Chapter 2: This chapter focuses on the literature review done related to the present work "Reactive Power Compensation in Solar PV System with Power Quality Analysis". This literature review gives an understanding of the future scope of solar energy, MPPT techniques in PV systems, modelling of the PV solar panel, power quality standards, and mitigation of the power quality problems and grid connected systems.

Chapter 3: This chapter gives the introduction and electrical modelling of the PV model to derive its output characteristics. The dependence of PV on solar irradiation and the temperature is discussed. This chapter also gives the idea of how design and applications of the boost converter for MPPT in the PV system using perturb and observe MPPT control techniques.

Chapter 4: This chapter focuses on MATLAB/simulation parameters, the model of MPPT in the photovoltaic system and discussed the design and application of boost converter in a grid connected PV system. SRFT and unit template current control techniques are studied and implemented on the design grid connected PV system.

Chapter 5: In this chapter MATLAB/simulation of grid interconnected PV solar system and their controlling techniques, results are discussed at different irradiation, temperature, and load conditions.

Chapter 6: This chapter summarize the work which is done and reaches the conclusion with the future scope of the work.

CHAPTER 2

LITERATURE REVIEW

2.1: Introduction

In this chapter, many research paper related to PV module connected to grid and controlling of solar inverter are reviewed. The review work is done for the area mentioned below

- i. Renewable energy sources
- ii. Solar photovoltaic and MPPT techniques
- iii. Power quality
- iv. Inverter control techniques

2.2: Literature Survey

2.2.1: Renewable Energy Sources

India signed the Paris agreement, in this agreement 40% of India's power capacity would be based on non-fossil fuel sources and greenhouse gas emission intensity of its GDP will be reduced by 33-35% below 2005 levels by 2030. To fulfil the agreement government offer many schemes and subsidies for support to renewable energy sources. Due to major reforms and policies supporting cleaner, greener and cheaper sources of energy more than 750 million people have gained access to electricity which include power from onshore and offshore solar power plant, wind power plant, rooftop solar, solar pump etc[8].

2.2.2: Solar Photovoltaic and MPPT Techniques

The fundamental component in the photovoltaic model is solar cell, to obtain the more accurate and better result with reducing computational effort to reduce computational time for more accurate results obtained from the solar cell. Maximum power point is acquired by using MPPT algorithm techniques, efficiency of the overall PV system is improved [5]. The PV cell and their characteristics can be understood with the help of an equivalent model of PV cell [9]. Availability of several proposed techniques can be found on the literature based on single diode-based or double diode-based modelling [10]. The single diode-based model required easy modelling and less computational effort due to single diode-based solar cells with quite good accuracy

because of these reasons single diode-based model is mostly used in different papers. The double diode-based solar cell is more accurate compares to single diode-based solar cell [10]. There are several research papers available explaining various MPPT techniques and algorithms [11], latest soft computing algorithms and comparing them on the basis of their complexity of the algorithm and tracking the maximum power point (MPP) under different solar irradiation and temperature[12].

2.2.3: Solar Energy in India

In India the present installed capacity of renewable energy is about 34.6 % of total capacity, hydroelectric plants are the major sources of renewable energy followed by wind energy, and solar energy, solar power is a promising option by the inception of the PV for the future energy consumption [12]. PV systems can be used as stand-alone systems (up to several kW) or grid connected system (up to several MW) [1]. Solar power sector in India has emerged as a fast upcoming section in last years. It supports the government agenda of sustainable growth, while emerging as an integral part of the solution to meet the nation's energy. In the end of the year 2019 India has achieved 5th rank in the world in solar power deployment in solar power, The capacity of solar energy has increased by more than eleven times in the last five year from 2.6 GW in march 2014 to 28.18 GW march 2019 with technology improvements, The reduction in solar cell/ module tariff in India is now competitive and has achieved parity. In grid connected solar PV system capacity 28.18 GW and off-grid solar PV system capacity 212 MW. This gives the short analysis of solar energy development in India and a review of government energy support for solar energy.

2.2.4: Power Quality

The problem arises in the electric system because of inductive load and continuous varying the load, due to the voltage sag and swell, harmonics in supply voltage, and current notches in supply voltage. The low power factor and unbalancing in load current in the three phase system [13].this paper gives an explanation of how the problems arise in the grid connected system and how they can be improved in power quality issues [14] explain how the voltage sag and swell increases and decreases the supply voltage for a short duration whereas if the variation for the long time duration is termed as overvoltage and under-voltage. [15] discusses how the non-linear load or using DC load through AC-DC converter, laptop, mobile charger, etc due to harmonics injected at the distribution level and because of these reasons non sinusoidal current and

the voltage.[16] discusses the reactive power load demand at the distribution end due to low power factor and loading effect will arise, overloading on the supply wires and cables causes voltage dip problem arises [17]. There may be zero sequence harmonics because of unbalancing in the load demand in the load demand injected at the load end in three-phase four systems. The problem occurs because of low power quality de-rating of end-user equipment, mail operation and failure of protective equipments, breaking of cables, high power loss in subsystem etc [18]. The failure in protective equipment in the hospitals, industries, commercial buildings, and sub-stations may result in huge losses. Therefore, to maintain the quality of power several standards are needed to follow and maintain an acceptable level at the distribution level [19].These have been developed [1] as guidelines for mitigation and control of problems related to harmonic distortion at the distribution level [20]. This standard gives the guidelines for the designing of an electric power system with the non-linear load and this non-linear load does not affect the power quality of the user connected at the same utility grid. The problems related to the low power factor and inductive load used power devices include static compensator (STATCOM), static var compensator (SVC), unified power flow controller (UPFC) [14]. These devices included power electronics devices and the sensor for the compensation of power and maintain the acceptable voltage limits [21].

2.2.5: Grid Connected PV System

Grid connected PV systems are used for integrating PV solar power into the grid. The integration of the PV solar system with the grid will caused many problems. These include harmonics, voltage fluctuation, low power factor, reactive power, load management etc. and integrating the PV solar farm must fulfil the quality standard of power quality [14]. The PV solar system is operated mainly in two modes, standalone mode and grid connected mode. The standalone mode has a low power handling capacity and requires power storage devices. The use of power storage device in PV solar systems becomes more costly and bulky. The grid connected PV system has a large rating power handling capacity and does not require any additional storage devices [22].

Using PV solar as grid integration mode, it also supports against power quality issues like load unbalance condition, load reactive power demand, load harmonics compensation etc. the grid connected inverter operates when PV solar system connects to the grid. Extracting the solar energy feed to the grid through converter and capacitor.

The boost converter triggering is controlled with the MPPT control techniques so it gives the PV maximum power output to the grid. The VSI transfers the energy to the grid and mitigates the power quality of the grid.[23] Proposed the use of a PV solar system which consist a boost converter using the MPPT control techniques in VSI and use of PV inverter for reactive power compensation in the grid. The output power fed to the grid at a point of common coupling (PCC) but need to use harmonics elimination at PCC. The use of filter for minimising the harmonics, different types of filter are used like L, LC, LCL etc [24].Proposed the design of the PV system with dealing with the PV array, boost converter, DC-link capacitor, DC-link capacitor voltage and interfacing of the inductor. [18] Proposed grid interconnecting 5 kW PV solar system to grid with the enhancement of power quality.[15] Proposed the use of PV solar system to improve the power quality, power factor and regulate the voltage at PCC using controller [12].

2.2.6: Inverter Control Techniques

Power converted from the PV module is DC. A VSI convert the DC power into the AC power so that it can integrate with the grid. B. Singh in [12] design a hardware prototype of 5 kW PV system connected to grid and studied its behaviour at varying in solar irradiation and MPPT control technique. The designing and controlling of inverter briefly explained in [13].

They can be classified into conventional control and adaptive control in [15] simulation of a characteristics study of a grid interconnected PV system using SRF control technique. In A. Rana [15] apply unit template current control for the grid connected PV system to analyse the performance with the grid. In [21] N. Dhyani apply unit template to study the power quality and load harmonics compensations. A detailed analysis of a grid connected PV system is explained in [12]. Synchronous reference frame with indirect current control is studied in [18]. A. J. Rana in [19] discussed application of unit template current control and maintained the DC-link voltage with varying in load and solar irradiation. K. M. Rafi in [20] discussed the correction in power factor using the solar PV system integrated with the grid. N. Dhyani in [21] discussed the implementation of distribution energy sources and analyse the load demand at the distribution end. S. Bhat [22] analyses in 5 kW solar PV system is connected to grid and mitigated the problems and challenges, used SRFT controlled technique for controlling the PV inverter. B. Singh in [23] used IRPT based control technique for 50 kW interface grid connected system and power quality analysis,

studied power factor correction and eliminates the load harmonics. A. Rajendran in [24] used SRFT control technique to maintain the DC-link voltage stable at varying in load demand and changes in solar irradiation.

The various inverter current control algorithm are present in literature are designed in keeping the speed of the algorithm in mind. In grid integrated PV system is essential for the grid current to remain as much as undisturbed from external disturbances as possible.

In [25] the IEEE 1159 standard are given which are elemental for harmonics control practices and IEEE 519 standard according to the revised standard of 2014 permissible THD is below 5%.

2.3: Conclusion

The literature review is done in this chapter in the relevant area for the present work “reactive power compensation in solar PV system with power quality analysis” in detail. The literature review is done to understand the PV solar system, MPPT techniques, modelling of photovoltaic, power quality standards and power quality mitigations problems and grid integrated system.

CHAPTER 3

SOLAR PHOTOVOLTAIC GENERATION SYSTEM AND MAXIMUM POWER POINT TRACKING

3.1: Introduction

In order to maximise the accuracy solar cell modelling finds its part and most important aspect in photovoltaic with reducing efforts so it reduces the computational time. Reducing the computational time will give more accurate results too easy to implement the maximum power point tracking algorithm. System efficiency is overall improved using MPPT techniques. The better results and characteristics of solar PV give a boost to develop solar energy around the world. The continuous research in the field of solar cell and photovoltaic due to the cost is getting down and their efficiency increases with the time. The large solar plants and solar parks are developing across the world based on PV. The photovoltaic is environmental friendly and it does not give any harmful radiation.

The PV panel is a combination of series and shunt connection of solar cells. A typical solar panel only gives 35-40 % solar irradiation into the electrical energy. The MPPT techniques are used in improve the efficiency of the solar panel. The MPPT techniques work on the maximum power transfer theorem. The output power of the solar panel is maximum when the thevenin impedance of sources is matched with the load impedance; hence the main motive of the MPP is to match the source impedance with the load impedance so the PV panel is able to deliver maximum output. The PV must have the capability to track the MPP under changing temperature and irradiation conditions.

The implementation of PV systems is more reliable and efficient, and then it needs to understand the equivalent model of the PV array and its output characteristics. This chapter gives an introduction of the PV and their electric modelling to derive its output characteristics. The use of these output characteristics of PV gives the analysis of how the output of PV depends on solar irradiation and temperature. This chapter gives the application of the MPPT techniques on PV systems to improve their efficiency.

3.2: Photovoltaic

The photovoltaic cell is the smallest unit of the PV array as shown in Figure 3.1; the photovoltaic cell is used for converting the solar energy into electrical energy. The

photovoltaic cell is a P-N junction based device that works when solar irradiation falls on the surface than if the light photon energy is more than the energy band gap of the P-N junction, and then free electrons are started getting loose from the atoms in the semiconductor material. In the continuous process of atoms releasing the electrons, if electrical conductors form on the positive side or negative side then it is able to capture the electric current that is electricity. The DC electrical power is generated on the output side of the PV. The generation of the current from the PV is proportional to the solar irradiation.

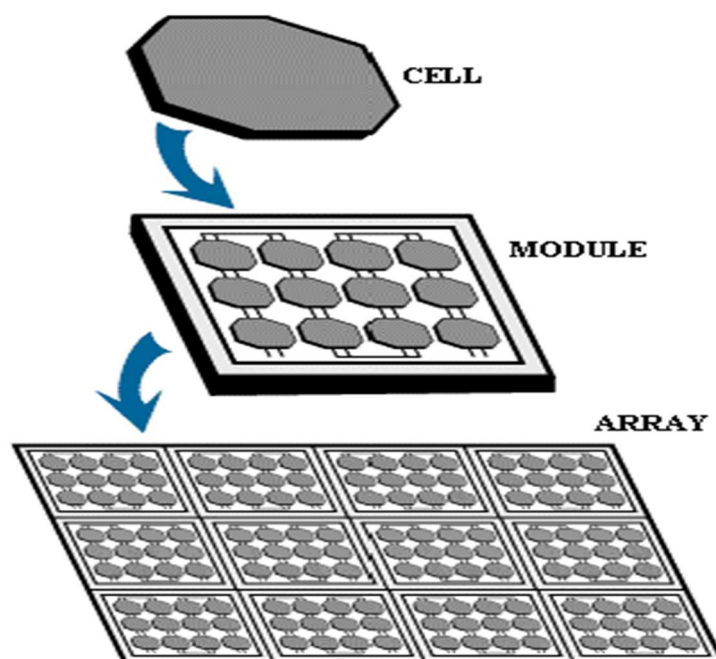


Figure 3.1: Structure of PV array

The PV cell open circuit voltage is 0.5 to 0.6 volt approx to their terminal when solar irradiations fall on its surface. The generated small amount of power is 0.1 to 0.3 watt. The PV cells are connected in series/shunt and laminated together to form a PV module. The output open circuit voltage is about 15 to 20 volt and the power is about 100 to 350 watt. These PV models are further series connected and parallel connected to form a PV array and reach on load demand. The PV array can be designed for domestic loads (kW) and commercial loads (MW).

3.3: Electrical Model of Photovoltaic Cell

The analysis for the output characteristic of the photovoltaic cell is needed to understand the equivalent mathematical model of solar cells. The PV cell can be modelled as a double diode model or single diode model. The double diode model gives more accurate results compared to the single diode model but computational calculation becomes difficult. The block diagram of double diode model is shown in Figure 3.2.

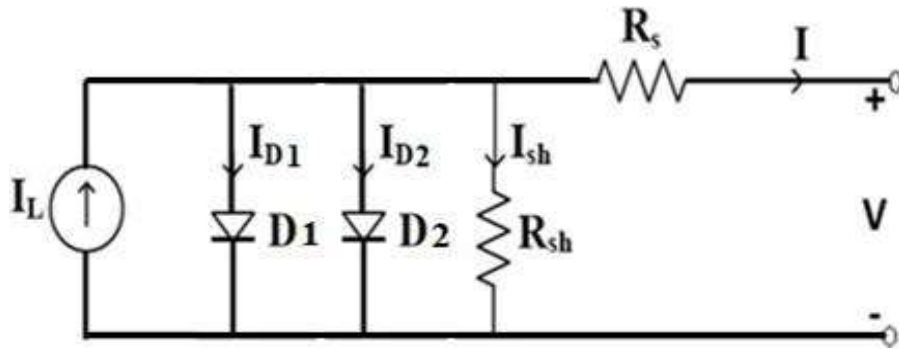


Figure 3.2: Double diode model of PV cell.

The equivalent model of the single-diode model is an approximation of double-diode model with one diode is eliminated as shown in Figure 3.3. In single diode model calculation is easier and acceptable accuracy, widely used for analysis and design purposes [13]. The single diode model studies how the output voltage and current characteristics depend on solar irradiation.

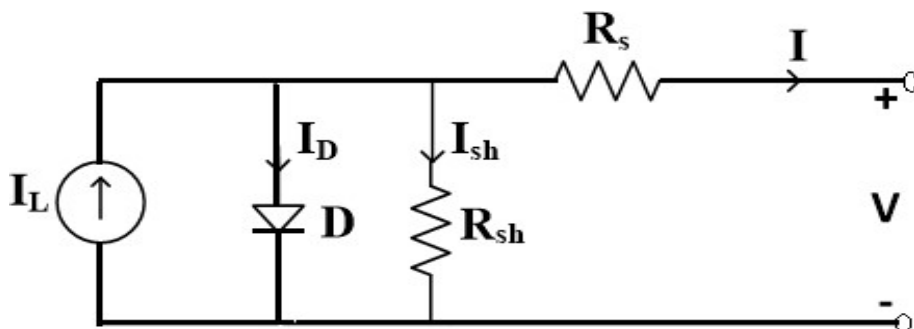


Figure 3.3: Single diode model of PV cell

$$I = I_L - I_D - I_{sh} \quad (3.1)$$

From figure 3.3, obtained equation (3.1) the output current of I expressed in terms of photon current, diode current and shunt current as shown.

$$I_D = I_0 \left(e^{\frac{q(V+I.R_s)}{kT}} - 1 \right) \quad (3.2)$$

$$I_{sh} = \frac{V+I.R_s}{R_{sh}} \quad (3.3)$$

$$I = I_L - I_0 \left(e^{\frac{q(V+I.R_s)}{kT}} - 1 \right) - \frac{(V+I.R_s)}{R_{sh}} \quad (3.4)$$

Here I_0 is the reverse saturation current which depends on the material doping level. k is Boltzmann constant = 1.38×10^{-23} J/k, T is cell temperature (K), q is the charge of electrons = 1.678×10^{-19} coulombs, R_s is effective series resistance, shunt current (I_{sh}) current passing through shunt resistance (R_{sh}), V is the terminal voltage of a PV cell.

From the above equation 3.4, is used to plot the characteristics of PV cells. There are two characteristics of PV cells that are mostly used for the analysis of the maximum power point of PV. One is P-V characteristics, which is used to analyse output power and voltage of PV and other one is to analyse I-V characteristics to analyse output current and voltage of PV.

In Figure 3.4, show the I-V characteristic of PV cells at different temperatures. Here MPP is the maximum power point of the PV, V_{OC} is open circuit voltage of the PV, I_{SC} is short circuit current of PV, I_m is maximum power point current.

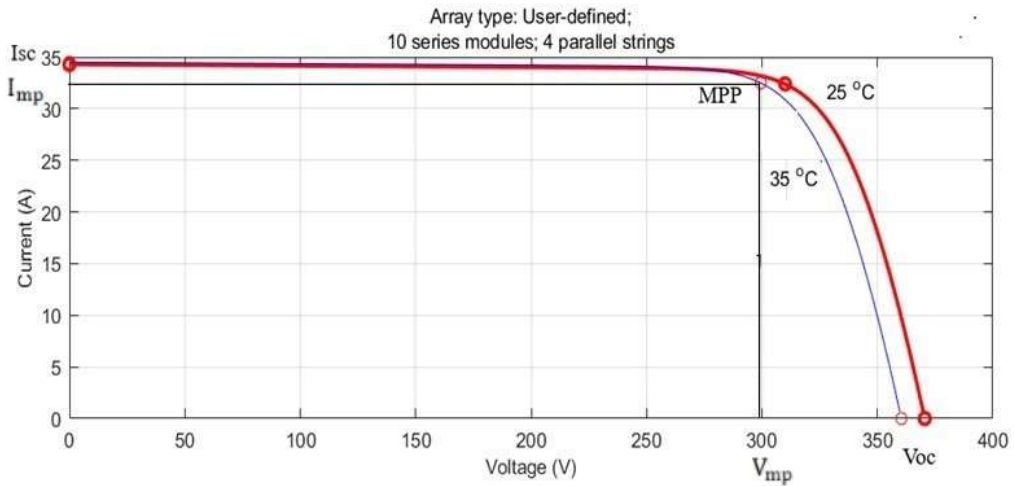


Figure 3.4: I-V characteristics of PV cell at different temperature

In Figure 3.5 show the P-V characteristics of the PV array at different temperatures. As shown in Figure by changes in environmental temperature the effect on changes in voltage is less affected.

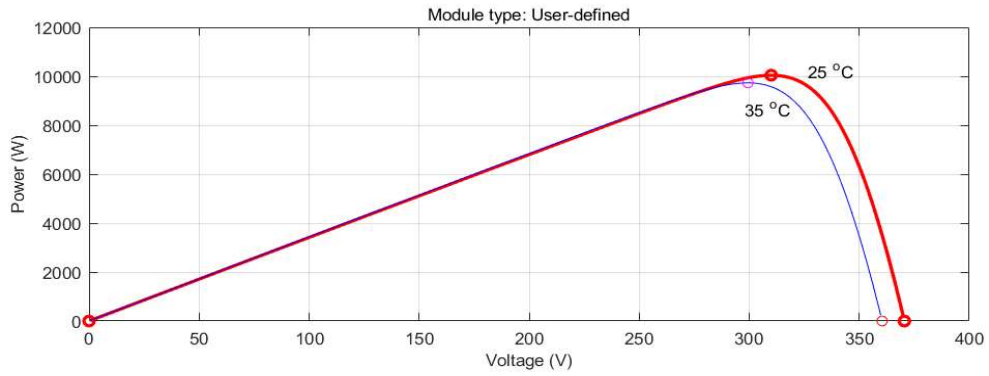


Figure 3.5: P-V characteristics of PV cell

At different irradiation I-V characteristics of PV in Figure 3.6 and P-V characteristics in Figure 3.7 are shown.

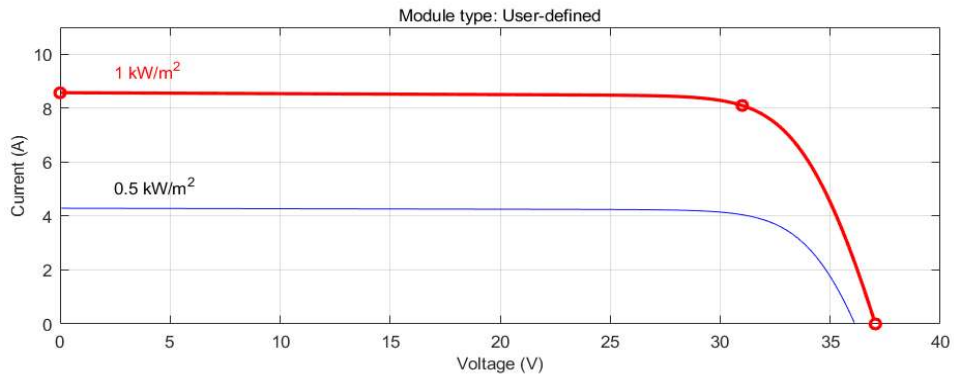


Figure 3.6: I-V characteristics of PV at different irradiation

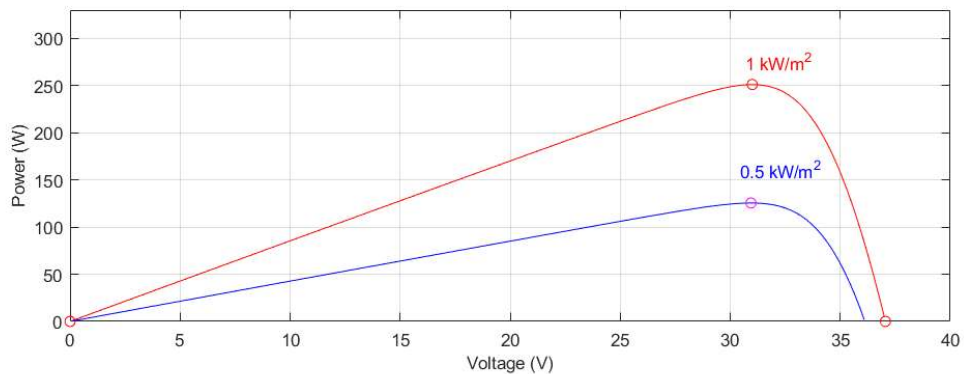


Figure 3.7: P-V characteristics of PV at different irradiation

From Figure 3.4 and 3.7, illustrate the I-V and P-V characteristics of PV depend on solar irradiation and temperature respectively. With decreasing in solar irradiation short circuit current (I_{sc}) decreases and open circuit voltage (V_{oc}) slightly

decreases, thus the output power decreases as shown in Figure 3.5 and 3.7. In PV array if the temperature ($^{\circ}\text{C}$) increases then open circuit voltage of PV slightly reduces as shown in Figure 3.4.

3.4: Maximum Power Point Tracking in Photovoltaic System

From figure 3.4 to 3.7 it is clear that for the output power of PV cell is maximum when the output voltage of PV operates at V_{mp} and output current of PV is operated at I_{mp} , this operating point is called MPP.

Since I-V and P-V characteristics depend upon solar irradiation and temperature and these are varying throughout the day so MPP is also varying. If the PV array is directly connected to load then the operating point of PV depends on load impedance and environmental condition but not always, being operating in MPP thus underutilising PV characteristic. To utilise the maximum power from the PV array, implement the MPPT techniques using the DC-DC converter. MPPT objective is to operate the PV at MPP when the variable load is connected irrespective of changes in environmental condition.

$$P_m = V_{mp} * I_{mp} \quad (3.5)$$

The MPPT technique is implemented in the PV solar system using the DC-DC converter (boost converter, buck converter, buck-boost converter etc) several control techniques are used to control the duty cycle of the DC-DC converter.

MPPT control algorithm are listed below

1. Perturb and observe
2. Incremental conductance
3. Fractional open circuit voltage
4. Fractional short circuit current
5. Neural network
6. Fuzzy logic control

In conventional control techniques "perturb and observe" and 'incremental conductance' algorithms are widely used because they are easy to implement and less costly whereas fuzzy logic and neural network control are advanced soft computing control techniques. These soft computing control techniques are used in the PV solar

system for triggering the gate pulse of the DC-DC boost converter. Employing soft computing control techniques extract the maximum power of PV.

3.5: Conventional Control Algorithms for MPPT

Perturb and observe algorithm and incremental control techniques are popular because of easy implementation and less cost.

3.5.1: Perturb and Observe Algorithm

Perturb and observe algorithm implementation is easier and gives acceptable results so it is popular and widely used. In perturb and observe output of the PV voltage and current sensed by using a sensor and corresponding changes in output power is calculated. The time complexity is less to find closer to MPP but it doesn't stop at MPP and keeps perturbing in both directions.

The left side of MPP, dp/dv is positive on the left side of MPP and right side of MPP dp/dv is negative. At $dp/dv=0$ is MPP point as shown in Figure 3.8 based on these observations the flowchart for the perturb and observe algorithm is developed as shown in Figure 3.9 [5].

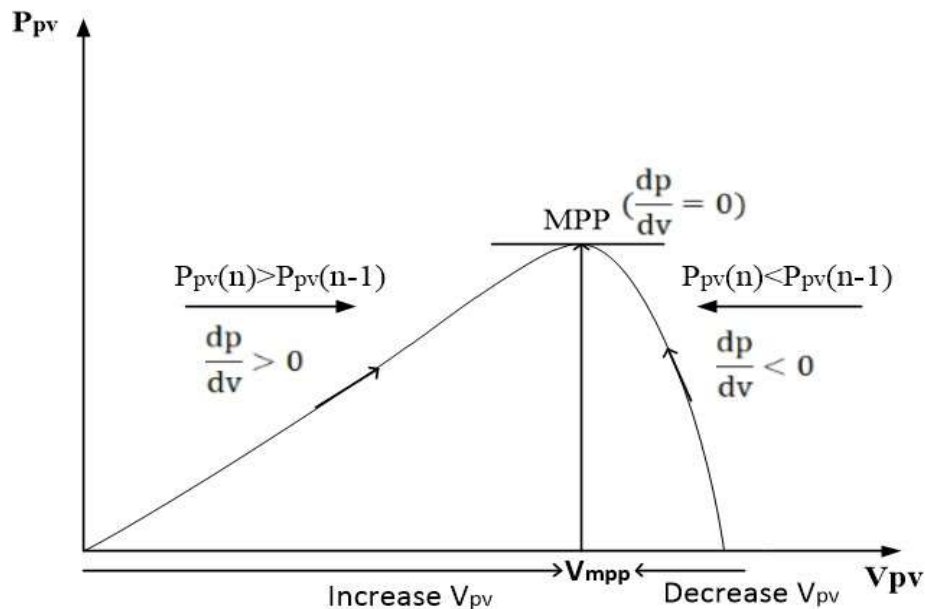


Figure 3.8: Algorithm of perturb and observe MPPT control technique

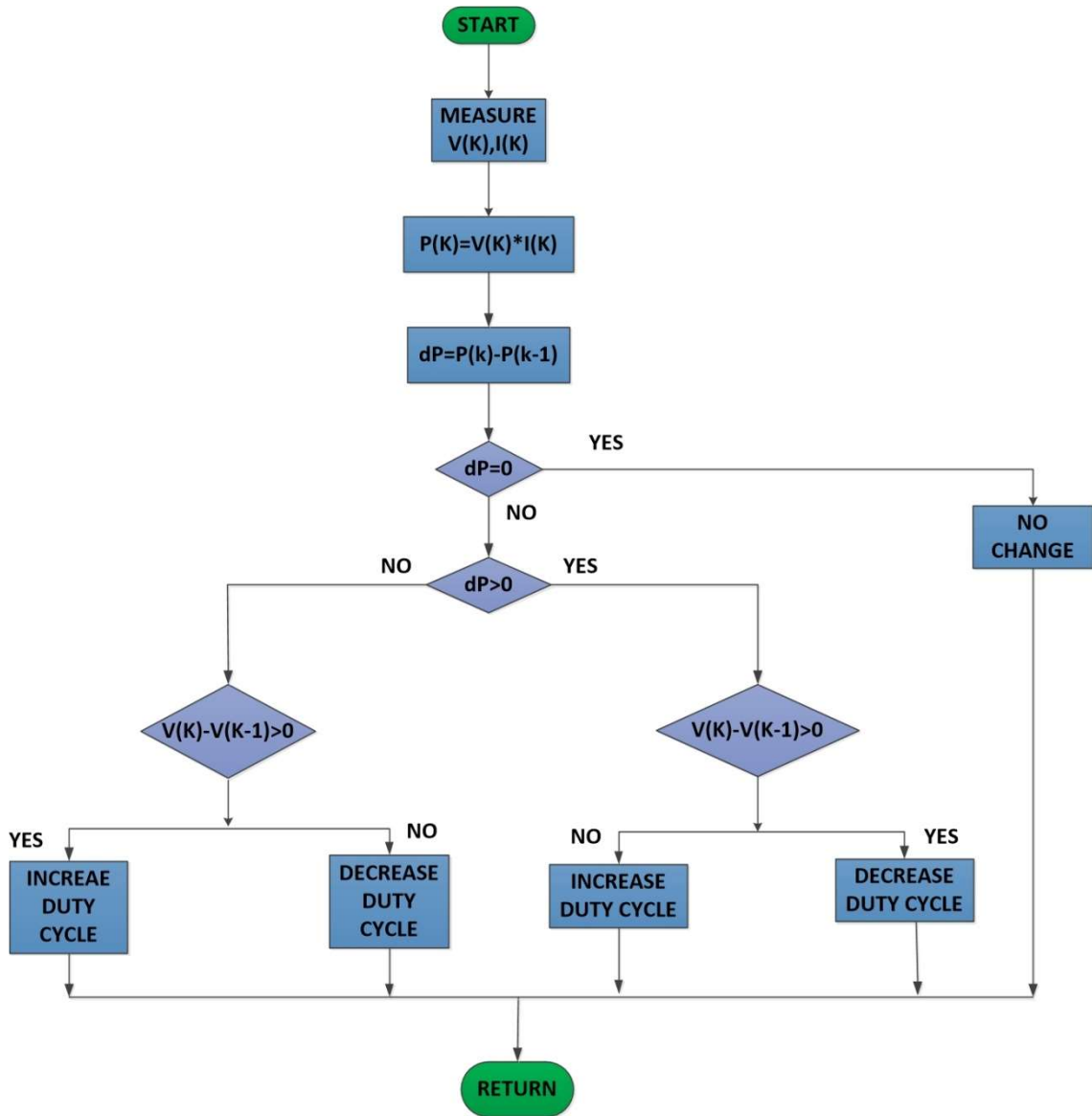


Figure 3.9: Flowchart of perturb and observe algorithm for MPPT in the photovoltaic system

3.5.2: Incremental Conductance Algorithm

An incremental conductance (INC) technique is another conventional and popular control technique. The mathematical background for INC is explained in [29].

$$P=V*I \quad (3.6)$$

$$\frac{dP}{dV} = \frac{\partial(V*I)}{\partial V} \quad (3.7)$$

$$\frac{\partial P}{\partial V} = I + \frac{V \partial I}{\partial V} \quad (3.8)$$

For the maximum power output from PV, $\frac{\partial P}{\partial V} = 0$ has to be satisfied, therefore from equation 3.8 we get;

$$\frac{\partial I}{\partial V} = -\frac{I}{V} \quad (3.9)$$

By equation 3.9 we get the conditions of MPP for INC MPPT control technique. It can be seen from Figure 3.4 and 3.6, that I-V characteristics are less negative on left side of MPP and more negative on right side of MPP. This can be written in equation as shown below

$$\frac{\partial I}{\partial V} > -\frac{I}{V}, \text{ left side of MPP} \quad (3.10)$$

$$\frac{\partial I}{\partial V} < -\frac{I}{V}, \text{ right side of MPP} \quad (3.11)$$

By using the equation 3.9 to 3.11 forms the algorithm of INC control techniques. In INC MPPT the switching cycle of boost converter is controlled in that way the condition $\frac{\partial I}{\partial V} = -\frac{I}{V}$ is satisfied. The MPP is gotten by contrasting the immediate conductance term (I/V) with incremental conductance term. Figure 3.10 clarifies the flowchart of INC calculation. The flow chart of INC is shown in Figure 3.10.

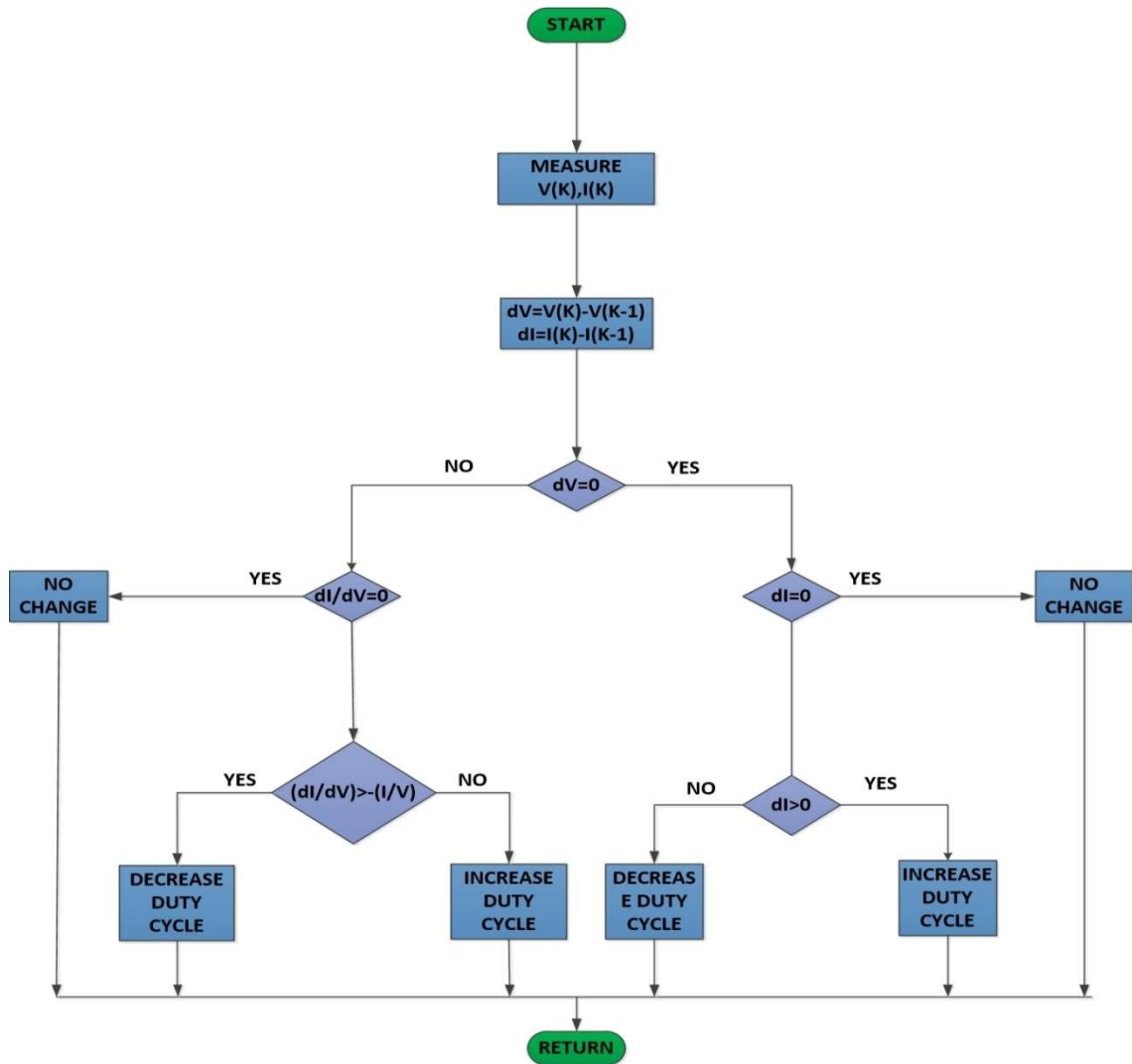


Figure 3.10: Flow chart for the incremental conductance algorithm for MPPT.

3.6: Conclusion

A PV arrangement of appropriate rating is needed to get the ideal power. All the boundaries required for the advancement of a matrix coordinated PV system. The maximum power point calculation is needed for calculating the parameter for the boost converter.

CHAPTER 4

GRID CONNECTED PV SYSTEM

4.1: Introduction

In this present chapter, we discussed the grid interconnected PV system. The detailed description and results related to MATLAB/simulation of grid interconnected systems. The simulation model is illustrated at different temperature, irradianations and with variation in load. The analysis is done related to power quality issues and their control techniques working under different loads and environmental conditions.

4.2: Grid Connected PV System

The PV system is connected at the point of common coupling where it gives support to distribution end and the utility to mitigate the power quality issues like reactive load demand, unbalancing in the load, load harmonics [12]. The working of a PV inverter at the utility grid is able to improve the load handling capability of the grid and improve voltage stability, power factor for the consumer. PV grid integrated system consists of PV module, boost converter followed by MPPT techniques, inverter and filter are used as shown in Figure 4.1.

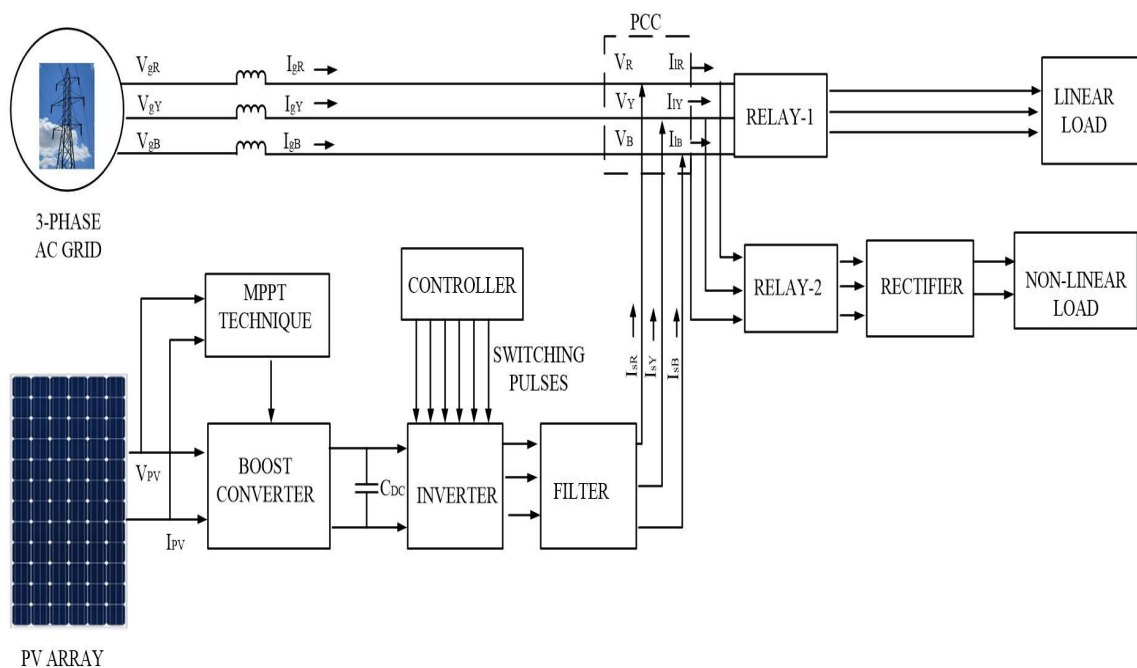


Figure 4.1: Block diagram of grid interconnected PV solar system

The PV solar system gives the output electrical power when the solar irradiation falls on its surface; the ionisation is started in the P-N junction based solar cell. The performance of the boost converter depends on MPPT control techniques; MPPT techniques sense the output voltage and current from PV solar with the use of sensors. The controlling of boost converter can be done using various MPPT control techniques like perturb and observe, incremental conductance, fractional voltage and current, fuzzy logic, ANN based control techniques are used for the control switching of the boost converter [12]. By using MPPT techniques, we are able to extract the maximum power from the PV array and feed into the DC-link capacitor. The DC-link capacitor which is used to form an interface between the boost converter and alternating current. The VSI works as current sources and is connected in parallel with the grid as shown in Figure 4.1, it compensates the load demand, reactive power and improves the voltage profile at the utility grid. The PV solar system support load demand and reduce the loading effect. In PV grid connected mode controlling of PV inverters is done using various techniques in which synchronous reference frame theory (SRFT) and unit template control techniques at various operations and conditions are performed in MATLAB simulation.

4.3: Implementation of Grid Connected PV System

The PV array used in the simulation model of the grid connected system; specification is given below in table at 1000 W/m² and 25 °C.

Table 4.1: PV array specification of grid connected system

PARAMETERS	RATING
Open circuit voltage (V_{oc})	370 V
Short circuit current (I_{sc})	34.28 A
Voltage at MPP	310 V
Current at MPP (I_{mpp})	32.4 A
Maximum power (P_m)	10 kW
Temperature coefficient of V_{oc} (% per °C)	-0.27269
Temperature coefficient of I_{sc} (% per °C)	0.061694

In MATLAB 2018 inbuilt have PV module which can be used according to desired parameter and capacity. The PV which used in the model has ten series connected strings and four parallel modules are connected to form a PV array. The output characteristic of the PV array is shown in Figure 4.2 and Figure 4.3.

Figure 4.2 show the I-V and Figure 4.3 show P-V characteristics at temperatures 25°C, 35°C and 45°C. The MPP operating point is mentioned in output characteristics of the PV.

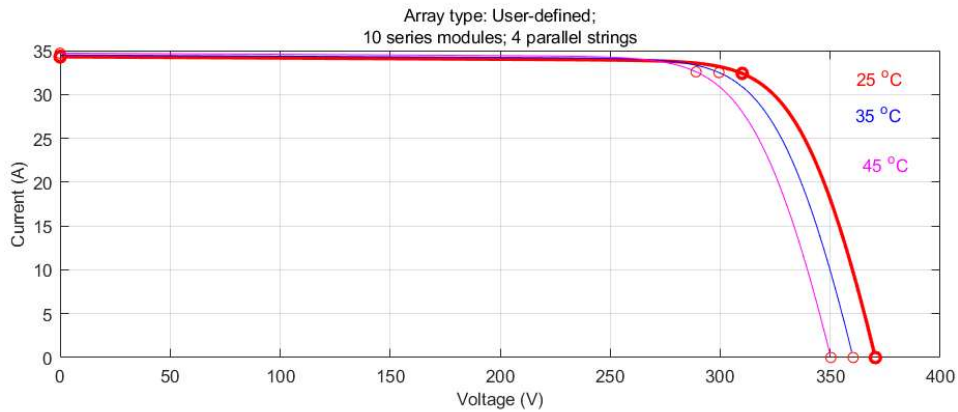


Figure 4.2: I-V characteristics of PV array for grid connected systems

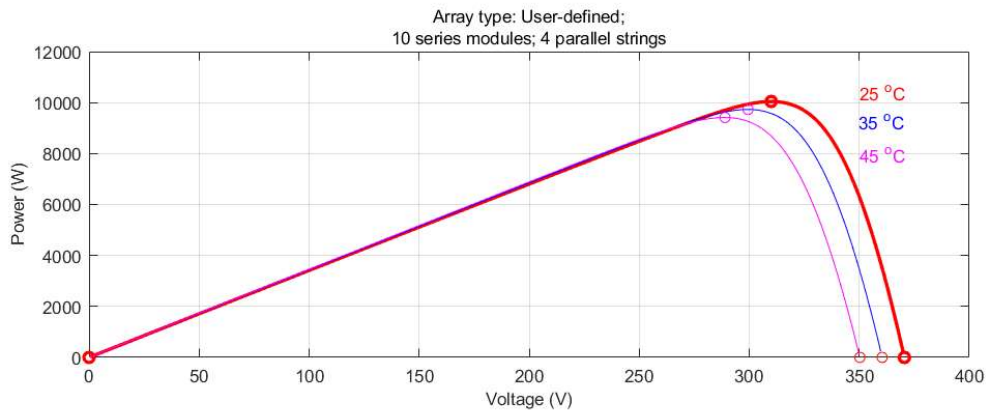


Figure 4.3: P-V characteristics of PV array for grid connected systems

4.3.1: Inductor for Boost Converter

The inductor L_b is used in boost converters to minimize the current ripple. The selection of inductor value used inductor ripple current equation 4.1 [17].

$$\Delta i_1 = V_{dc} \frac{D(D-1)}{2L_b F_{SW}} \quad (4.1)$$

In equation 4.1, Δi_1 is the ripple current through the boost converter is present. For the selection of inductor value, consider [25] ripple current should less than 5% of the short circuit current of PV array (34.28 A), which is equal to 1.714 A. The switching frequency is 20 kHz. DC-link voltage is taken as $V_{dc}= 800$ V. D is the duty cycle of the boost converter and calculating the inductor value here used $D=0.5$ because at this value current ripple is maximum so using the appropriate value of given parameters in equation 4.1, calculating the value of the inductor. The calculated value is approx $L_b=3$ mH.

4.3.2: Selection of IGBT and Diode for Boost Converter

The selection of the IGBT and diode for the boost converter should be selected such that they safely block the DC-link voltage and capable of PV output current with the safety factor. The boost converter used DC-link capacitor, we have taken $V_{dc}=800$ V, so IGBT and diode must have 1200 V rating with taken as 1.5 safety factor and current rating for both devices should have more than 69 A with safety factor 2 is taken.

4.3.3: Choice of DC-Link Voltage

In VSI the DC-link voltage selection of peak phase voltage should be more then or twice on the AC side of VSI [5]. The outer loop that operates on DC voltage error should control the control of the voltage at DC-link. In grid interconnected system for VSI the DC-link capacitor selection and voltage at DC-link is crucial parameters. The DC-link capacitor is charged up to curtain level across the switching devices using the anti-parallel diode when grid is connected to VSI and HCC controls the switching devices [12].

$$V_{dc} \geq \frac{2*\sqrt{2}*V_{LL}}{\sqrt{3}} \quad (4.2)$$

In equation 4.2, V_{LL} is the line to line voltage of AC side is 415 V. The calculating value of V_{dc} using equation 4.2 is 680 V, the selected value is approx 800 V.

4.3.4: Selection of DC-Link Capacitor

The selection of the DC-link capacitor use energy conservation principle. The extracting power from the PV is fed to the DC-link capacitor through the boost converter and VSI extracts this energy from the DC-link capacitor to transfer to the utility grid. The selected value of the DC-link capacitor (C_{dc}) should ensure a stable

DC-link voltage with minimum voltage ripple. The value of the DC-link capacitor can be calculated using equation 4.3 [26].

$$C_{dc} = \frac{I_{mpp}}{2 * \omega * V_{dc \text{ ripple}}} \quad (4.3)$$

Here in equation 4.3, I_{mpp} is the maximum current comes from PV is 32.58 A at standard irradiation 1000 W/m², ω is the angular frequency is 314 rad/sec, $V_{dc \text{ ripple}}$ is the ripple in the DC-link voltage it is taken to be 16 V (2% of the V_{dc}). The calculation of the value of C_{dc} using the given parameters is come to be 3.5 mF.

4.3.5: Interfacing Inductor

The interfacing inductor filter is connected between the ac side of VSI and PCC as mention in Figure 4.1. The selection value of interfacing inductor (L_r) should be minimising the current ripple in the ac side. The basic equation for calculating L_r is shown in equation 4.4.

$$L_r \frac{di_c}{dt} = V_f - V_s \quad (4.4)$$

Here V_s is the instantaneous PCC voltage of the corresponding phase and V_f is the instantaneous inverter pole voltage of any phase. The ripple current through the interfacing inductor is maximum when V_s is at its peak equal to V_{sm} at the instant, the average value of inverter pole can be considered equal to $1.1 * V_{sm}$ assuming a voltage drop across L_r is 10%. Thus equation 4.4 can be modified into equation 4.5.

$$L_r \frac{di_c}{dt} = 1.1V_{sm} - V_s \quad (4.5)$$

$$L_r \frac{di_c}{dt} = 0.1V_{sm} \quad (4.6)$$

di_c Is the ripple in inductor current at ac side is taken to be 0.5 A, dt is the switching time interval it is taken to be 0.1 ms, $V_{sm}=340$ V, all parameter are put in equation 4.6, the calculated value of L_r comes out to be 6.8 mH. The selected values are taken in MATLAB simulation is 7 mH.

4.3.6: Voltage Source Inverter

The three phases of two-level voltage source inverter (VSI) used in Figure 4.4. VSI has three legs. Each leg is made of two IGBT switches, the upper switch connected to the positive terminal of the DC-link capacitor and the bottom switch connected to the negative of the DC-link capacitor. The common midpoint of each leg is connected to

each phase of the ac side. The IGBT switches have inbuilt reverse conducting diode, the voltage rating of the IGBT should be selected as it has the capability to block the DC-link voltage. In MATLAB simulation used $V_{dc}=800$ V, therefore with a safety factor of 1.5 the voltage rating of the IGBT should be 1200 V. The current rating of each switch depends on how much current carry through the switches. The current is composed of the PV array power, load balancing, and load reactive power and harmonics compensation currents. Thus, the current rating depends on the PV array output and load compensation is required.

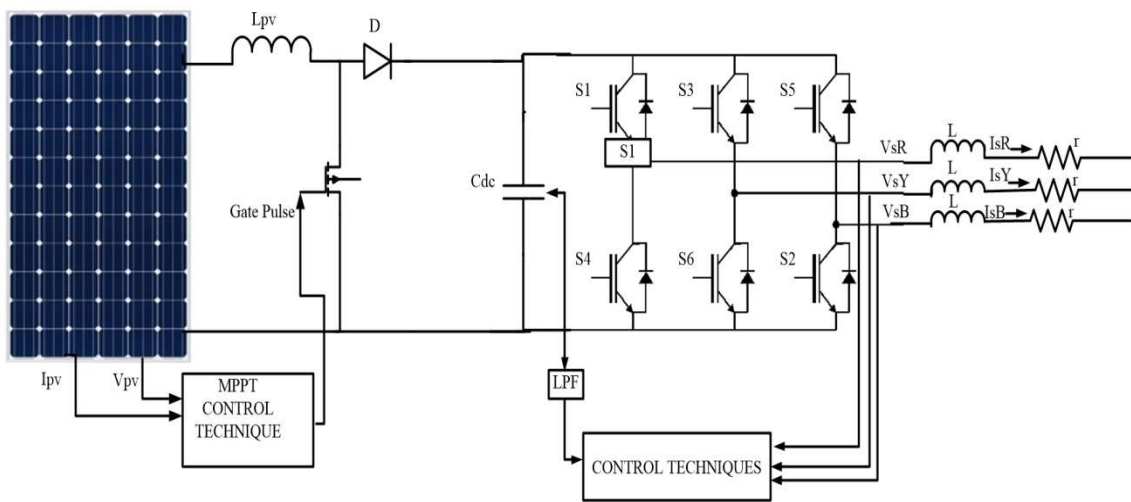


Figure 4.4: The complete circuit configuration of the three-phase PV system

4.4: Controls of Grid Connected System

The grid connected system has two separate controls for the VSI stage and boost converter stage. The VSI is connected parallel with the PCC and switching is done using the current control HCC techniques, in the HCC the reference current is taken from the SRFT and unit current control template, which is used to synchronise the PV system with the grid at PCC. The boost converter stage controlling is done using the MPPT control techniques, in MATLAB/simulation used perturb and observe control techniques which is discussed in CHAPTER 3.

4.5: Conventional Control Algorithm

The controlling for VSI in grid connected systems various control algorithms are used. Control algorithm is classified as conventional control, intelligent control and adaptive control techniques. Conventional control refers to the methods and theories

which are developed to control dynamic system with the help of difference equations framework. It includes techniques like SRFT, unit template theory and power balance theory etc.

Conventional control algorithms are as

- SRFT based current control algorithm
- Unit template based current control algorithm
- SRFT based indirect current control algorithm
- IRPT based current control algorithm

The present work has done in MATLAB/simulation with the use of SRFT and unit template current control to calculate the reference current which VSI should supply to the grid and second is to generate the switching pulse for VSI, so that its output current track the reference current in every phase.

The fundamental approach used in conventional control algorithm is to convert the three phase components into the two stationary frames as shown in Figure 4.5 for eliminating the harmonics and control the active and reactive components.

The space vector quantities matrix are given below, where F is the function of the voltage and the current.

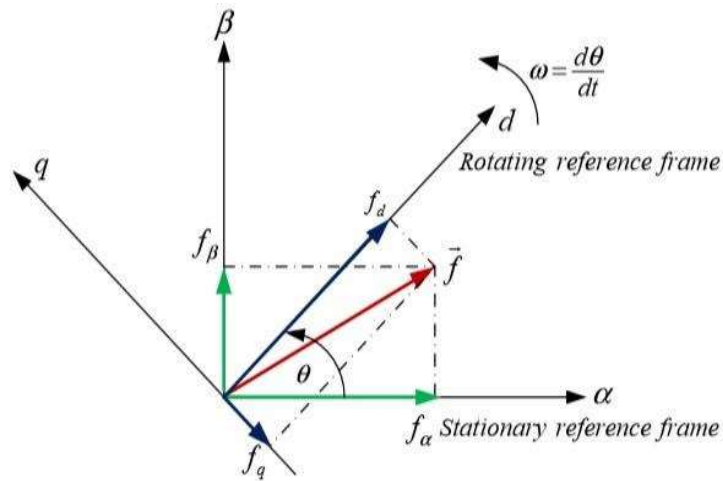


Figure 4.5: Two reference frames used in control algorithm

$$\begin{bmatrix} F_{\alpha} \\ F_{\beta} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} F_a \\ F_b \\ F_c \end{bmatrix} \quad (4.7)$$

$$\begin{bmatrix} F_d \\ F_q \end{bmatrix} = \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} F_{\alpha} \\ F_{\beta} \end{bmatrix} \quad (4.8)$$

$$\begin{bmatrix} F_d \\ F_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} 1 - \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} F_a \\ F_b \\ F_c \end{bmatrix} \quad (4.9)$$

$$\cos\omega t = \frac{V_g\alpha^2}{\sqrt{V_g\beta^2 + V_g\alpha^2}} \quad (4.10)$$

$$\sin\omega t = \frac{V_g\beta^2}{\sqrt{V_g\beta^2 + V_g\alpha^2}} \quad (4.11)$$

Phase components $\cos\omega t$ and $\sin\omega t$ are generated using the PLL and grid voltage taken as reference current for the PLL. The load current and inverter output current after the filter are transferred into the α - β frame using matrix shown in equation 4.7 and by using the matrix shown in equation 4.8 transfer the α - β frame into the d-q reference frame and control the instantaneous active and reactive power components.

4.6: SRFT Based Current Control Algorithm

Conversion of three phase load current into synchronously rotating dq frame is it's initially step. It is shown in Figure 4.6 where load current, grid voltage and DC-link voltage are feedback signal, load current transfer into dq0.

In SRFT control techniques grid voltage sensed for the angular frequency and load current sensed and transferred into the two reference frame (dq) as shown in equation 4.6

Here ω is the angular frequency of the SRFT and kept equal to the grid frequency so we are able to transfer the fundamental component of grid voltage and current transfer into the d-q frame. The grid frequency is measured using the phase lock loop.

In Figure 4.6 shown the i_d components corresponds to the instantaneous real power of load and i_q components corresponds to instantaneous reactive power of load. The i_d components have both average $i_{d,avg}$ and oscillatory components $i_{d,ac}$ given by equation 4.12, it is gone through the low pass filter (5th order butter worth low pass filter) to take the average instantaneous real power components $i_{d,avg}$.

$$i_d = i_{d,avg} + i_{d,ac} \quad (4.12)$$

As shown in figure 4.6 the output of DC-link pass through the PI controller i_{pdC} together with i_{davg} must be deliver by the grid, where as the remaining components $i_{d,ac}$ and i_d should be supplied by the VSI.

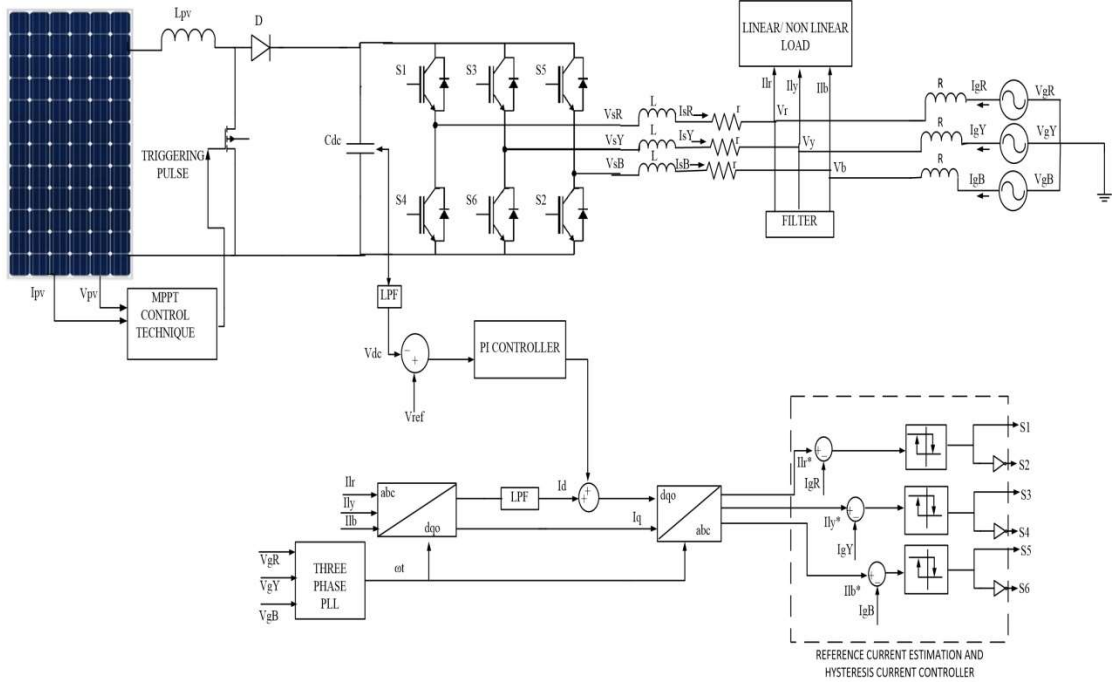


Figure 4.6: Schematic layout of the proposed grid interfaced PV system using SRFT

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos \phi & -\sin \phi & 0.5 \\ \cos(\phi - \frac{2\pi}{3}) & -\sin(\phi - \frac{2\pi}{3}) & 0.5 \\ \cos(\phi + \frac{2\pi}{3}) & -\sin(\phi + \frac{2\pi}{3}) & 0.5 \end{bmatrix} \begin{bmatrix} I_{lr} \\ I_{ly} \\ I_{lb} \end{bmatrix} \quad (4.13)$$

$$\begin{bmatrix} i_{lr}^* \\ i_{ly}^* \\ i_{lb}^* \end{bmatrix} = \begin{bmatrix} \cos \phi & \sin \phi & 0.5 \\ \cos(\phi - \frac{2\pi}{3}) & -\sin(\phi - \frac{2\pi}{3}) & 0.5 \\ \cos(\phi + \frac{2\pi}{3}) & -\sin(\phi + \frac{2\pi}{3}) & 0.5 \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \\ i_0^* \end{bmatrix} \quad (4.14)$$

4.7: Unit Template Based Current Control Algorithm

In unit template format based current control calculation the three phase PCC voltage and voltage at DC-link is sensed to generate reference current to be supplied by the grid. The schematic layout of the proposed grid interfaced system using unit template current control algorithm is given in Figure 4.7.

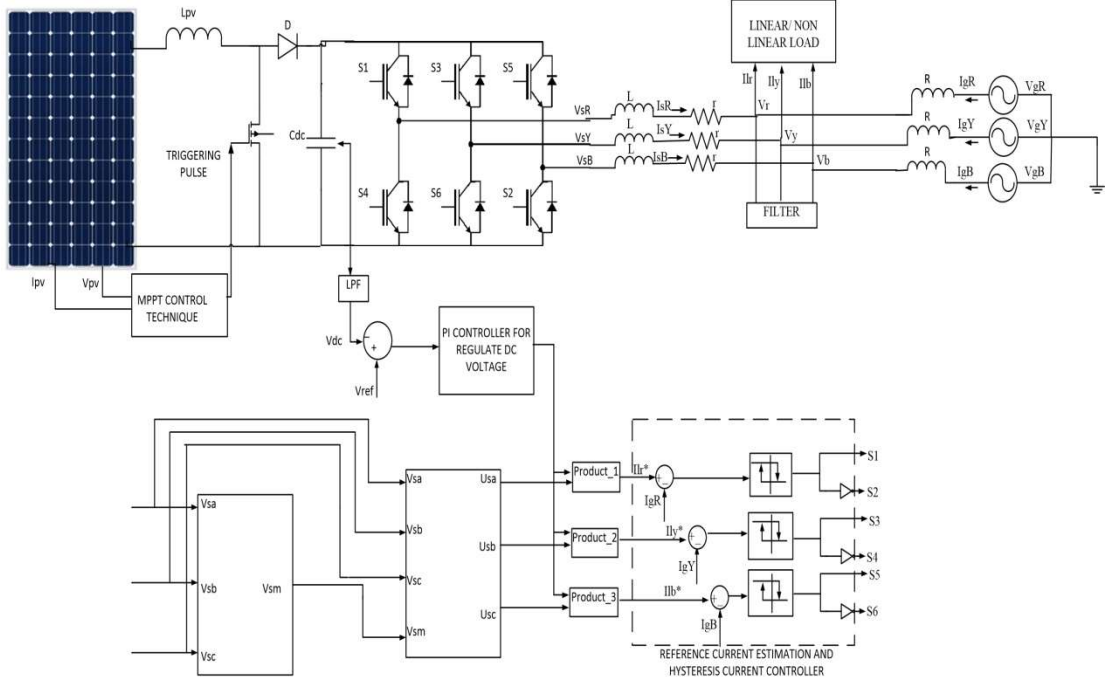


Figure 4.7: Schematic layout of the proposed grid interfaced PV system using unit template current control

The peak value of per phase PCC voltage v_{sm} is calculated as

$$v_{sm} = \sqrt{\left[\left(\frac{2}{3}\right)(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\right]} \quad (4.15)$$

In equation 4.15 V_{sa}, V_{sb}, V_{sc} are instantaneous PCC voltages. After V_{sm} is calculated, unit template for each grid phase current u_{sa}, u_{sb}, u_{sc} are calculated as.

$$u_{sa} = \frac{V_{sa}}{V_{sm}} \quad (4.16)$$

$$u_{sb} = \frac{V_{sb}}{V_{sm}} \quad (4.17)$$

$$u_{sc} = \frac{V_{sc}}{V_{sm}} \quad (4.18)$$

The reference grid current are obtained by multiplying these unit template with output of dc link pass through the PI controller $I_{s,peak}$ as shown in Figure 4.7

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = i_{s,peak} \begin{bmatrix} u_{sa} \\ u_{sb} \\ u_{sc} \end{bmatrix} \quad (4.19)$$

Here $i_{sa}^*, i_{sb}^*, i_{sc}^*$ are instantaneous values of reference grid currents.

4.8: Hysteresis Current Controller for Voltage Source Inverter

Hysteresis current control (HCC) strategy is used for giving switching pulse to a VSI. In three stages two level VSI, if top switch of any leg is closed (ON) with base switch of a similar leg open (OFF) at that point yield current of the comparing stage will increment, if the base switch is shut with top switch open in a leg both switches are not on simultaneously as this will short circuit the DC-link. The property of three phases VSI make it possible to control output current of each phase independently by giving switching pulses to the corresponding leg. The switching of the VSI should be done such that the VSI output current follow the generated reference current in each phase. In HCC control techniques reference current are compared with the actual current within a hysteresis band and switching pulses are generated accordingly. A simple control block diagram for implementation hysteresis band PWM is shown in Figure 4.8

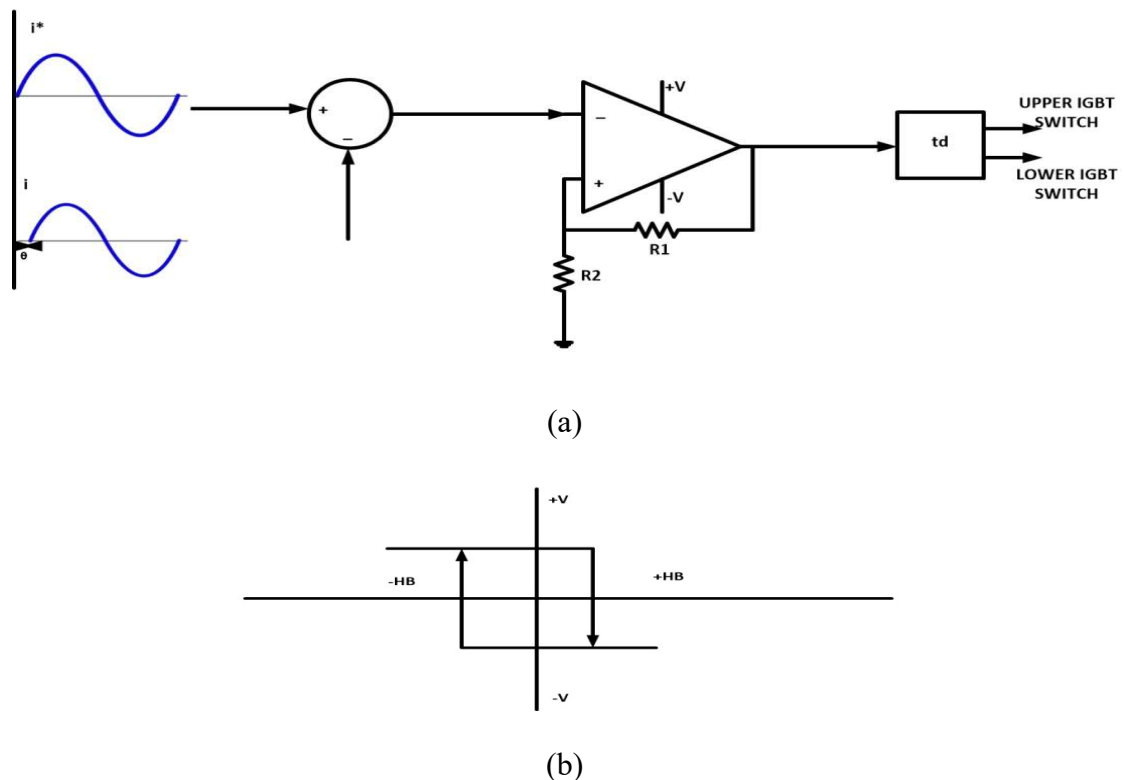


Figure 4.8: Control block diagram for hysteresis current controller

The error in the control loop is input to a Schmitt trigger circuit. The width of the hysteresis band hysteresis band (HB) is given by

$$HB = V \frac{R_2}{R_1 + R_2} \quad (4.20)$$

Upper switch is on; $(i^* - i) > HB$

Lower switch is on; $(i^* - i) < -HB$

In hysteresis band current control with upper switching closed, the positive current slope is given by:

$$\frac{di}{dt} = \frac{0.5V_d - V_{PCC} \sin wt}{L} \quad (4.21)$$

Similarly with the lower switch closed, the negative current slope is given by:

$$\frac{di}{dt} = \frac{-(0.5V_d - V_m \sin wt)}{L} \quad (4.22)$$

Here $\frac{di}{dt} = \frac{\Delta i}{\Delta t}$ (4.23)

In equation 4.22 $0.5 * V_d$ is the applied voltage, V_m is the voltage across the PCC, L is the effective lead inductance, Δt is the switching frequency and $\Delta i = (i^* - i)$.

4.9: MATLAB Simulation Parameters of Grid Connected PV System

MATLAB/simulation model is developed for a grid connected system and parameters are discussed in this chapter. System parameters are used in grid connected systems as shown in Table 4.2

Table 4.2: PV solar system specification

PARAMETERS	VALUES
3-phase AC Source	415 V, $R_s = 0.01 \Omega$, $L_s = 60 \mu H$
Load	(i) 415 V, 6 kVA, 0.8 lagging pf, (three phase linear load) (ii) Three phase diode rectifier, $R_{dc} = 250 \Omega$ (non linear load)
Interfacing Inductor (L_r)	7 mH
Reference DC-Link Voltage (V_{dc})	800 V
DC-link Capacitor (C_{dc})	3.5 mF
Switching Frequency of Boost Converter (F_{sw})	20 kHz
Inductor for Boost Converter	3 mH
PV Array	$P_{mpp} = 9.415 \text{ kW}$, $V_{mpp} = 310 \text{ V}$, $I_{mpp} = 32.58 \text{ A}$.

The simulation model is run with perturb and observe control technique to obtain the maximum power from the PV array. SRFT and unit template current control techniques are used for triggering the VSI in grid connected PV system. These SRFT and unit template current control output compared with the reference signal in HCC loop. The outputs of the HCC loop triggering the VSI.

The waveform of PCC voltage, grid current, load current, inverter current, DC-link voltage, PV output voltage, PV output current, PV output power and THD (total harmonics distortion) analysis are obtained for four different cases. These are given below.

4.9.1: Linear Load with Constant Irradiation:

In this case, there are three phases 6 kW, 0.8 power factor lagging load is connected to the utility grid and PV array supplies maximum power 9.45 kW at 1000 W/m² solar irradiation and 25°C. At t=0 sec PV solar system is connected to the grid at the point of common coupling in this case will check the system performance with the grid

4.9.2: Non-Linear Load with Constant Irradiation:

In this case, the three-phase diode rectifier is used to connect $R_{dc} = 250 \Omega$ load on dc side. This case will check the system performance, power quality and stability of the DC-link voltage.

4.9.3: Unbalancing of Load with Constant Irradiation

In this case three-phase 6 kW, 0.8 power factor linear load is connected to the grid and PV supply 9.4 kW power at standard solar irradiation and at t=0.20 sec to t=0.40 sec in three-phase load, one of the phase load is disconnected. This case will check the system performance under unbalancing of the load and DC-link voltage stability.

4.9.4: Linear Load with Changing in Solar Irradiation

In this case, there is 6 kW, 0.8 power factor load is connected to the grid and PV solar farms supply the power to the grid at PCC. The solar irradiation reduced from 1000 W/m² to 500 W/m² at t=0.25 sec. This case tests the system performance and DC-link voltage stability of the system under changing solar irradiation.

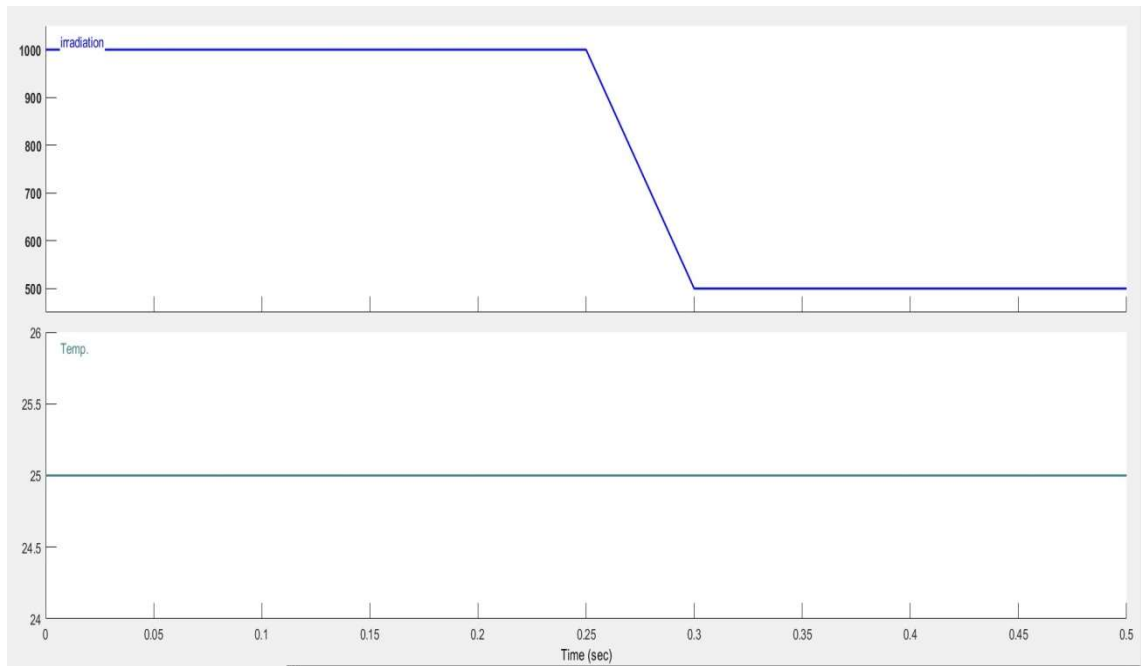


Figure 4.9: Graph of changing in irradiation and temperature

4.10 Conclusion

PV solar system parameters are calculated in this chapter. Boost converter is designed for the development of a grid integrated PV system and implementation of conventional control techniques SRFT and unit template current control is done. The values of various parameters are given in a tabular form in Table 4.2.

CHAPTER 5

SIMULATION RESULTS

5.1: SRFT MATLAB Simulation Results

5.1.1: Simulation Results at Linear Load with Constant Irradiation

In this section at irradiation, 1000 W/m^2 with 25°C are used on PV array, The PV solar system is integrated to the grid at $t=0$ sec using the relay at the PCC. The switching of the VSI is done using the SRFT control techniques and triggering of boost converter is done using perturb and observe MPPT control technique to obtained the maximum power output from the PV system. The system stability by using SRFT can be analysed by using the output waveform as shown.

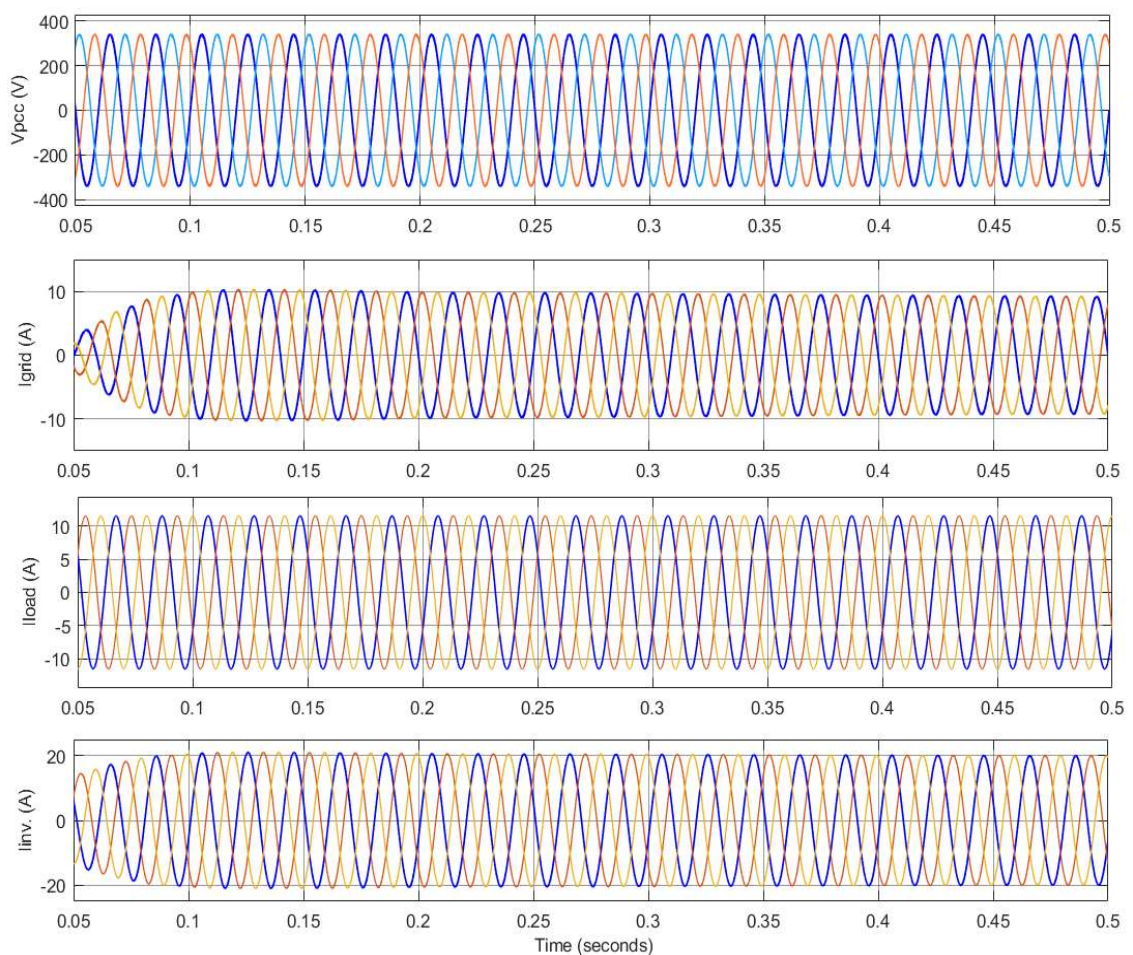


Figure 5.1: Show the results of PCC voltage, grid current, load current and PV inverter output current for linear load

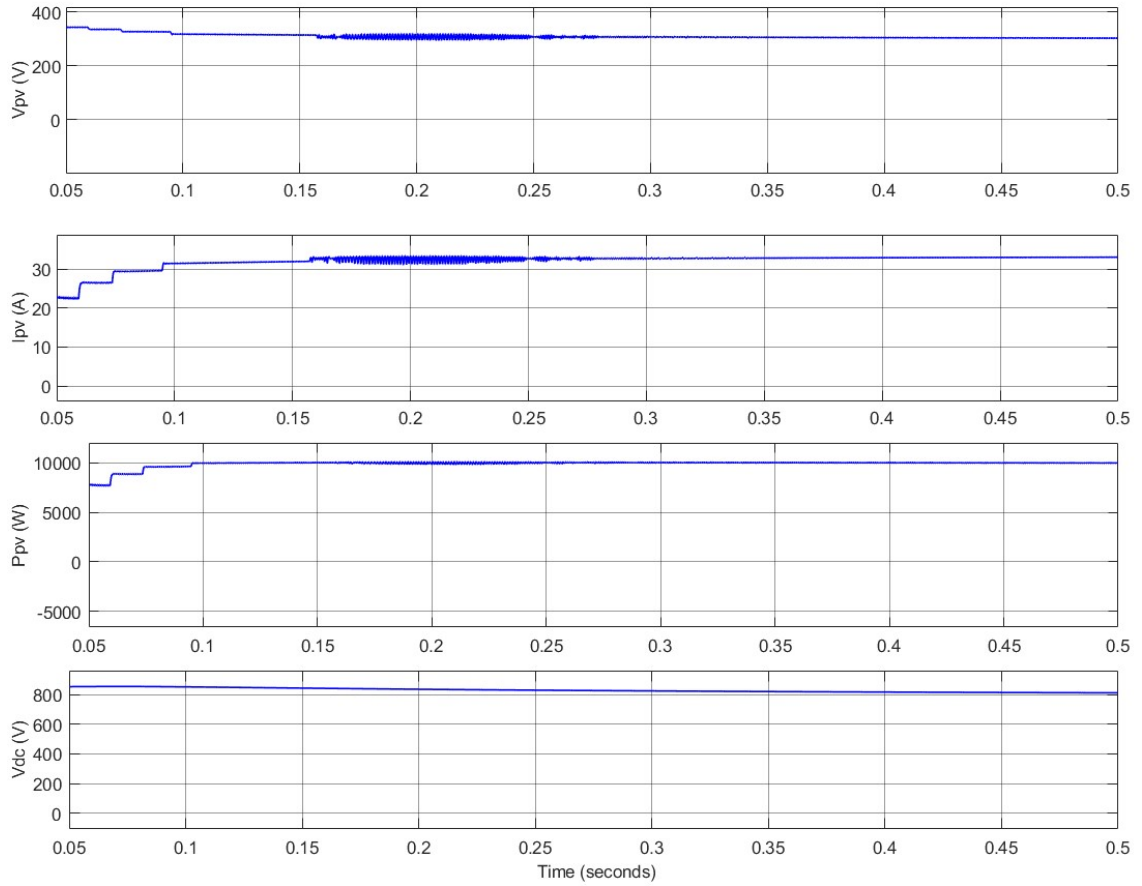


Figure 5.2: Show the simulation results of voltage, current, output power of PV and DC-link voltage

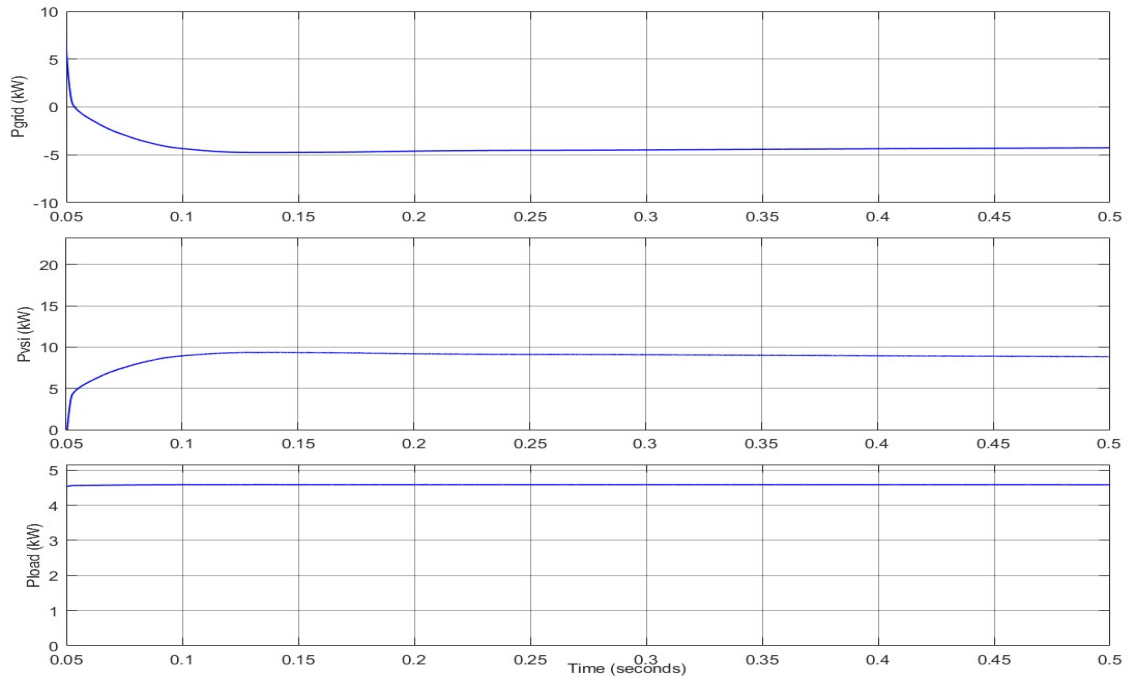


Figure 5.3: Show the simulation of active power of grid, output of PV system and linear load

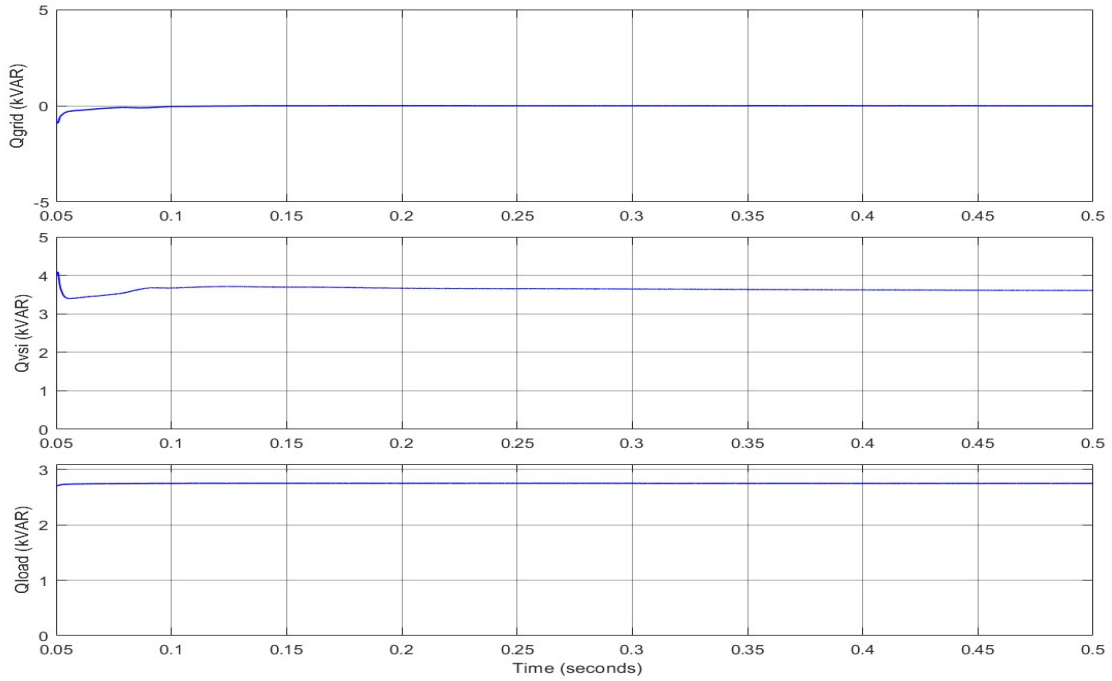


Figure 5.4: Show the simulation results of reactive power of grid, inverter and linear load

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The linear load 6 kW, 0.8 pf lagging load is connected at distribution end. The results of in Figure 5.1; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.2; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.3; P_{load} , P_{vsi} , P_{grid} and Figure 5.4; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable approx 800 V and active power of the grid (P_{grid}) have negative it means PV solar system is delivering the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power (Q) of the grid at zero which is indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power (Q_{grid}) remain zero.

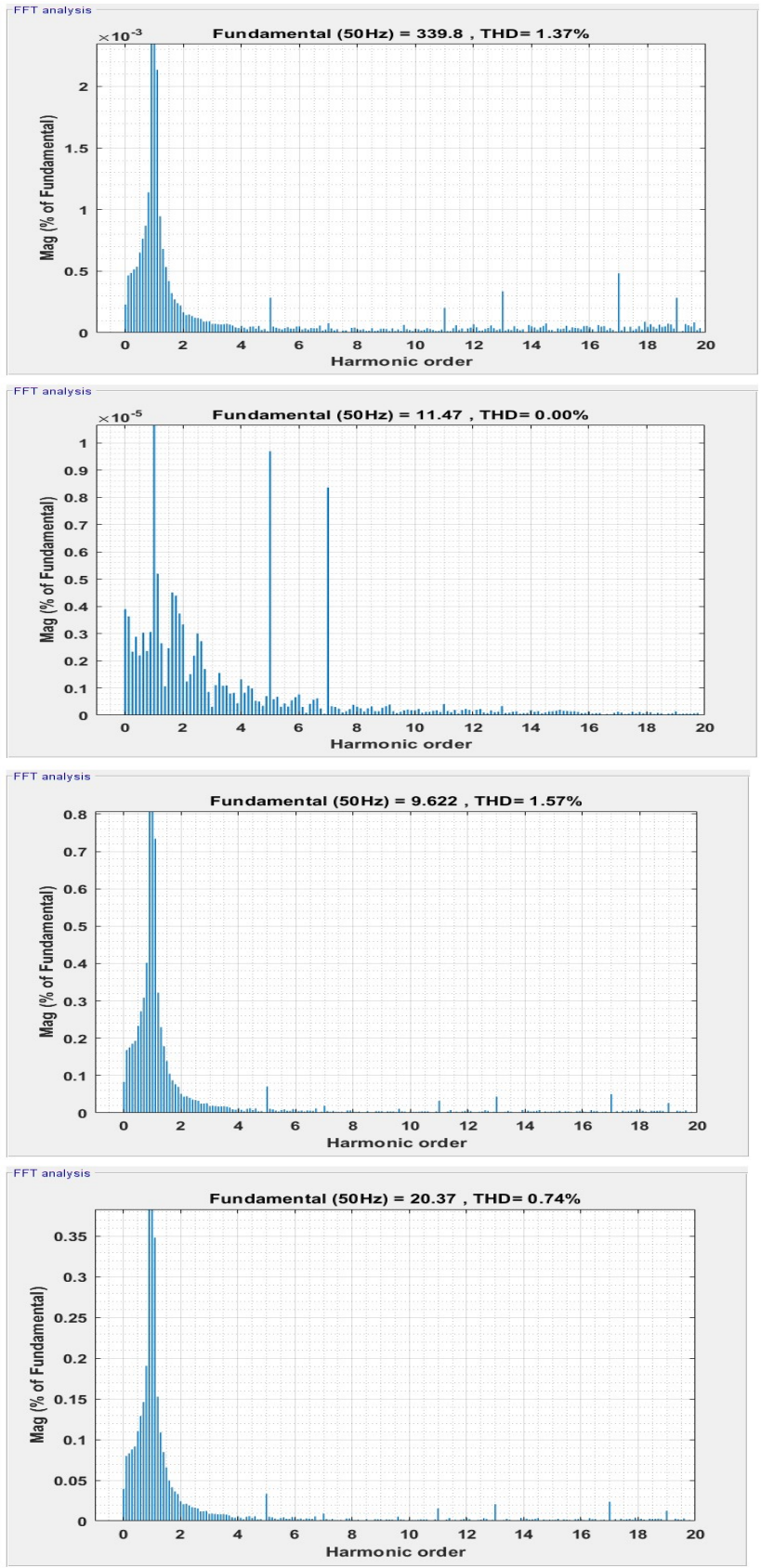


Figure 5.5: FFT analysis of voltage of PCC, grid current, PV inverter output current and load current respectively

Figure 5.5 FFT analysis PCC voltage, grid current, PV inverter output current and load current using SRFT control technique respectively. THD in V_{pcc} , I_{grid} , I_{inv} and I_{load} , are 1.37%, 0.0%, 1.57%, 0.74%, respectively.

5.1.2: Simulation Results at Non-Linear Load with Constant Irradiation

This subsection discusses the system performance when the resistive load R_{dc} 250 ohm is connected using the three-phase rectifier on the dc side. Worldwide mostly AC supply is available so I need to use an adapter for connecting with the AC sources. The widely used these gadgets harmonics arise in the system due to energy loss in form of heat, damaging of wire, mal-operation of relays are various problems arise so need to use filters or reactive power compensation to maintain the synchronous stability of voltage and current at the utility grid.

The system stability using the SRFT control techniques for non-linear load is analysis waveforms are shown

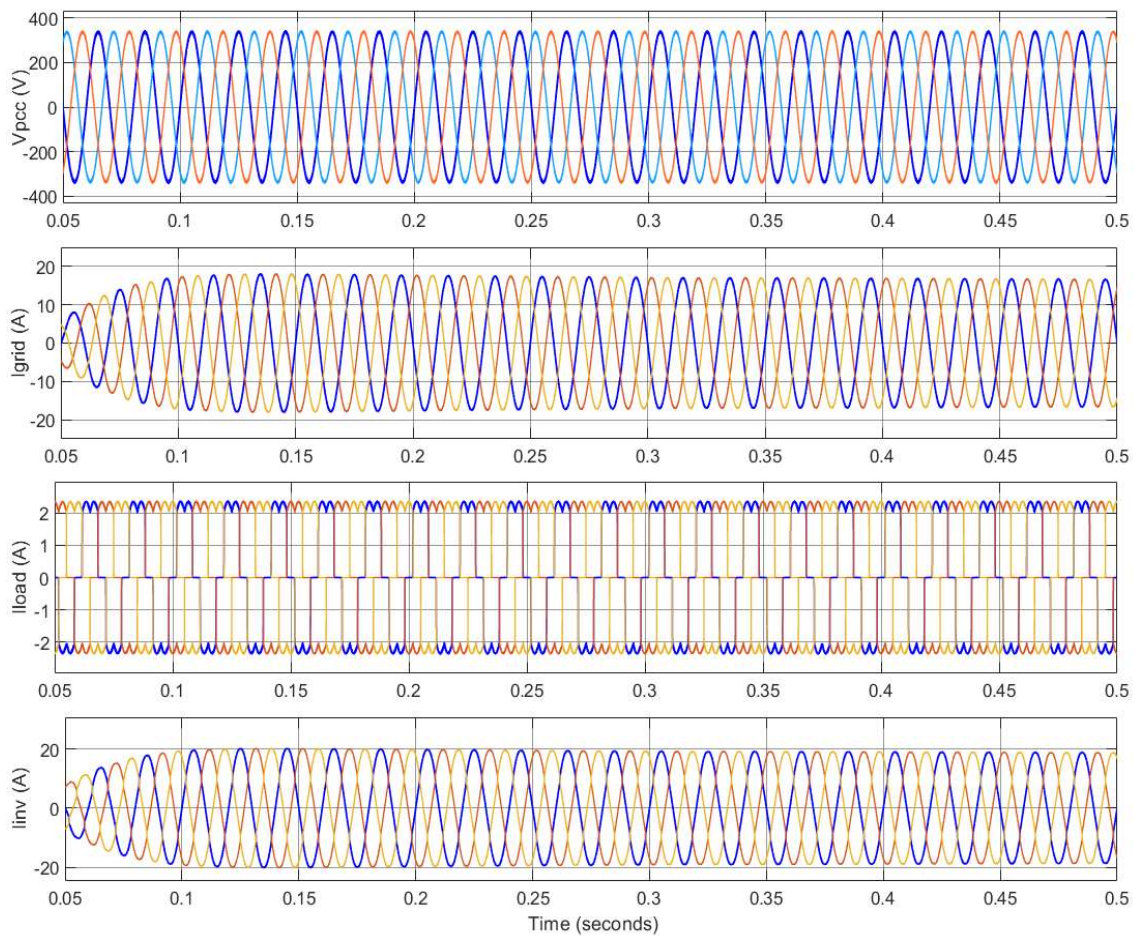


Figure 5.6: Show the simulation results of PCC voltage, grid current, load current and PV inverter output current for non-linear load

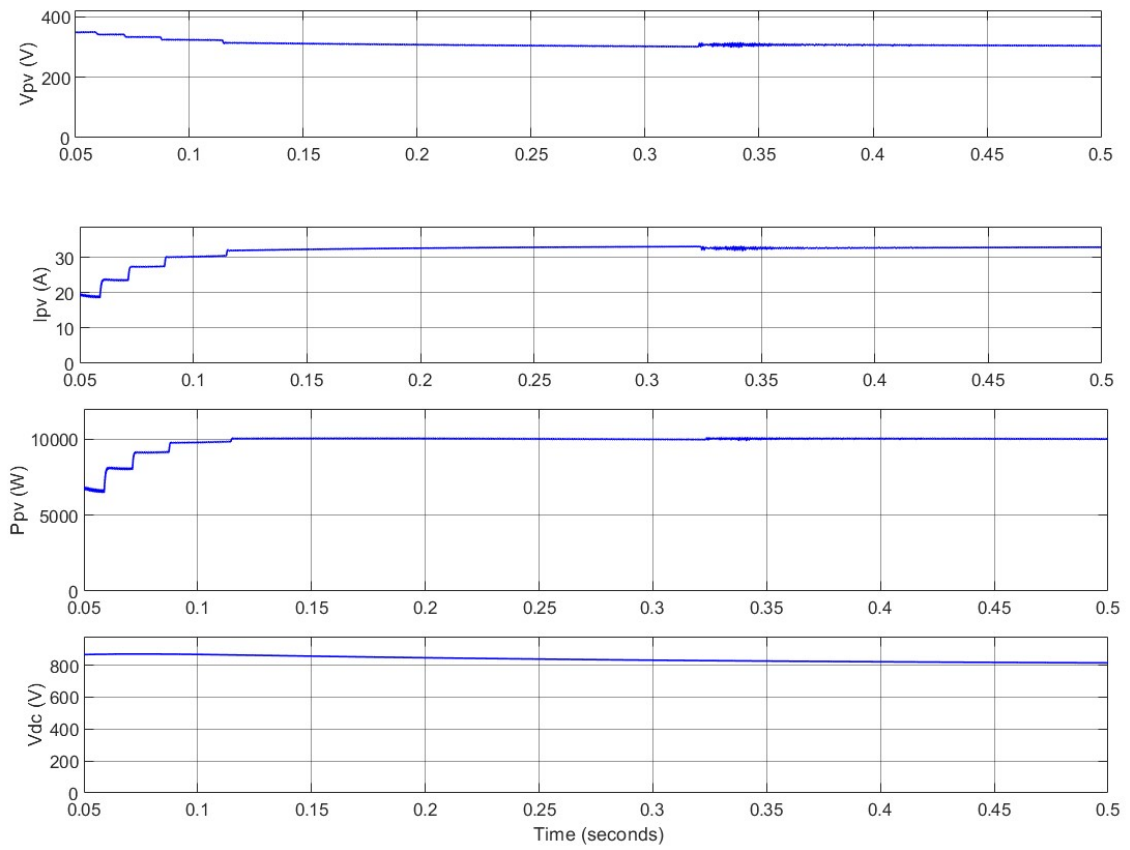


Figure 5.7: Show the simulation results of voltage, current, power of PV and DC-link voltage

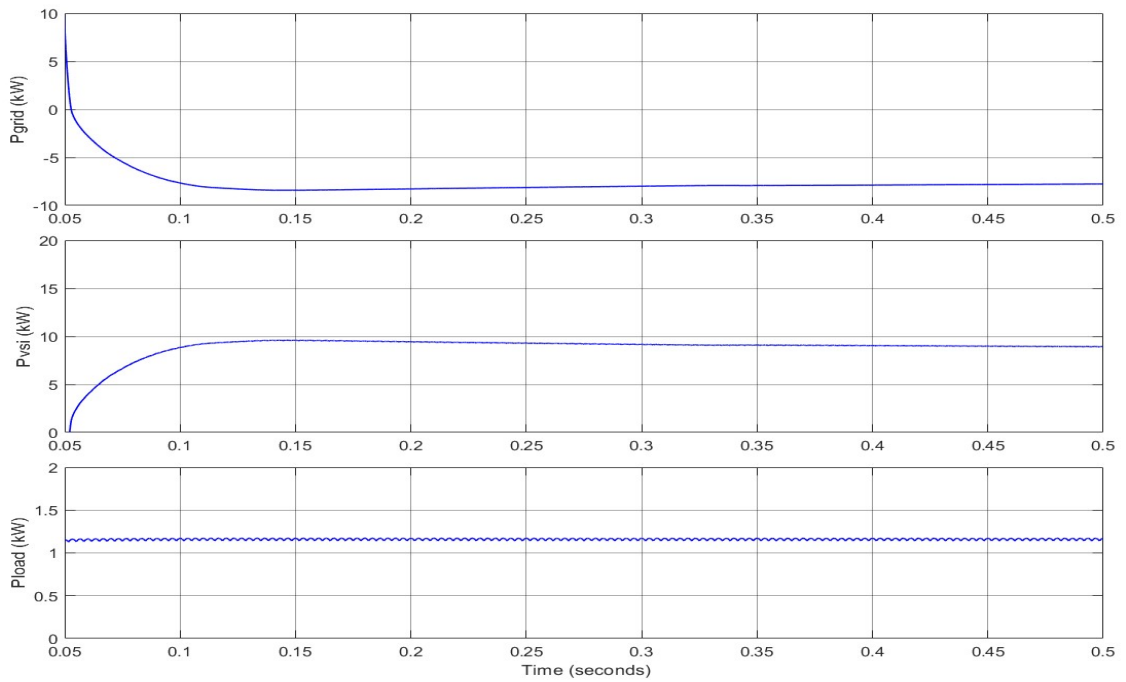


Figure 5.8: Show the simulation results of SRFT based active power of grid, PV system and load at non-linear load

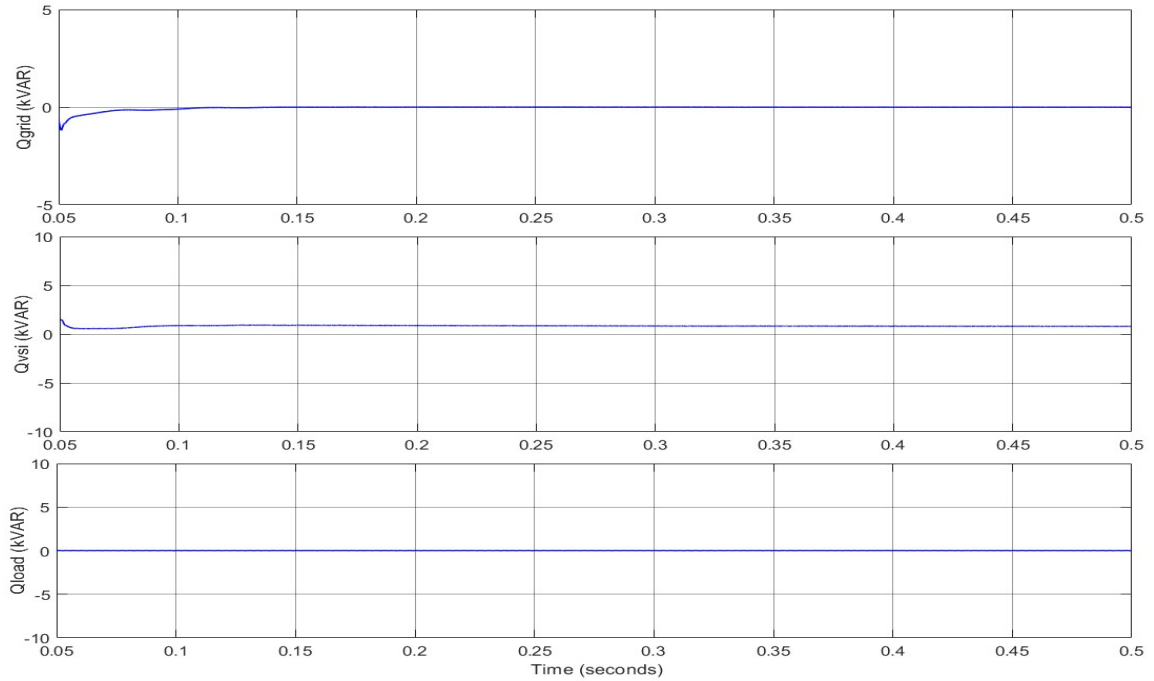


Figure 5.9: Show the simulation results of reactive power of grid, inverter and non-linear load

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The non-linear load $R_{dc}=250$ ohm dc load is connected at distribution end. The results of in Figure 5.6; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.7; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.8; P_{load} , P_{vsi} , P_{grid} and Figure 5.9; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable approx 800 V and active power of the grid P_{grid} have negative it means PV solar system is deliver the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power (Q) of the grid at zero which is indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode.

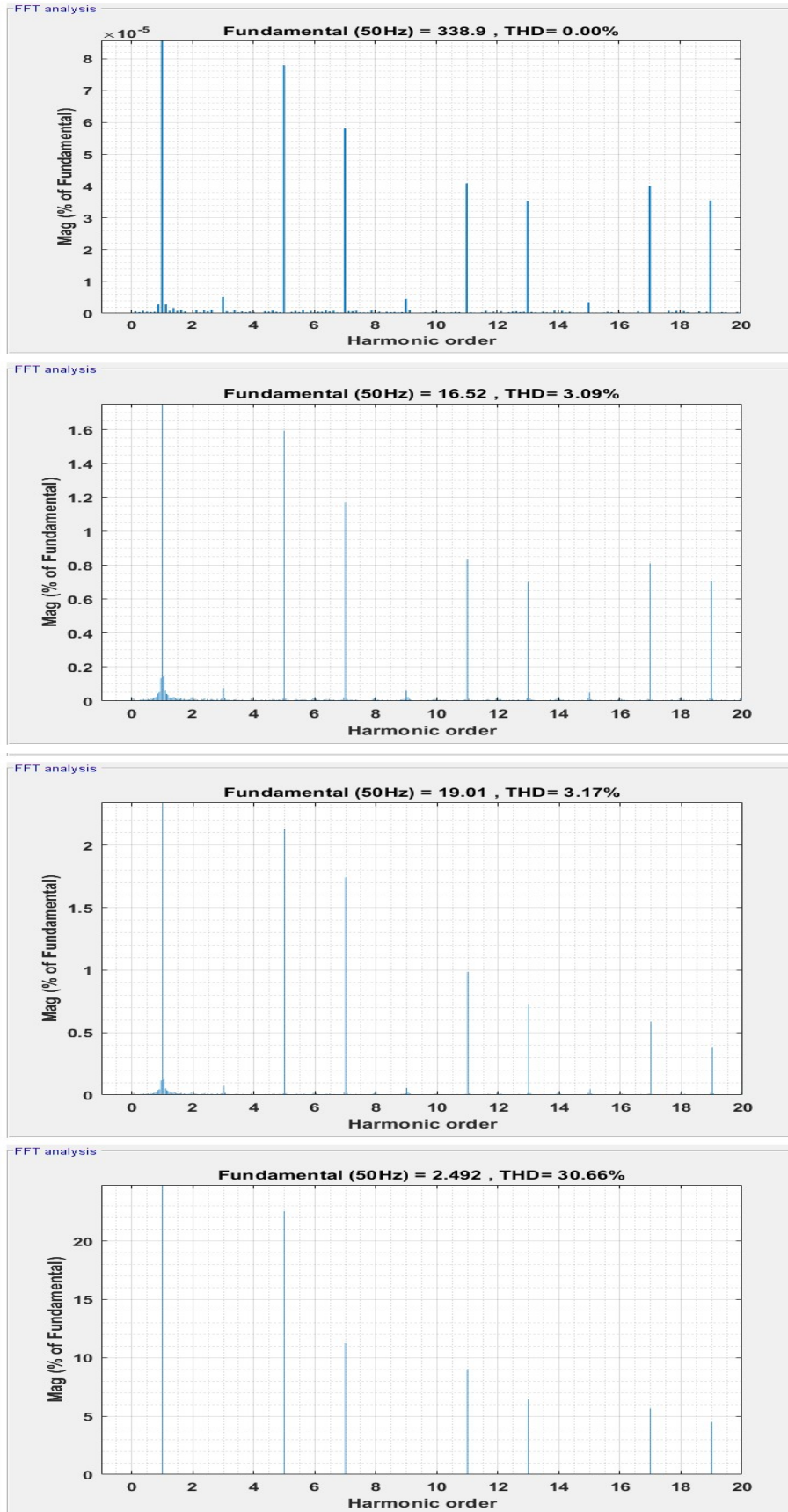


Figure 5.10: FFT analysis of voltage of PCC, grid current, PV inverter output current and load current respectively

Figure 5.10 FFT analysis PCC voltage, grid current, PV inverter output current and load current for non-linear load using SRFT control technique respectively. THD in V_{pcc} , I_{grid} , I_{inv} and I_{load} , are 0.0%, 3.09%, 3.17%, 30.66%, respectively.

5.1.3: Unbalancing in Load with Constant Irradiation

In this section at irradiation, 1000 W/m^2 with 25°C are used on PV array, The PV solar system is connected to the grid at $t=0$ sec. using the relay at the point of common coupling. The triggering of the VSI is done using the SRFT control techniques and triggering of boost converter is done using perturb and observe MPPT control technique for obtained the maximum power output from the PV system.

An imbalance is created from 0.2 sec to 0.4 sec by disconnecting the phase b; the MATLAB/simulation model waveforms are given for analysis the system performances.

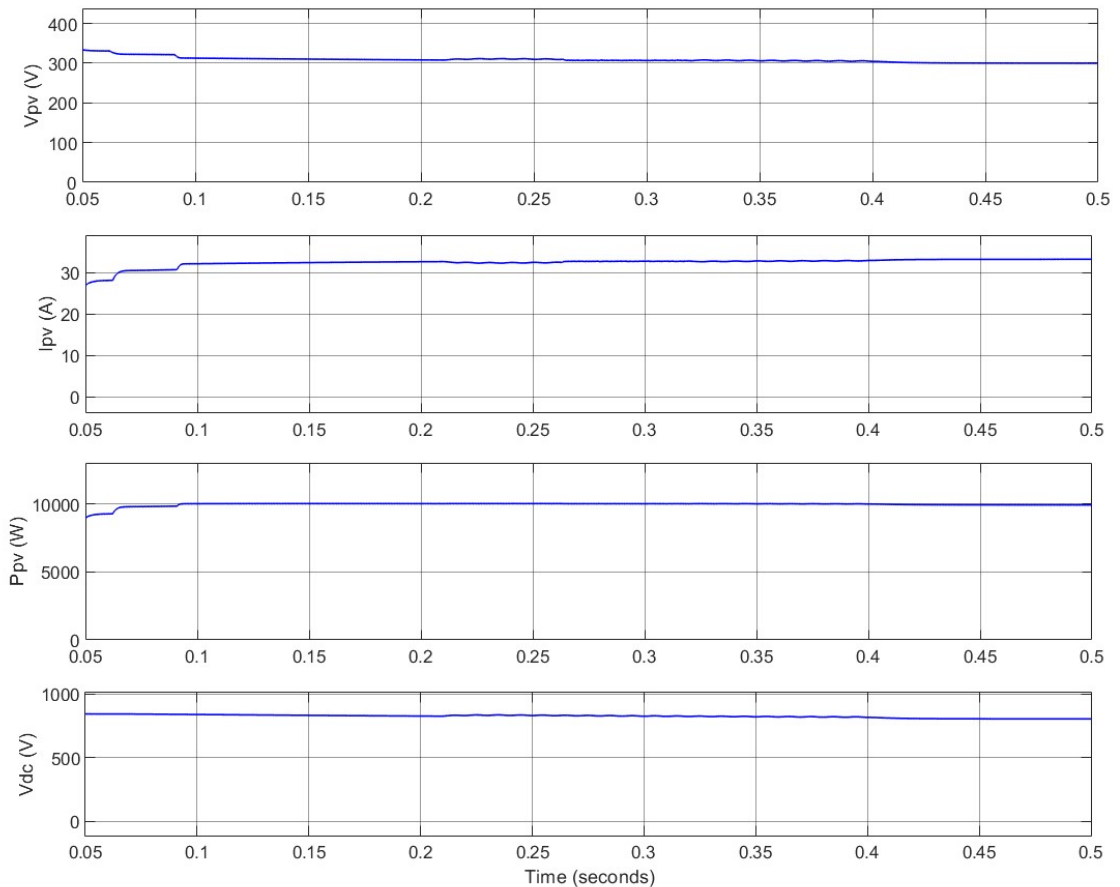


Figure 5.11: Show the simulation results of voltage, current, power of PV and DC-link voltage for unbalanced linear load

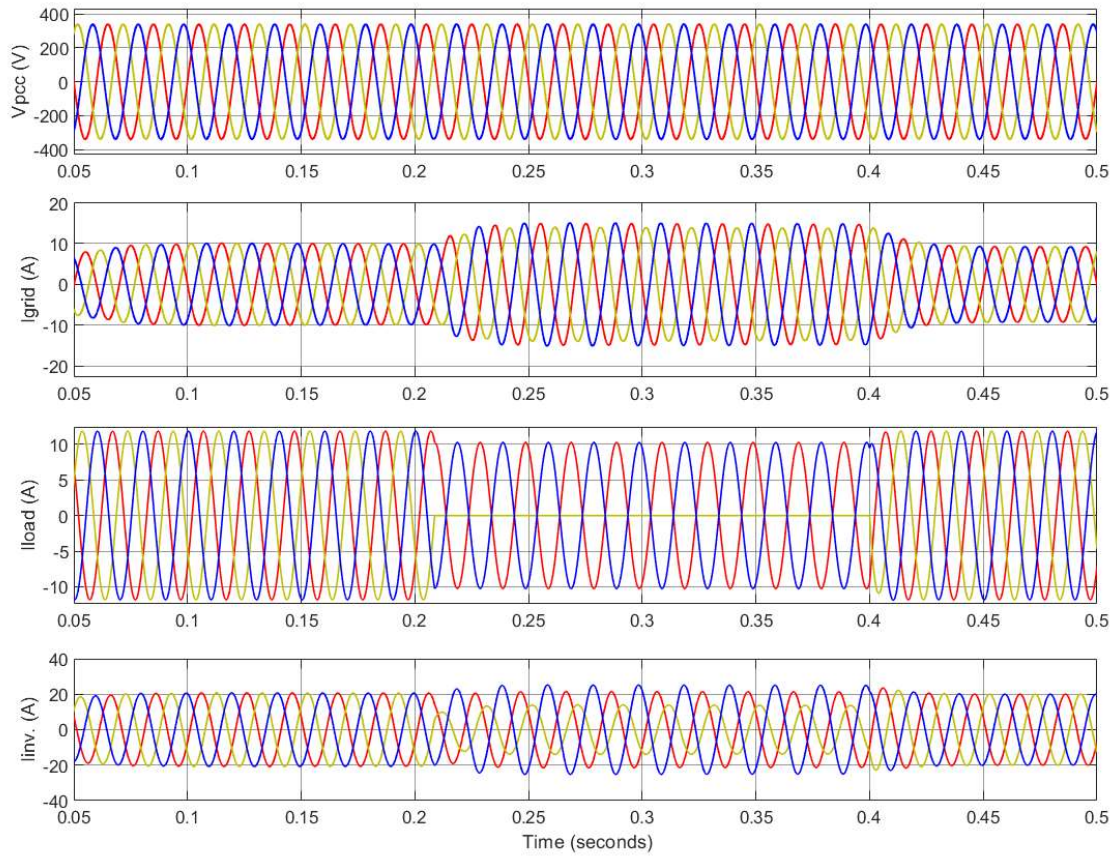


Figure 5.12: Show the simulation results of PCC voltage, grid current, load current and PV inverter output current for linear load

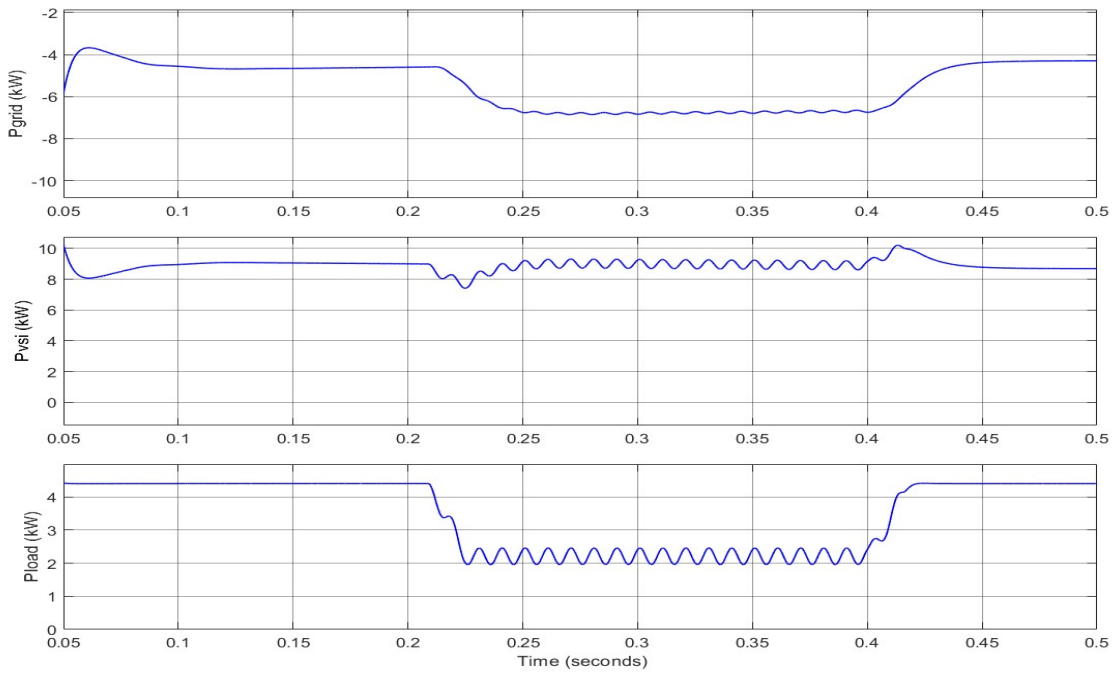


Figure 5.13: Show the simulation results of grid, PV system and load power at unbalanced linear load

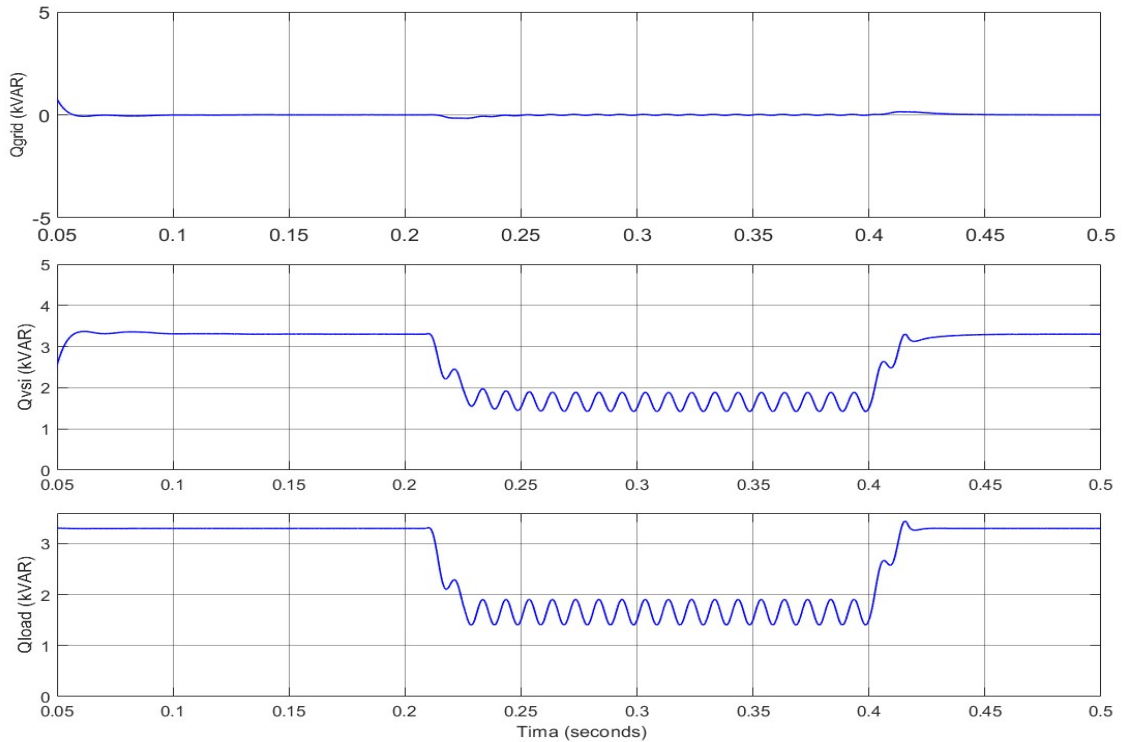


Figure 5.14: Show the simulation results of grid, PV system and load reactive power at unbalanced linear load

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The linear load 6 kW, 0.8 pf lagging load is connected at distribution end. The results of in Figure 5.11; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.12; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.13; P_{load} , P_{vsi} , P_{grid} and Figure 5.14; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable approx 800 V and active power of the grid P_{grid} have negative it means PV solar system is deliver the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power of the grid is at zero which indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power Q_{grid} remain zero.

At 0.2 sec slightly disturbances in power, voltage and current of the PV and settled back to steady state conditions as shown in given results.

5.1.4: Linear Load with Changing in Solar Irradiation

In this section at irradiation, 1000 W/m^2 reduce to 500 W/m^2 at 0.25 sec with 25°C are used on PV array, The PV solar system is integrated to the grid at $t=0$ sec. using the relay at the PCC. The switching of the VSI is done using the SRFT control techniques and triggering of boost converter is done using perturb and observe MPPT control technique to obtained the maximum power output from the PV system. The simulation model results are taken for comparative analysis and to understand the behaviour of the model with changes in environmental conditions. The PV solar system stability by using SRFT current control technique can be analysis by using the output waveform of the simulation model.

The MATLAB/simulation model is performs with dynamic changes in solar irradiation and obtained waveforms results are given

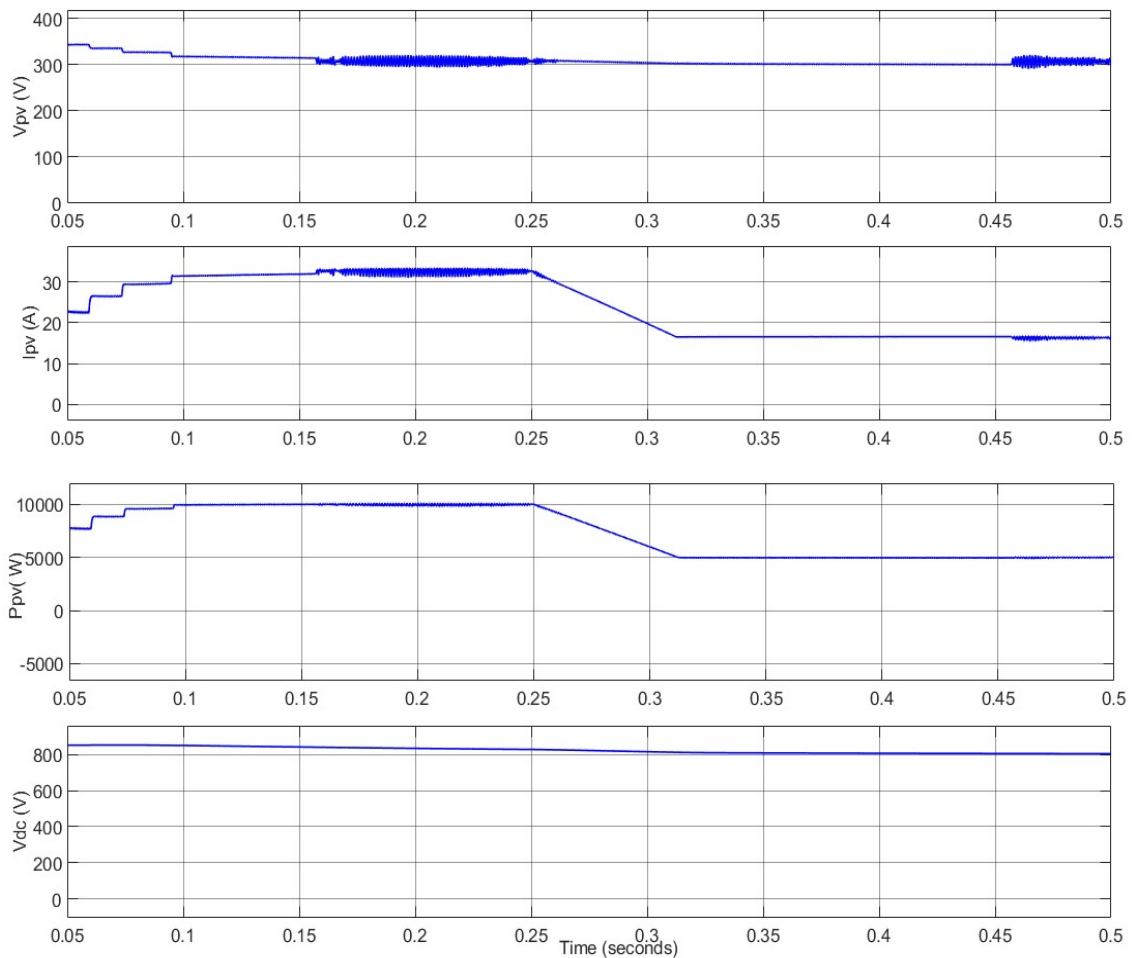


Figure 5.15: Show the simulation results of voltage, current, power of PV and DC-link voltage

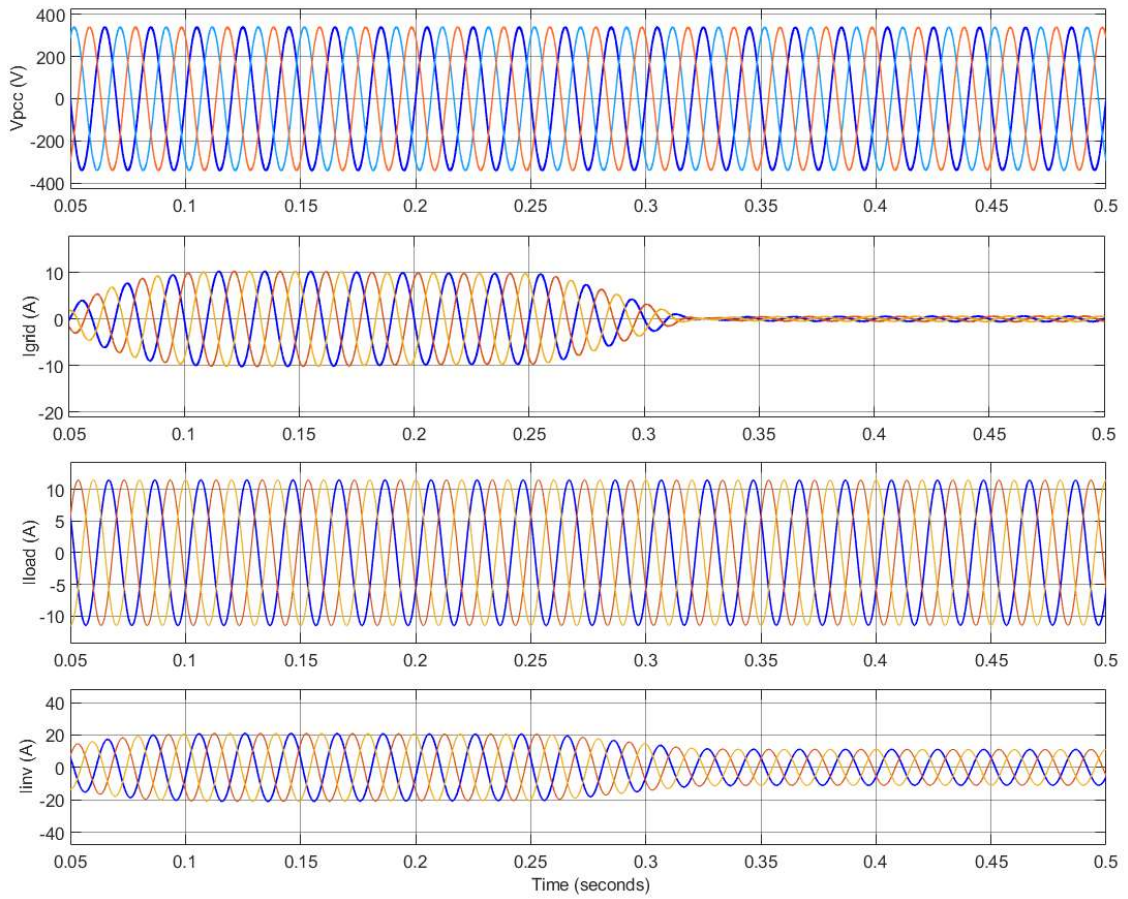


Figure 5.16: Show the simulation results of PCC voltage, grid current, load current and inverter current

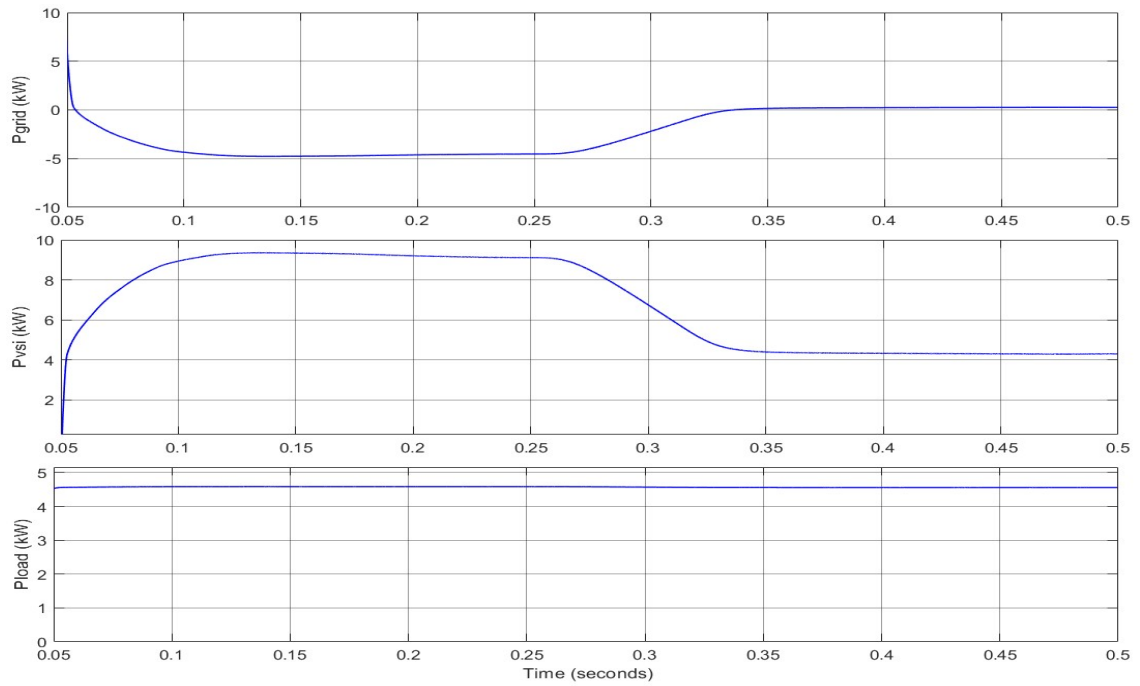


Figure 5.17: Show the simulation results of active power of grid, PV inverter and load demand

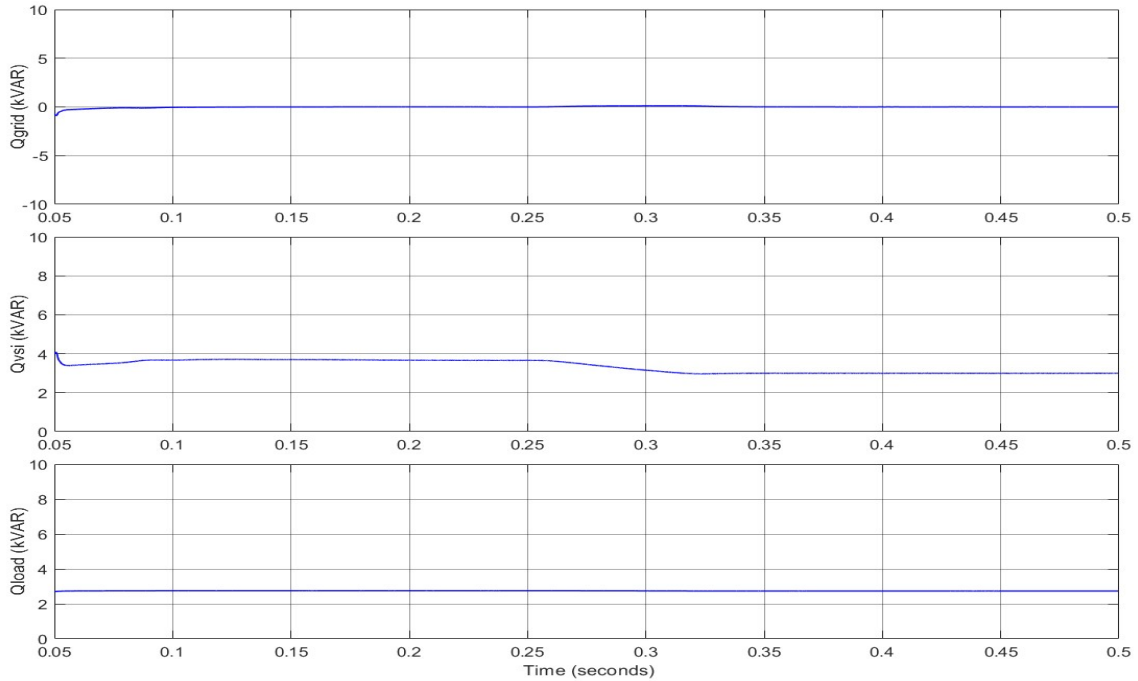


Figure 5.18: Show the simulation results reactive power of grid, inverter and load demand

Solar irradiation is reduced from 1000 W/m^2 to 500 W/m^2 on 0.2 sec. Changing in the solar intensity of the PV array affects the PV current such that fall in irradiation leads to fall in PV current along with PV power. This can be easily observed in the PV characteristics plot, where the PV power and current are reduced to half when solar irradiation become half and voltage remain almost undisturbed. The loss in delivering the PV solar power, grid gain the active power becomes low.

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The linear load 6 kW, 0.8 pf lagging load is connected at distribution end. The results of in Figure 5.15; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.16; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.17; P_{load} , P_{vsi} , P_{grid} and Figure 5.18; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable at 800 V and active power of the grid P_{grid} have negative it means PV solar system is deliver the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power of the grid is at zero which indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power Q_{grid} remain zero.

Table 5.1: Comparison of different parameters for linear and non-linear load using SRFT

PARAMETER	LINEAR LOAD	NON LINEAR LOAD
	At 1000 W/m ²	At 1000 W/m ²
V_{pv} (V)	310	312
I_p (A)	32.4	32.4
P_{pv} (kW)	10.04	9
V_{dc} (V)	800	802
V_{pcc} (V)	415	415
I_{grid} (A)	-9.62	-16.52
I_{inv} (A)	20.37	19.01
I_{load} (A)	11.47	2.50
P_{inv} (kW)	9.5	10
Q_{inv} (kVAR)	3.8	0.5
P_{grid} (kW)	-4.5	-8
Q_{grid} (kVAR)	0	0
P_{load} (kW)	4.8	1.2
Q_{load} (kVAR)	3.6	0

In Table 5.2 show the comparison analysis for the linear load and non-linear load at 1000 W/m² and 25 °C.

5.2: Unit Template Current Control MATLAB Simulation Results

5.2.1: Linear Load with Constant Irradiation

In this section at irradiation, 1000 W/m^2 with 25°C are used on PV array, The PV solar system is connected to the grid at $t=0$ sec. using the relay at the point of common coupling. The triggering of the VSI is done using the SRFT control techniques and triggering of boost converter is done using perturb and observe MPPT control technique to obtained the maximum power output from the PV system. The system stability by using SRFT can be analysis by using the output waveform of the simulation model.

The results of simulation model are taken for various system parameters for the comparative analysis of the control techniques. The time limit is taken 0.05 sec to 0.5 sec for the waveform results.

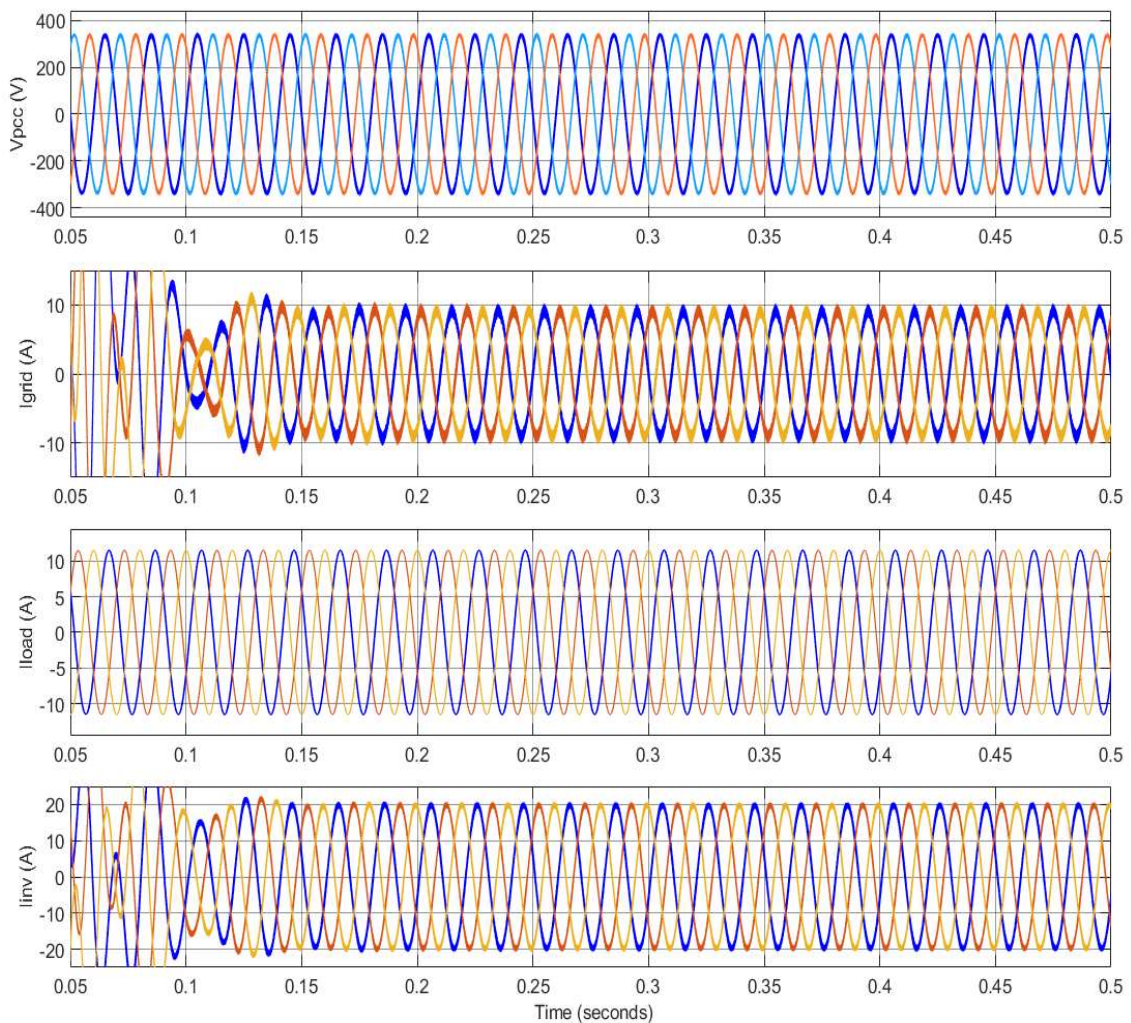


Figure 5.19: Show the simulation results of PCC voltage, grid current, load current and PV inverter output current

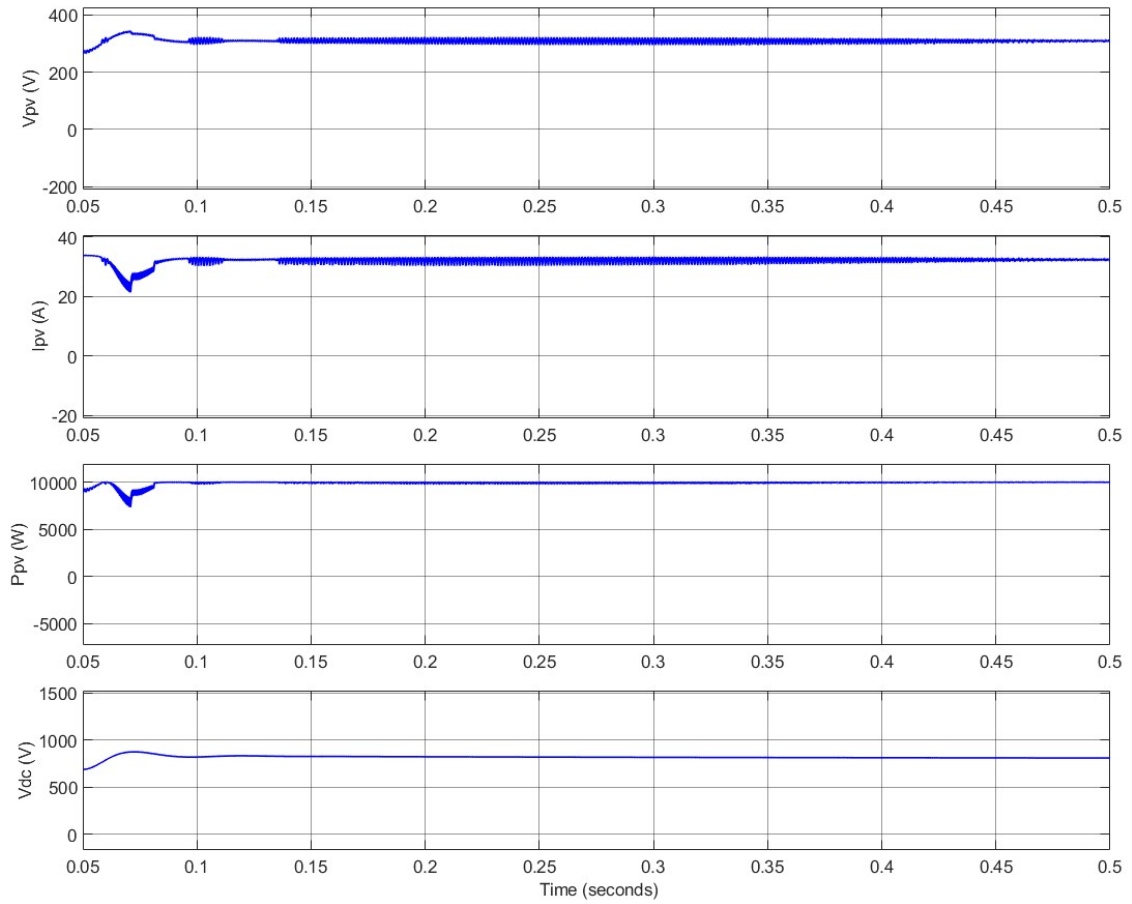


Figure 5.20: Show the simulation results of voltage, current, power of PV and DC-link voltage

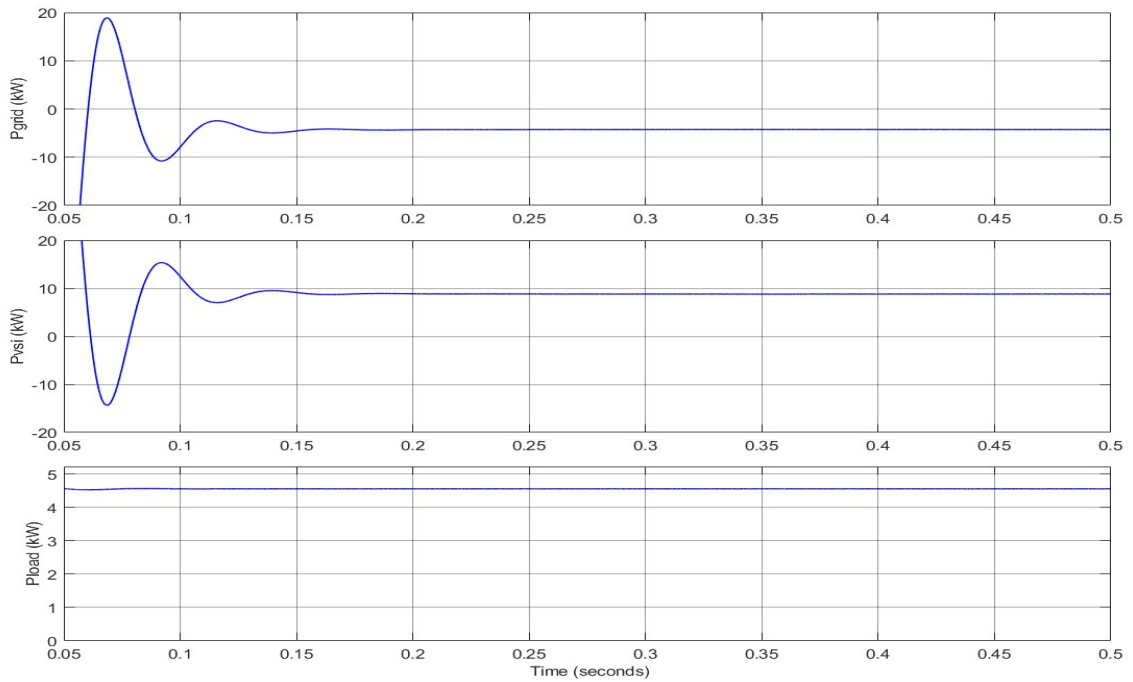


Figure 5.21: Show the simulation results of active power of grid, inverter and load demand

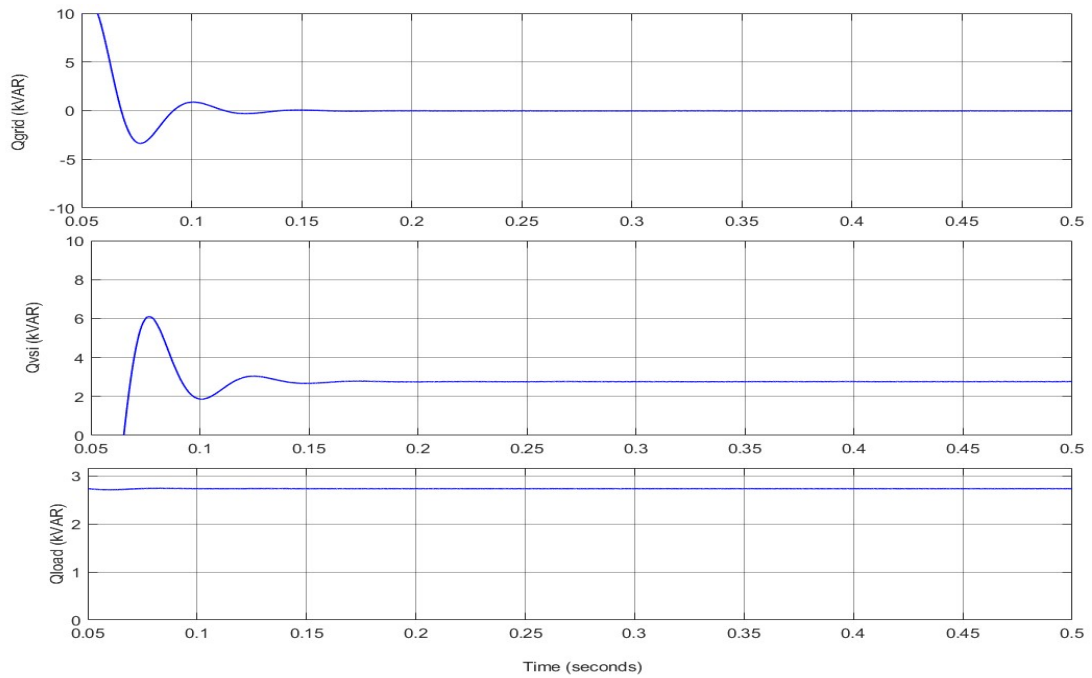


Figure 5.22: Show the simulation results of reactive power of grid, inverter and load demand

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The linear load 6 kW, 0.8 pf lagging load is connected at distribution end. The results of in Figure 5.19; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.20; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.21; P_{load} , P_{vsi} , P_{grid} and Figure 5.22; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable approx 800 V and active power of the grid P_{grid} have negative it means PV solar system is delivering the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power Q of the grid is at zero which indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power Q_{grid} remain zero.

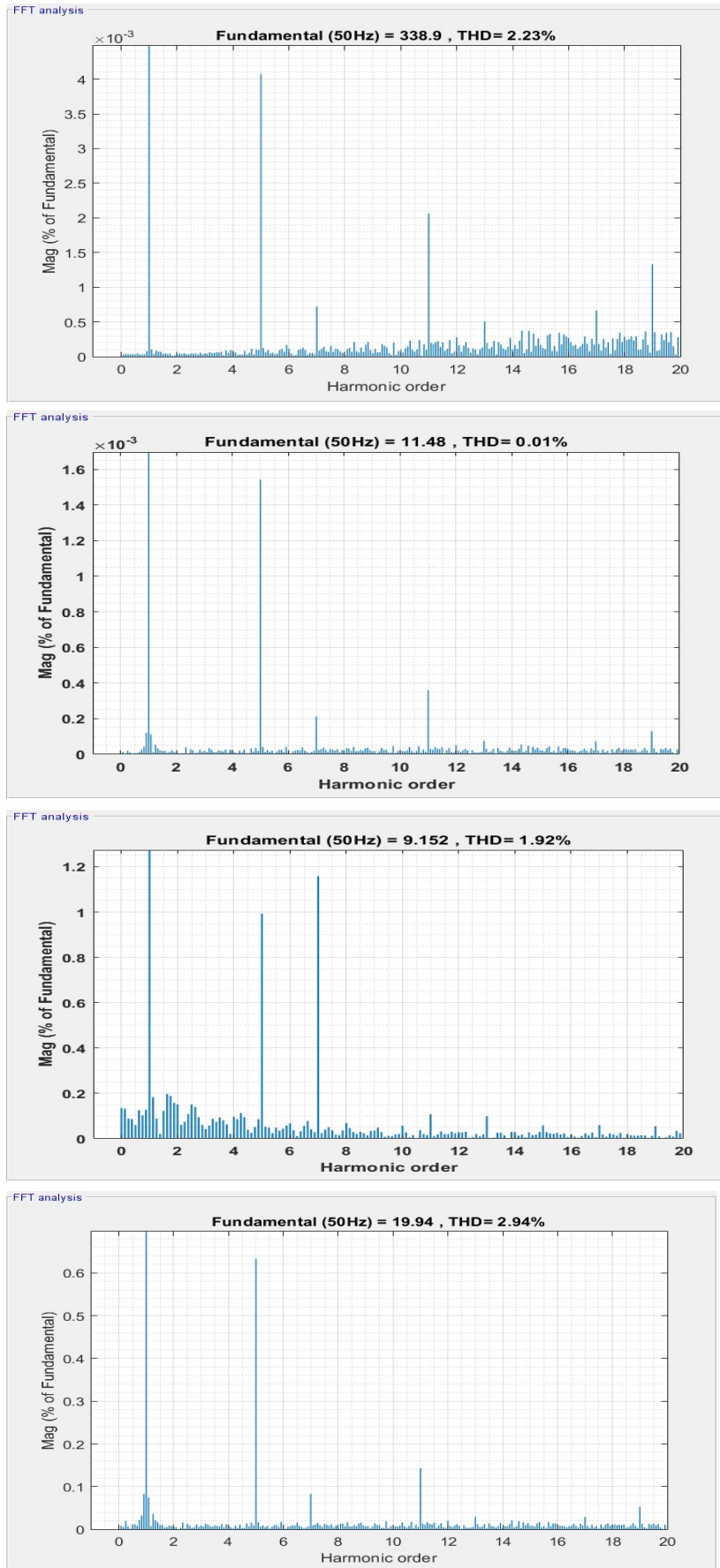


Figure 5.23: Harmonics profile of V_{pcc} , load current, grid current and PV inverter current respectively

Figure 5.23 FFT analysis PCC voltage, grid current, PV inverter output current and load current using unit template current control technique respectively. THD in V_{pcc} , I_{grid} , I_{inv} and I_{load} , are 2.23%, 0.01%, 1.92%, 2.94%, respectively.

5.2.2: Simulation Results at Non-Linear Load with Constant Irradiation

This subsection discusses the system performance when the resistive load R_{dc} 250 ohm is connected using the three-phase rectifier on the dc side. Worldwide mostly AC supply is available so I need to use an adapter for connecting with the AC sources. The widely used these gadgets harmonics arise in the system due to energy loss in form of heat, damaging of wire, mal-operation of relays are various problems arise so need to use filters or reactive power compensation to maintain the synchronous stability of voltage and current at the utility grid.

The system stability using the unit template current control techniques for non-linear load is analysis waveforms are shown

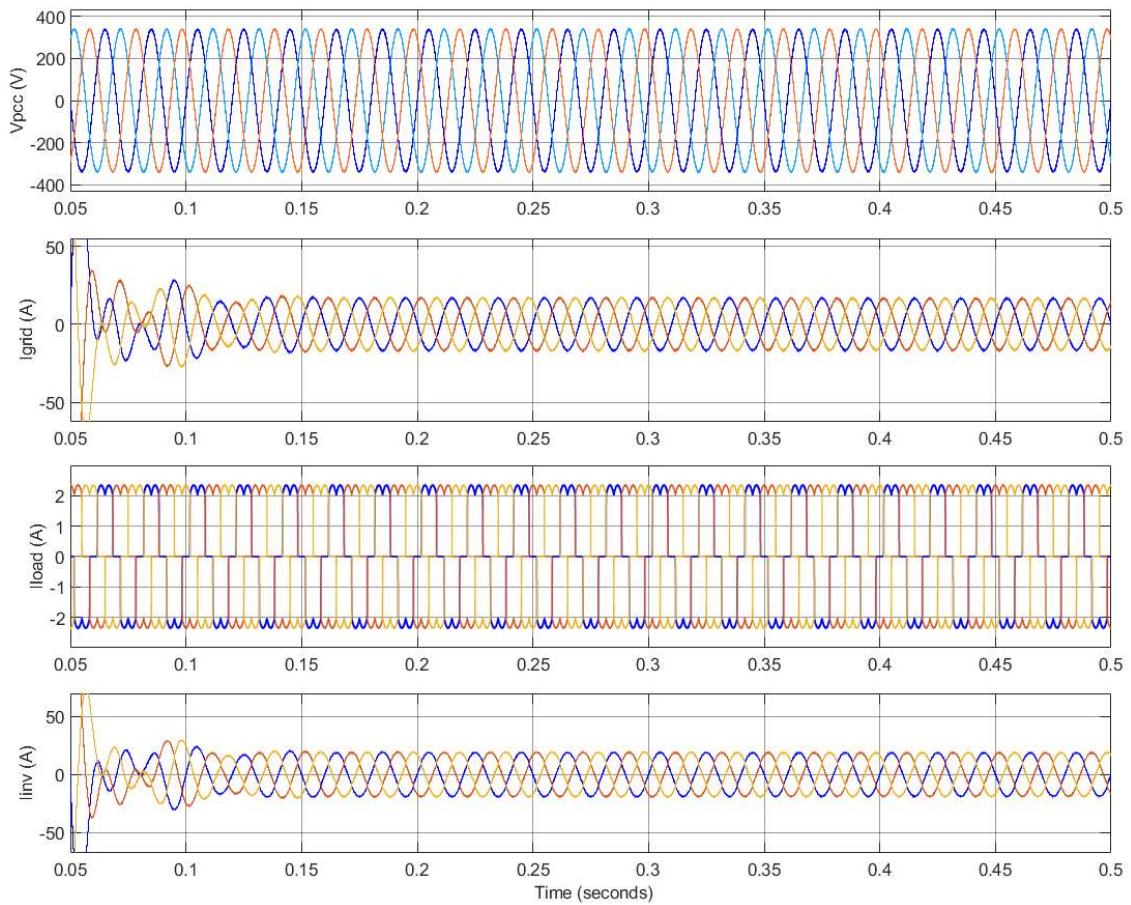


Figure 5.24: Simulation results show the THD of PCC voltage, load current, grid current and inverter current for non-linear load

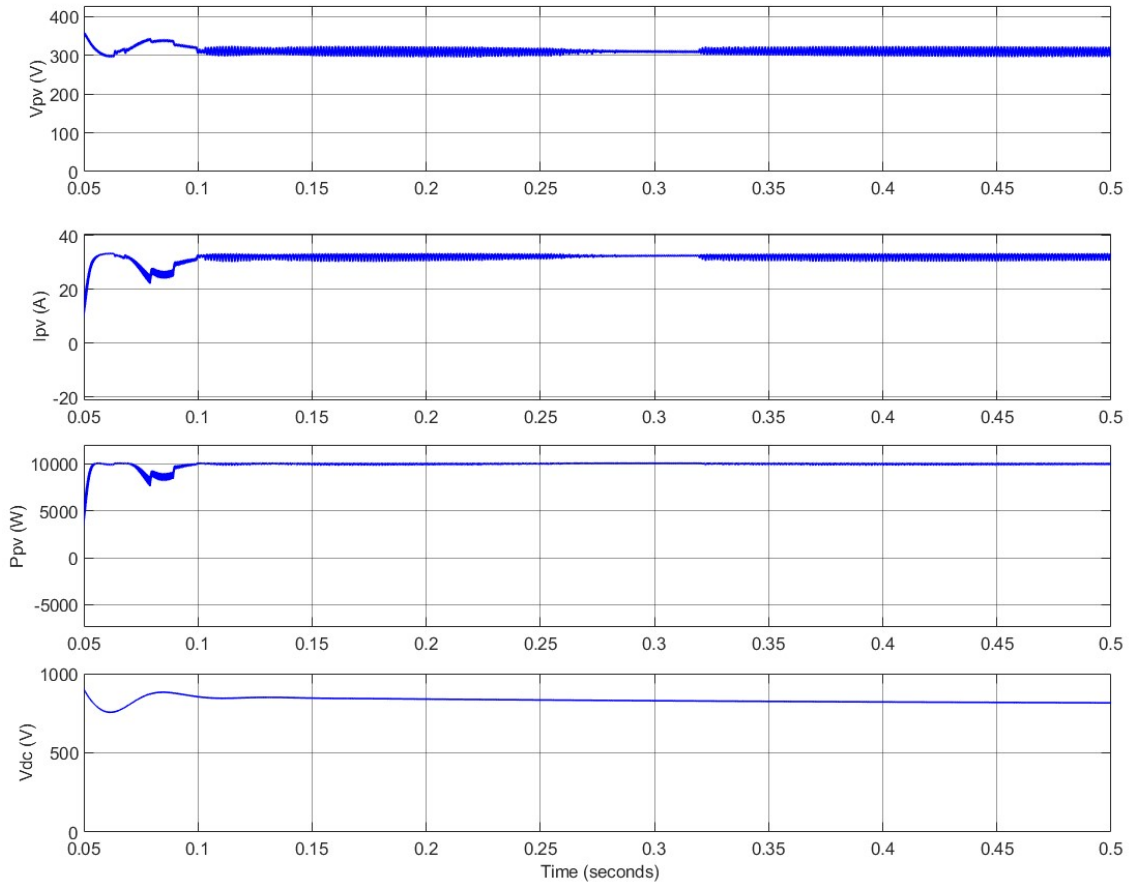


Figure 5.25: Show the simulation results of voltage, current, power of PV and DC-link voltage for non-linear load

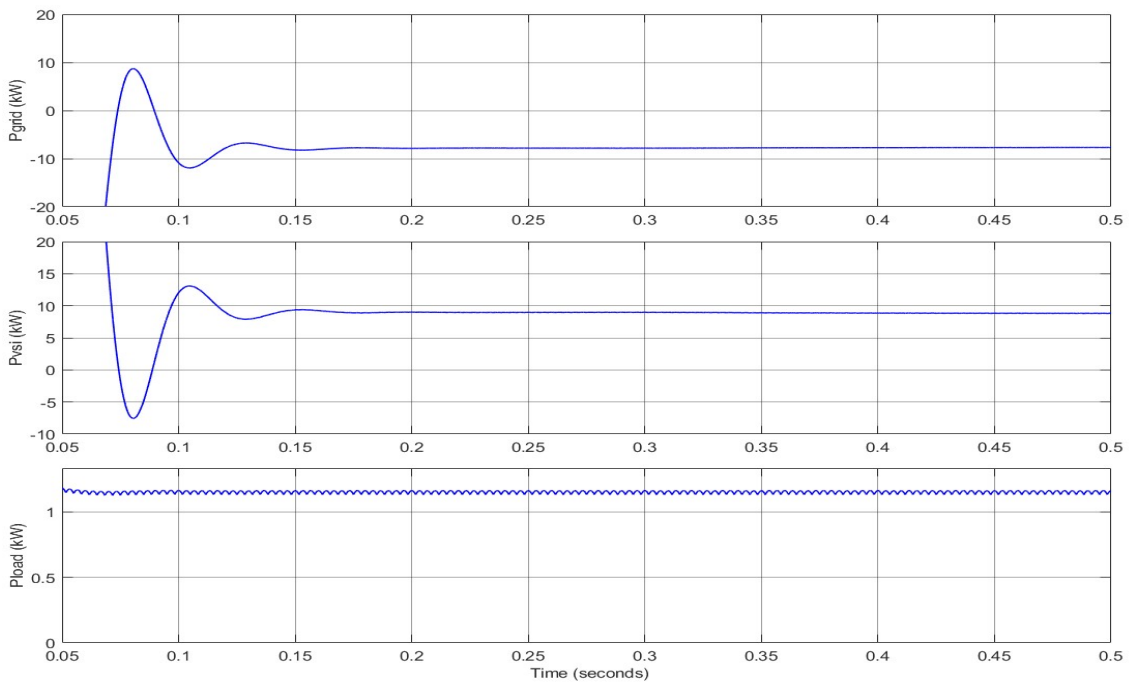


Figure 5.26: Show the simulation results of grid, PV system and load power for non-linear load

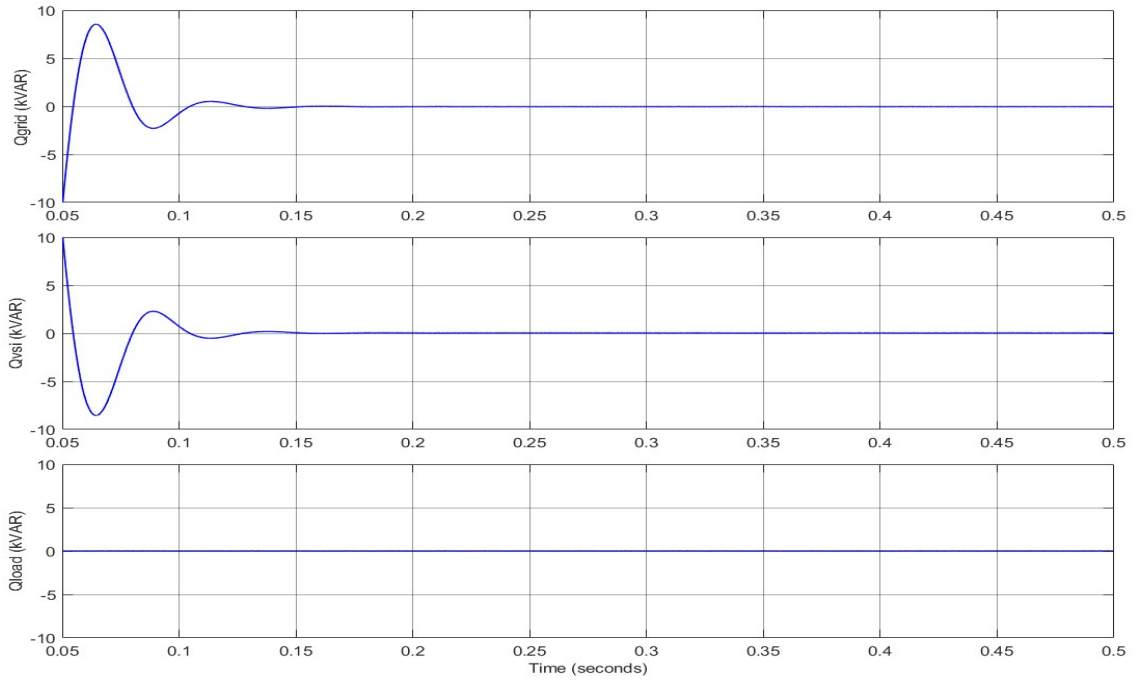


Figure 5.27: Show the simulation results of reactive power of grid, inverter and load demand with non-linear load

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The non-linear load $R_{dc}=250$ ohm dc load is connected at distribution end. The results of in Figure 5.24; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.25; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.26; P_{load} , P_{vsi} , P_{grid} and Figure 5.27; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable approx 800 V and active power of the grid P_{grid} have negative it means PV solar system is delivering the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power of the grid is at zero which indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power Q_{grid} remain zero.

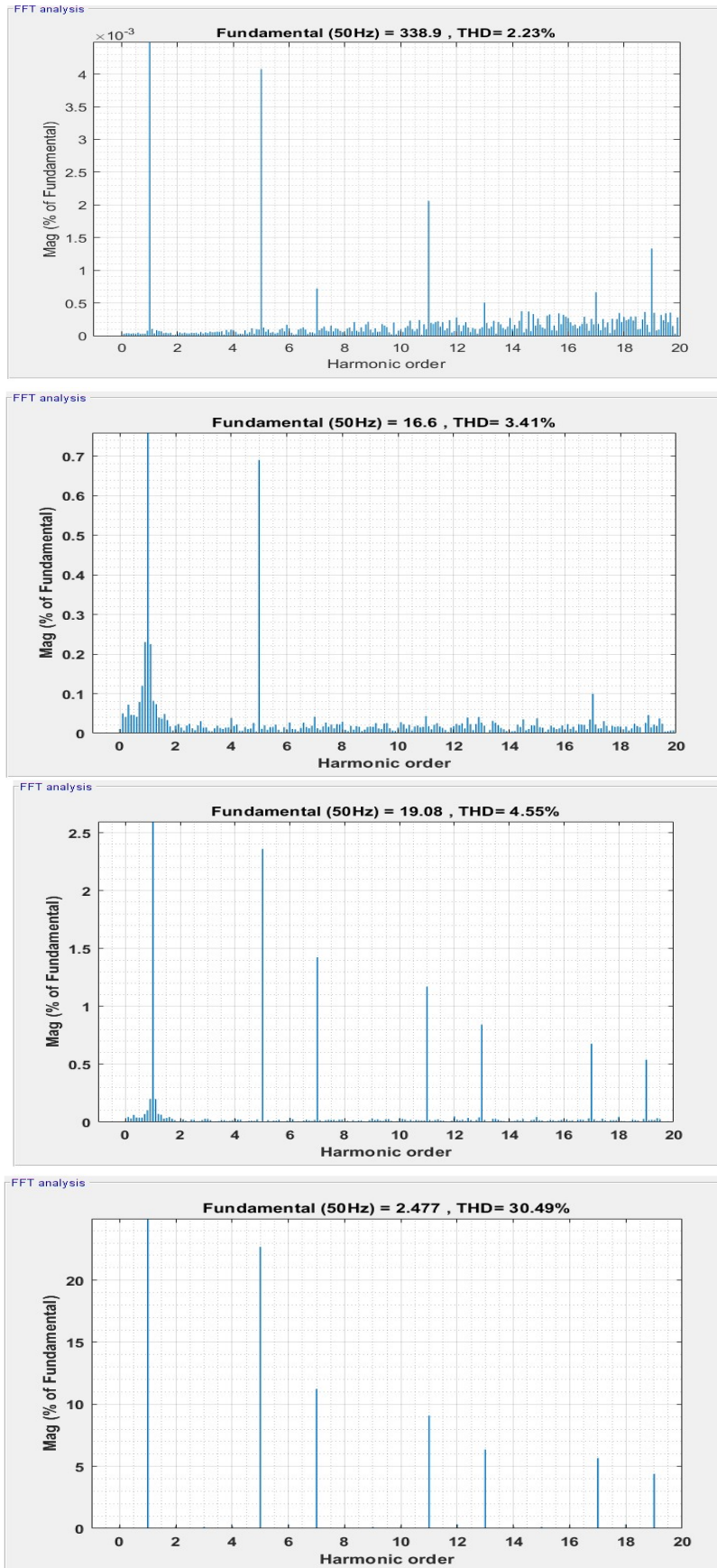


Figure 5.28: FFT analysis of voltage of PCC, grid current, PV inverter output current and load current respectively

Figure 5.28 FFT analysis PCC voltage, grid current, PV inverter output current and load current for non-linear load using unit template current control technique respectively. THD in V_{pcc} , I_{grid} , I_{inv} and I_{load} , are 2.23%, 3.41%, 4.55%, 30.49%, respectively.

5.2.3: Unbalancing Load with Constant Irradiation

In this section at irradiation, 1000 W/m^2 with 25°C are used on PV array, The PV solar system is connected to the grid at $t=0$ sec. using the relay at the point of common coupling. The triggering of the VSI is done using the unit template current control techniques and triggering of boost converter is done using P&O MPPT control technique for obtained the maximum power output from the PV system.

An imbalance is created from 0.2 sec to 0.4 sec by disconnecting the phase b; the MATLAB/simulation model waveforms are given for analysis the system performances.

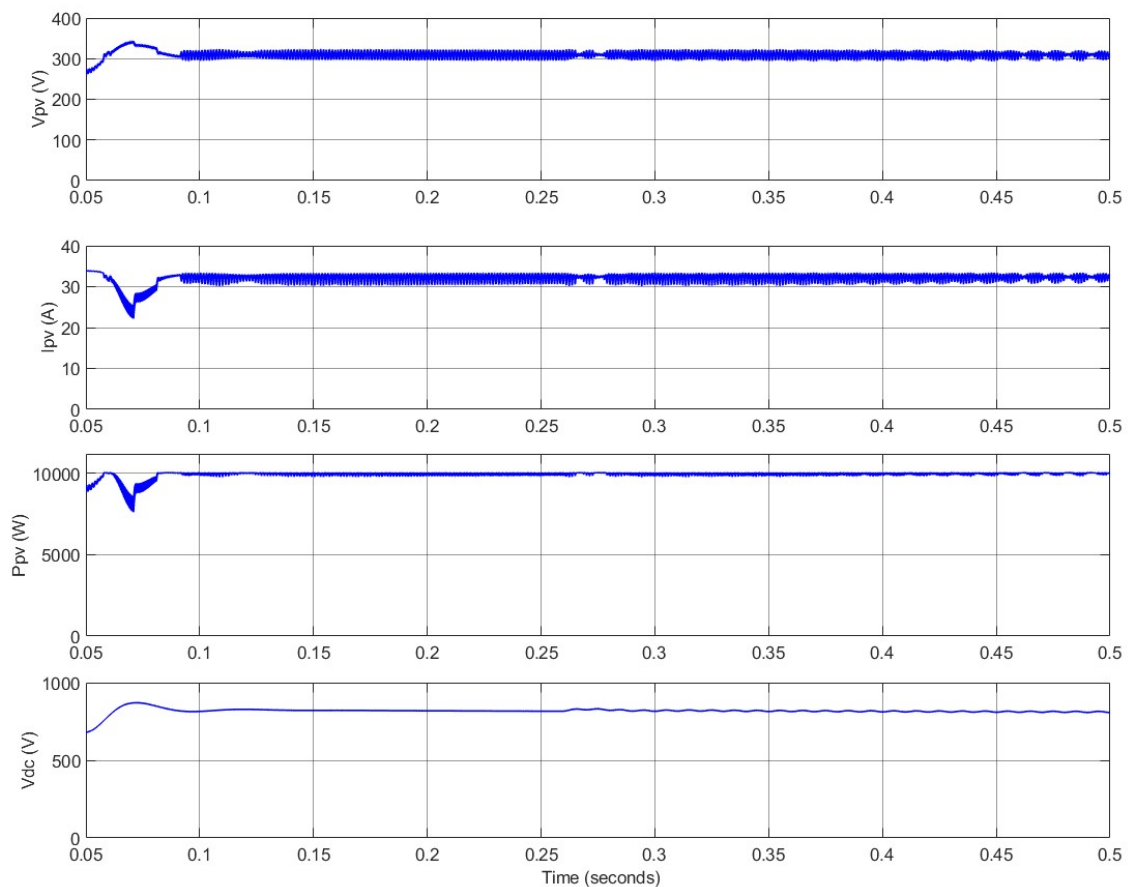


Figure 5.29: Show the simulation results of voltage, current, power of PV and DC-link voltage

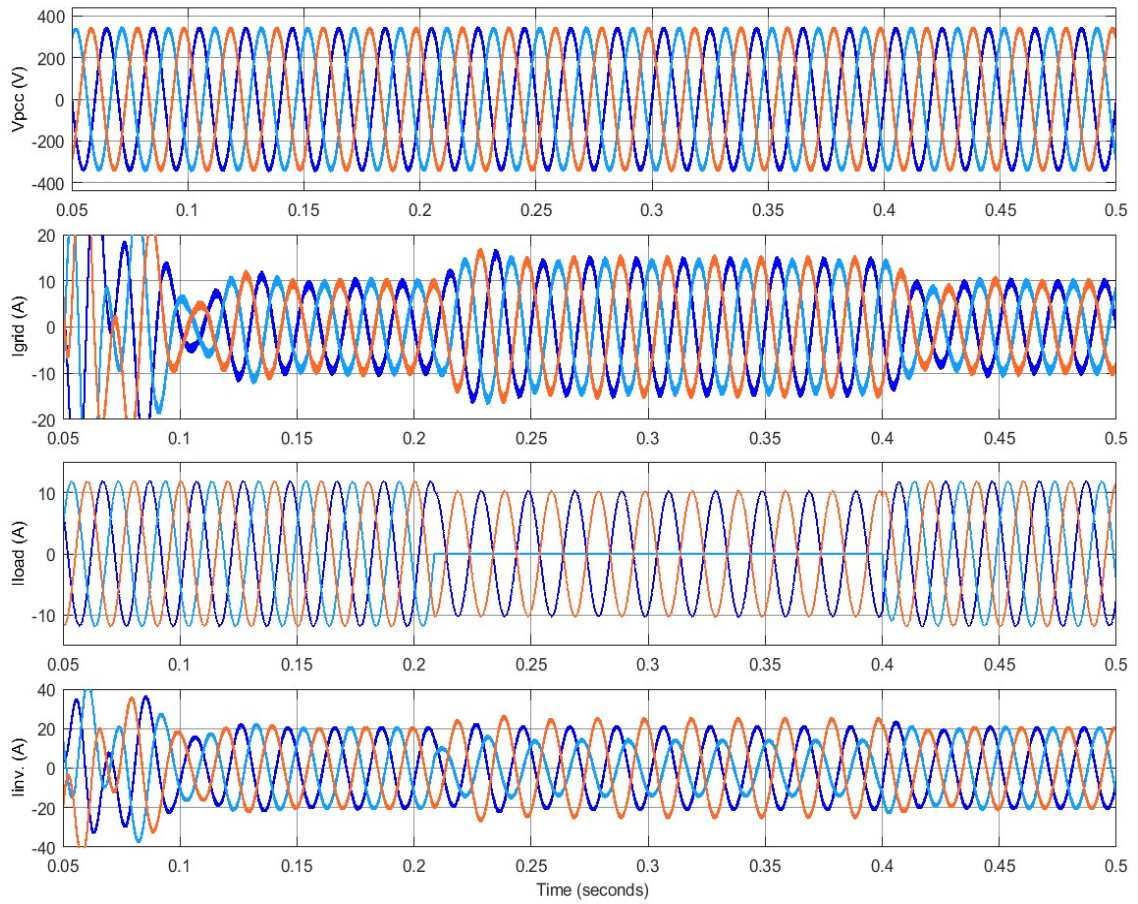


Figure 5.30: Show the simulation results of PCC voltage, grid current, load current and PV Inverter output current for dynamic switching of load

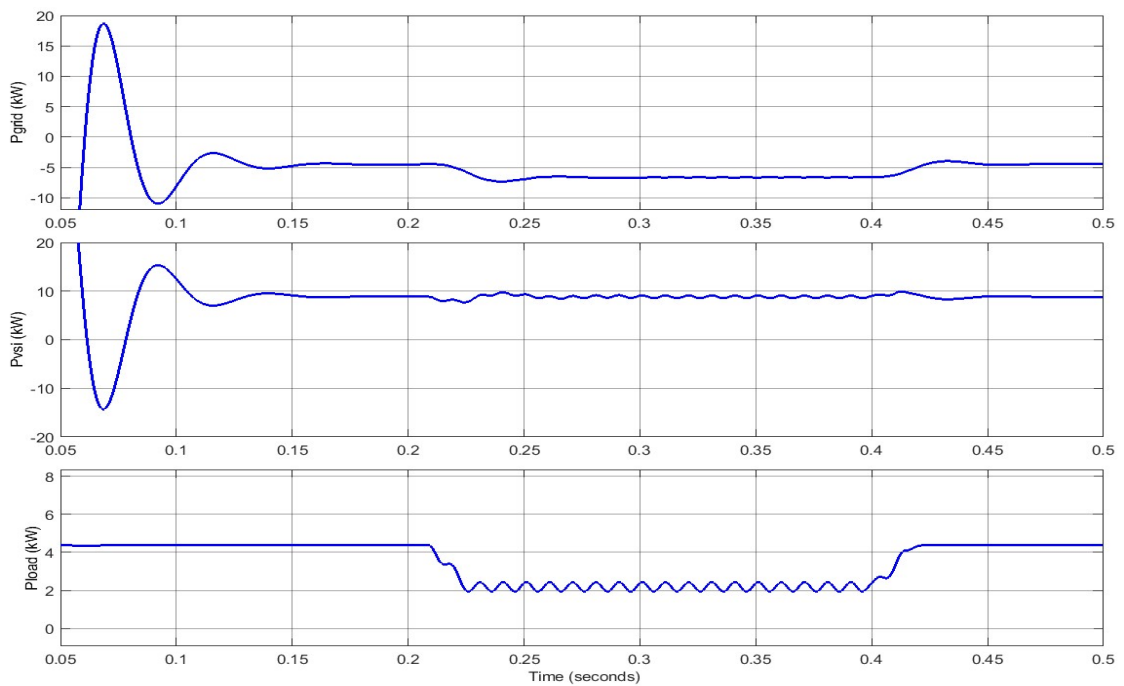


Figure 5.31: Show the simulation results of grid, PV system and load power at dynamic switching of load

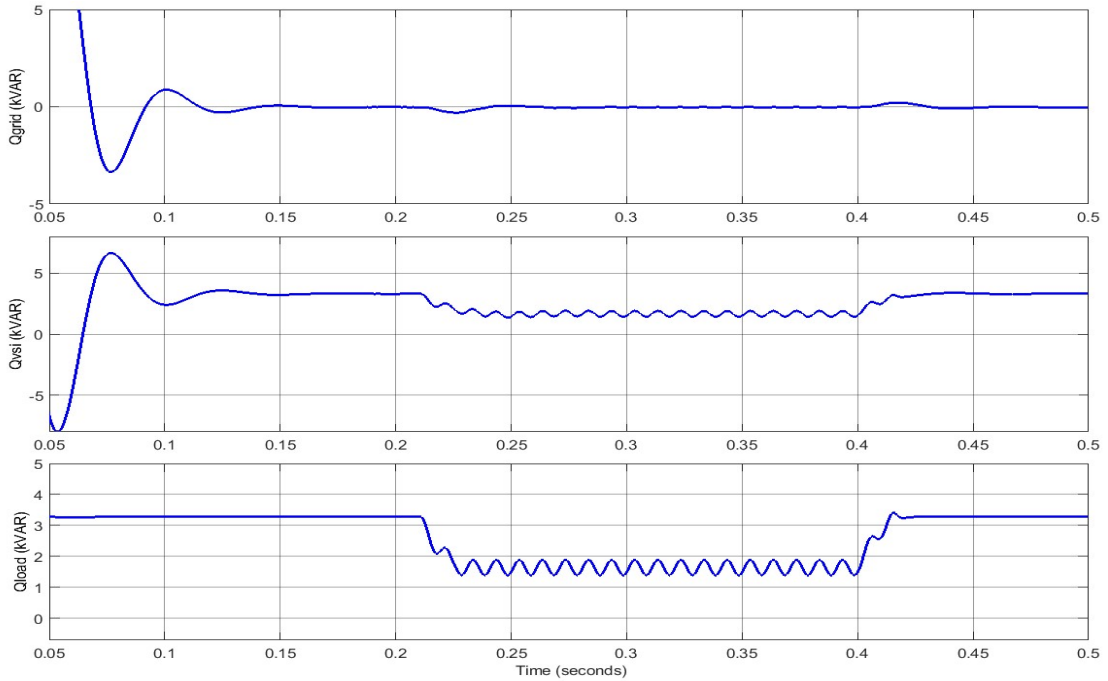


Figure 5.32: Show the simulation results of reactive power of grid, inverter and load demand at dynamic switching of load

In MATLAB/simulation model of grid connected PV solar system is connected to grid at PCC. The linear load 6 kW, 0.8 pf lagging load is connected at distribution end. The results of in Figure 5.29; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.30; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.31; P_{load} , P_{vsi} , P_{grid} and Figure 5.32; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable approx 800 V and active power of the grid P_{grid} have negative it means PV solar system is delivering the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power (Q) of the grid is at zero which indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power Q_{grid} remain zero.

At 0.2 sec slightly disturbances in power, voltage and current of the PV and settled back to steady state conditions as shown in given results.

5.2.4: Linear Load with Changing in Solar Irradiation

In this section at irradiation, 1000 W/m^2 reduce to 500 W/m^2 at 0.25 sec with 25°C are used on PV array, The PV solar system is connected to the grid at $t=0$ sec. using the relay at the PCC. The triggering of the VSI is done using the unit template current control techniques and triggering of boost converter is done using Perturb and observe MPPT control technique to obtained the maximum power output from the PV system. The system stability by using SRFT can be analysed by using the output waveform of the simulation model.

The MATLAB/simulation model performs with dynamic changes in solar irradiation and obtained waveforms results.

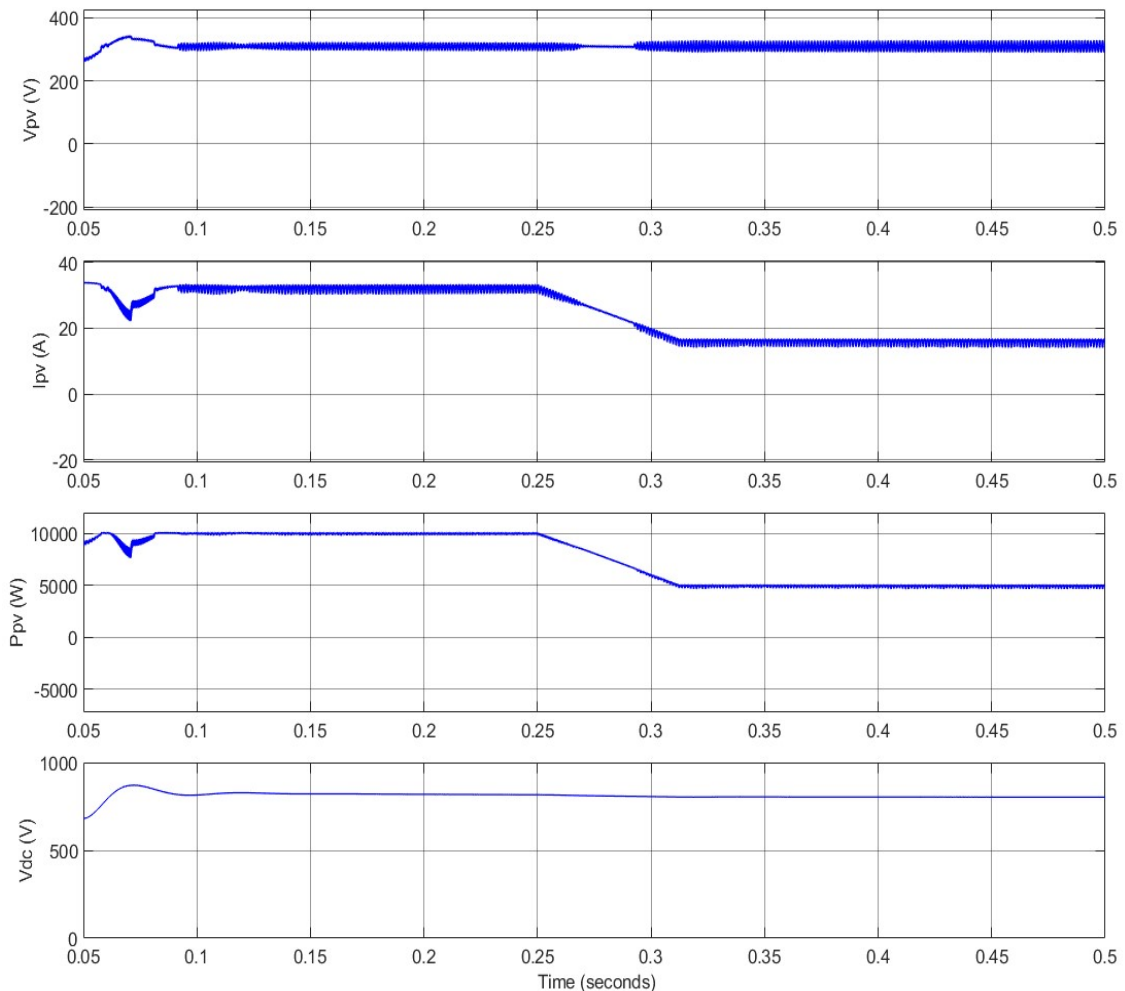


Figure 5.33: Show the simulation results of voltage, current, power of PV and DC-link voltage

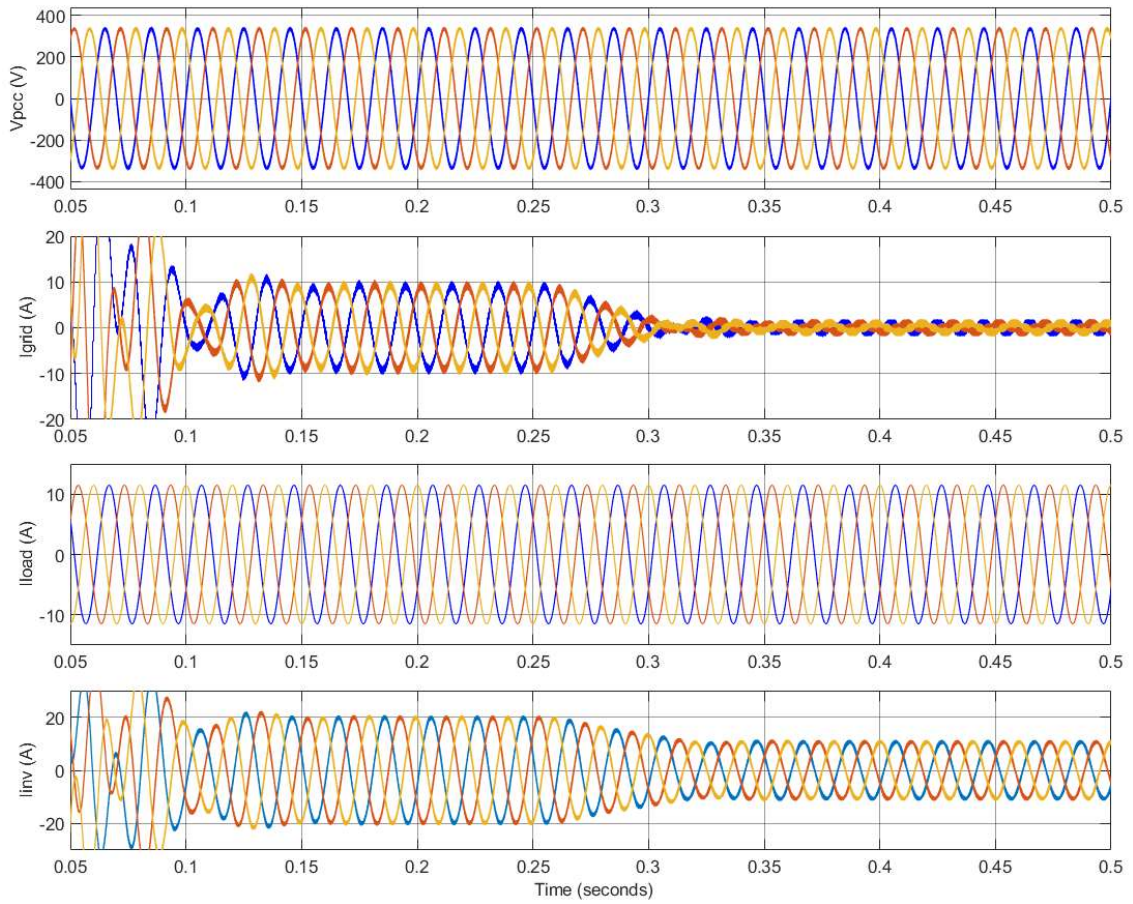


Figure 5.34: Show the simulation results of PCC voltage, grid current, load current and PV Inverter output current for changes in solar irradiation

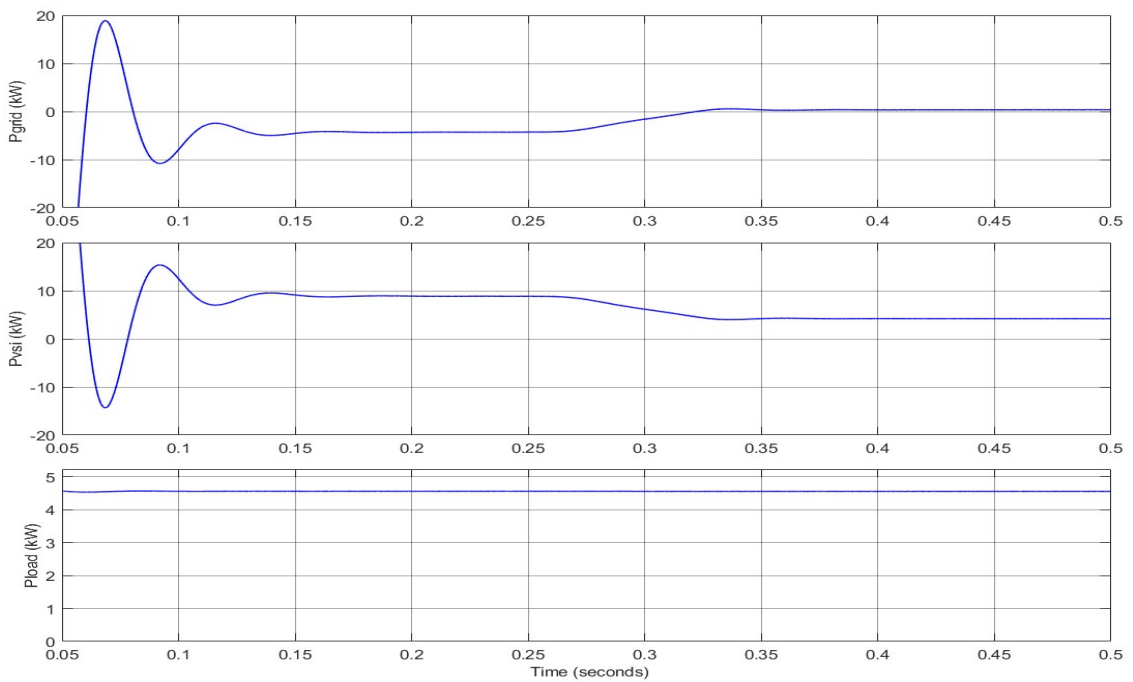


Figure 5.35: Show the simulation results of grid, PV system and load power at linear load

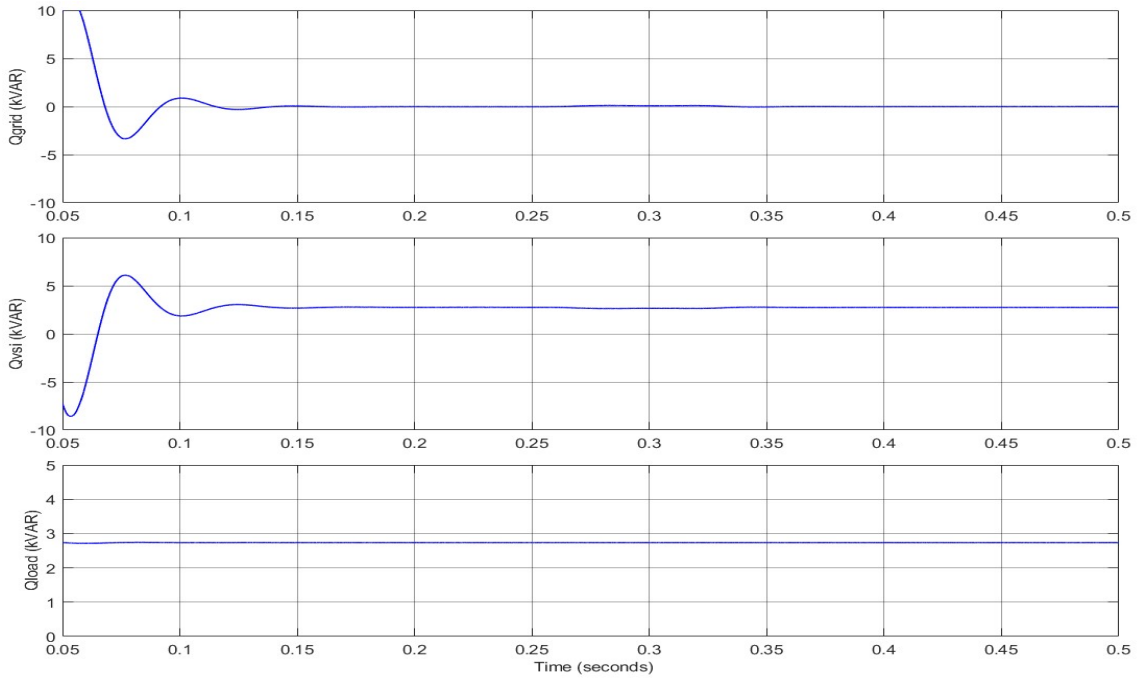


Figure 5.36: Show the simulation results of reactive power of grid, inverter and load demand with linear load

Solar irradiation is reduced from 1000 W/m^2 to 500 W/m^2 on 0.25 sec. Changing in the solar intensity of the PV array affects the PV current such that fall in irradiation leads to fall in PV current along with PV power. This can be easily observed in the PV characteristics plot, where the PV power and current are reduced to half when solar irradiation become half and voltage remain almost undisturbed. The loss in delivering the PV solar power, grid gain the active power becomes low.

In MATLAB simulation model of grid connected PV solar system is connected to grid at PCC. The linear load 6 kW, 0.8 pf lagging load is connected at distribution end. The results of in Figure 5.15; V_{pcc} , I_{grid} , I_{load} , I_{inv} and in Figure 5.16; V_{pv} , I_{pv} , P_{pv} , V_{dc} and in Figure 5.17; P_{load} , P_{vsi} , P_{grid} and Figure 5.18; Q_{grid} , Q_{vsi} , Q_{load} waveforms are plotted.

DC-link voltage maintained the stable at 800 V and active power of the grid P_{grid} have negative it means PV solar system is delivering the power to the grid and load demand P_{load} met by the PV solar system.

The reactive power Q of the grid is at zero which indicates that there is reactive power compensation in UPF (unity power factor) mode. Q_{grid} is maintaining almost zero due to UPF mode. From the simulation results the reactive power demand of the load met by the PV system and grid reactive power Q_{grid} remain zero.

Table 5.2: Comparison of different parameters for linear and non-linear loads using unit template current control

PARAMETER	LINEAR LOAD	NON-LINEAR LOAD
	At 1000 W/m ²	At 1000 W/m ²
V_p (V)	312	312
I_p (A)	32.2	32.2
P_{pv} (kW)	10.04	9
V_{dc} (V)	808	802
V_{pcc} (V)	415	415
I_{grid} (A)	-9.15	-16.60
I_{inv} (A)	19.94	19.08
I_{load} (A)	11.40	2.47
P_{inv} (kW)	9.4	9.8
Q_{inv} (kVAR)	3.8	0.5
P_{grid} (kW)	-4.5	-8
Q_{grid} (kVAR)	0	0
P_{load} (kW)	4.8	1.2
Q_{load} (kVAR)	3.6	0

5.3: Observations

5.3.1: Linear Load with Constant Irradiation

It is observed that SRFT and unit template current control gives the satisfactory response and achieve steady state frequently. The linear load is 6 kW, 0.8 lagging pf linear load connected at distribution end in simulation model. The MPPT control is tracking maximum power approx 10 kW from PV array at standard irradiation and temperature and this power is injected at PCC from where power deliver to the load and rest of the power given to the grid as shown simulation results that grid current out of 180° out of phase whit the grid voltage. Also from the simulation results it is observe that reactive power of load is met by the VSI. Thus the grid operates at unity power factor. The DC-link voltage is stable near of 800 V it is observed from the simulation results.

5.3.2: Non-Linear Load with Constant Irradiation

It is observed from the MATLAB/simulation results that all the control techniques give the satisfactory results for this case. In this the system supply the three phase diode rectifier dc load $R_{dc}=250$ ohm, it is connected at dc side. The three phases non-linear current have THD of 30.50%, however the grid current is closed to the sinusoidal in nature. The using of control techniques in simulation model provides the harmonics compensation. The MPPT continues to track the approx 10 kW of power from PV array and DC-link settled at 800 V. However, with the different control techniques there is a different in grid current THD and grid Voltage THD given in Table 5.1 that the grid current THD without compensation is 30.50%, there is a huge improvement in grid current THD when PV solar system is connected to grid.

5.3.3: Unbalanced of Linear Load in Simulation Model

It is observed that all the control techniques give the satisfactory performance in this case. Initially the MPPT control is tracking approx 10 kW from PV array at standard irradiation and temperature and this power is injected into the grid. The DC-link voltage is remaining stable at 800 V. At 0.20 sec one, out of the three phase of the load is removed which can be seen from the simulation results. After the disconnecting load from one of the phase small transient in DC-link voltage and settled back to steady state 800 V, The grid current still in three phase and remaining power of the PV array is deliver to the grid.

5.3.4: Linear Load with Changing in Solar Irradiation

It is observed from simulation results that SRFT and unit template based control techniques give the satisfactory results but SRFT control technique give better results as seen from the simulation results. The MPPT control is tracking maximum power approx 10 kW at standard solar irradiation and temperature and it is injected at PCC from which it is further distributed to load and grid. It is can be seen from the results that at 0.25 sec the solar irradiation start reducing up to 500 W/m² due to PV array also reduced the delivering of power approx 5 KW with little transient in DC-link voltage and settling back to 800 V. As a result of reduced PV output there is less power injected into the grid hence, we see a reduction in grid current.

Table 5.3: Current and voltage THD at linear load and non-linear load

	TYPES OF LOAD	VOLTAGE THD (%)	LOAD CURRENT THD (%)	GRID CURRENT THD (%)	PV INVERTER CURRENT THD (%)
SRFT	LINEAR LOAD	1.37	0	1.57	0.74
	NON LINEAR LOAD	0	30.66	3.09	3.17
UNIT TEMPLATE CURRENT CONTROL	LINEAR LOAD	2.23	0.01	1.92	2.94
	NON LINEAR LOAD	2.23	30.49	3.41	4.55

5.4: Conclusion

In this chapter grid conned PV system at different conventional control techniques are discussed. A MATLAB/simulation model for the grid connected system was developed with conventional control SRFT and unit template current control techniques. A simulation model for the grid connected system performance was done on various modes of operation for analysis purpose and gives satisfactory results. A system able to track MPP and deliver the power to grid and load, simultaneously compensate load reactive power, load harmonics, load unbalance and operate at unity power factor.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE OF THIS WORK

6.1: Conclusion

The main objective of this work is to understand the working of the PV system, MPPT control techniques, controlling of the inverter, integration of PV to grid and improve power quality of the grid. In this work we are able to understand output the characteristics of photovoltaic array, designing of boost converter and its application for MPPT in PV system is studied. The MATLAB/simulation model is developed for grid connected PV system is integrated with the grid and power quality enhancement is studied. The boost converter is used in MATLAB/simulation model and controlling is done using perturb and observe MPPT control technique. The three phase voltage source inverter is controlled by using conventional control techniques.

- Synchronous reference frame theory (SRFT)
- Unit template current control algorithm

The MATLAB/simulation model for both control techniques is developed and simulation results are obtained for various loads under load unbalancing and solar irradiation variation. The system is operated in UPF mode for power factor corrections. THD of AC voltage and current for all the algorithms are under 5% follow the IEEE standards.

It is observed that conventional algorithm SRFT and unit template current control provides satisfactory performance, but unit template current control take more time to settled at the steady state required value.

Table 6.1 show the comparison of different parameters of SRFT and unit template current control algorithm for linear and nonlinear loads.

Table 6.1: Comparison of different parameters of both SRFT and unit template current control

PARAMETER	SRFT			UNIT TEMPLATE CURRENT CONTROL		
	LINEAR LOAD		NON LINEAR LOAD	LINEAR LOAD		NON LINEAR LOAD
	At 1000 W/m ²	At 500 W/m ²	At 1000 W/m ²	At 1000 W/m ²	At 500 W/m ²	At 1000 W/m ²
V_p (V)	310	308	312	312	308	312
I_p (A)	32.4	16.4	32.4	32.2	16.1	32.2
P_{pv} (kW)	10.04	5.02	9	10.04	5.02	9
V_{dc} (V)	800	800	802	808	801	802
V_{pcc} (V)	415	415	415	415	415	415
I_{grid} (A)	-9.62	1.30	-16.52	-9.15	0.80	-16.60
I_{inv} (A)	20.37	10.18	19.01	19.94	9.97	19.08
I_{load} (A)	11.47	11.47	2.49	11.48	11.48	2.47
P_{inv} (kW)	9.5	5.1	10	9.4	5.1	9.8
Q_{inv} (kVAR)	3.8	3.8	0.5	3.8	3.8	0.5
P_{grid} (kW)	-4.5	0(approx)	-8	-4.5	0(approx)	-8
Q_{grid} (kVAR)	0	0	0	0	0	0
P_{load} (kW)	4.8	4.8	1.2	4.8	4.8	1.2
Q_{load} (kVAR)	3.6	3.6	0	3.6	3.6	0

6.2: Future Work

The future work is to study and apply other conventional and soft computing control techniques like artificial neural network, genetic algorithm, fuzzy logic etc. for MPPT and VSI control.

- Hardware implementation of grid connected PV system.
- Integrating battery storage in grid integrated PV.
- Study hybrid renewable energy systems; hybrid renewable energy system integrates PV with other renewable energies like biogas, wind with grid.

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