PERFORMANCE ANALYSIS OF TRANSFORMER-LESS INVERTER FOR SOLAR POWER CONVERSION

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by

ROHIT VERMA

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

ROORKEE – 247667

MAY 2016

CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in this report entitled "**Performance Analysis of Transformer-less Inverter for Solar Power Conversion**" in partial fulfilment of requirement for the award of degree of Master of technology in Electrical Engineering with specialization in Electric Drives & Power Electronics, and submitted in the Department of electrical Engineering of Indian Institute of Technology Roorkee, India, is an authentic record of my own work carried out during the period from June 2015 to May 2016, under the supervision of Dr. S.P. Srivastava, Professor & Head, Department of Electrical Engineering, of Indian Institute of Technology Roorkee, India.

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

Date: 23rd May, 2016 ROHIT VERMA

Place: Roorkee

CERTIFICATE

This is to certify that the statement made by the candidate is correct to the best of knowledge and belief. He has made a good efforts to compile the information and data form the past researchers.

Dr. S.P. SRIVASTAVA

Professor & Head

Department Of Electrical Engineering

Indian Institute of Technology, Roorkee

ROORKEE – 247667

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I would like to mention my parents for their endless support and encouragement and always believing and helping me to believe, that I can succeed at anything.

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Dated: 23rd May, 2015 ROHIT VERMA

Place: Roorkee

ABSTRACT

Solar energy is the most emerging renewable energy. Applications of solar energy are increasing for both gird connected and standalone system. Much more efforts have been made on the integration of renewable energies in to the grid in order to meet the imperative demand of a clean and reliable electricity.

The PV inverter is the key element of grid-connected PV power systems. The main function is to convert the DC power generated by PV panels into grid-synchronized AC power. It is also used to supply to the grid. That’s why they are becoming much popular than others. In this thesis, solar system is designed by using grid connected transformer-less inerter structure for single phase in single stage. There is a strong trend in the photovoltaic inverter technology to use transformer less topologies in order to acquire higher efficiencies combining with very low ground leakage current.

MPPT being the essential part of solar photovoltaic system is simulated using Perturb & Observe technique. A Heric DC-AC converter is employed to achieve this goal. Heric inverter is used for reducing the leakage current in the transformer-less inverter structure in the grid connected PV system.

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CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

With the rise in energy costs many people have been searching to alternative sources of renewable energy. One of the important energy sources available in the recent time is Sun, used as the source. The growth of technology throughout periods led to the people exploring renewable energy sources. The history of solar power is very old and its history spans over 7th century BC to today. In 1954, solar power evolved, with the first high solar cell made of silicon and its efficiency was low. During the 1980's, a solar power station was built in California with power capacity of 1MW. This was the first time designed for the utility scale. Today solar cells are used now in a wide variety of places.

Photovoltaic technology has been increased from a small scale to a large scale over the two decades. PV technology is used in grid connected system and stand-alone system. The development of power electronics and semiconductor technologies, the lessoning cost of PV panels, it is widely used. Photovoltaic technology is mainly focusing on the developing two parts: PV cell semiconductor material and power electronics converters (DC to DC converter and or DC to AC converters). Its main objective to improve the overall efficiency of solar power conversion. Despite improvement in solar cell materials, from polycrystalline, mono crystalline to amorphous and thin film, the conversion efficiency is not good and it is also very costly to convert it to electrical energy from solar energy. Thus, the performance of power electronics converters plays an important role in improvement overall power conversion efficiency and reducing the cost to generate electric power from solar energy.

Solar power conversion depends upon many factors, atmospheric conditions such as temperature, irradiance and partial shedding. As solar energy conversion is costly, it is a need of extracting maximum power from so that maximum utilization of solar energy happen if the atmospheric conditions is changing. So maximum power point tracking is very essential part in the solar power conversion. For tracking maximum power tracking is done by using DC/DC converter or without DC to DC converter. The tracking of maximum power without DC/DC converter is done by using inverter and it is done because it increases the efficiency of solar power conversion. This type of structure is used only single stage to convert solar energy into electrical energy. If DC to DC converter is used in solar power conversion, so there is a two stages to covert solar energy to electrical energy; DC to DC converter and DC to AC converter. Mostly for low power application, single stage solar power inverter is preferred due to its economical and efficiency reason.

Photovoltaic system is used in two ways; stand-alone PV system and grid connected PV system. Stand-alone system is also called as off-grid PV system in that system, it is not connected to the utility grid. In stand-alone system, battery charge controller is used for charging the battery and utilizing the maximum power from the solar panel. In the recent times, grid connected PV system is widely used. It is having advantage that it is connected to the utility grid. In grid connected PV system, battery charge controller is not used. Today, most of the solar PV inverters are grid connected. In the grid connected inverter. If the grid fails and there is no battery charge controller in the circuit then the power generated by the solar panel side is wasted, so now the grid connected PV system is also connected with utility grid and it is also having battery charge controller which is used to charge the battery. By using this, it provides better flexibility in the grid connected PV system.

1.1.1 GRID CONNECTED SOLAR SYSTEMS

Grid connected PV inverters are very much used in the recent times. The main function of the PV inverter is to develop the voltage which is same as the grid voltage. The advantage of the grid connected PV system is that whenever there is more generated power from the solar panel and then the extra power is given to the utility grid. If the power produced by the solar panel is not sufficient to give the load and in this case grid is used to give the extra power to load from the grid. In the grid connected PV system, control scheme is used to control and improvement the power quality of the system. The injected current in the grid should have the same frequency and phase, the power factor of the grid current should be unity power factor. In the grid connected system, grid synchronization should be there so that PLL is used to extract the frequency from the grid voltage. Inverter is the main part of the system it is used to converter DC from the solar panel to AC supply. There are two types of PV Inverter structures are used. The inverter structure may have a transformer for isolation or the inverter structure without transformer. Control scheme of Grid connected PV system must be very specific and it must follow some standards so that there should not any effects on the grid side and solar side. There must be monitoring of the system at both side. Control scheme of grid connected system must be specific as per requirement as it must follow its requirement as there must be synchronization between the grid voltage and the injected grid current so that the power factor of that point must unity. If in the system, there is a need of reactive power control then only dq synchronously rotating reference frame is used, dq synchronously reference frame is very good controlling method to control active power and reactive power separately. If there only need of controlling active power in the grid connected system, there is no need of using dq synchronously rotating reference frame. Grid synchronization is main part of the control scheme, it is used to extract the same phase angle from the grid voltage so that the grid voltage and the injected grid current in the system is synchronized. There are lots of technique for grid synchronization, PLL is the best method to extract the same phase angle from the grid voltage. Grid connected system provides better performance and flexibility than stand-alone system because in that system the extra power generated by the system can be easily supplied to the utility grid and it reduces the electricity bills for supplying power in the utility grid.

1.1.2 TRANSFORMER-LESS GRID CONNECTED SOLAR INVERTER

In the grid connected system, isolation must be provided, for providing isolation transformers are used. These transformers can be high frequency or low frequency; low frequency transformer are used at the grid side and these transformers are costly also. For providing galvanic isolation between the solar side and the grid side high frequency transformers are used in the DC to DC converter. If transformer are not used in the solar PV inverter, the structure is called transformer-less solar inverter. If the inverter structure is without transformer, there may be a chance of leakage current as there is no isolation between the two sides. So there may be a chance of flowing leakage current in the system which is not good for the system quality and human beings. This is the main problem in the grid connected transformer-less PV system.

There are many transformer-less inverter structure developed in which there provision of galvanic isolation at the time of zero voltage is switching. Due to this, the chance of flowing common mode leakage current in the grid connected system between the parasitic capacitance of solar panel and the grid side can be easily reduced. The common mode leakage current can be reduced only if the common mode voltage in the grid connected system is constant. The switching of switches in transformer-less inverter is very much important because it will make the common mode resonant voltage constant and reduce the leakage current in the grid connected system and it also used to provide the galvanic isolation in both sided so that there may not be problem in grid side and working at the grid side is safe. It plays a vital role in grid connected transformer-less inverter structure.

1.1.3 BENEFITS OF GRID CONNECTED TRANSFORMER-LESS INVERTER

As there is a limited source of energy so renewable energy is the main source of energy which can be used to generate electrical energy. PV inverter is the main medium to generate electrical energy from solar energy. Grid connected PV inverter is mainly used because in that system the extra power can be supplied to the grid so that the electricity bills of the house hold is reduced.

There are many benefits of installing grid connected transformer-less inverter

- Easy to install and Compact
- High conversion efficiency
- Flexible
- Reliable and High Power Quality

It can be seen that the efficiency inverter structure without transformer is around 97-98% and it is just 2-3% more than inverter structure with transformer. But it is good to install because increase in small efficiency leads to increase in generated power.

There are lots of advantage in the transformer-less inverter grid connected system. The main advantage of this system is that as there is no transformer, the structure is easy to install, lighter and compact.

1.2 LITERATURE REVIEW

Jazayeri, Moein, Sener Uysal, and Kian Jazayeri [11] presented a simple and practical simulation based on the single diode model for the solar cell. The solar cell can be simulated in matlab Simulink using the equation described in this paper. In that paper, presented one diode model with shunt and series resistance provide wide application areas and it can be easily simulates in the matlab Simulink. By using this solar cell, solar string can be made by connecting it in series. These series connected string is used to make solar panel if this string is connected in series that is voltage rating of the solar panel will increased and if these string is used in the parallel then the current rating of the solar panel will increased. One diode model of solar cell is used and it provide wide area applications.

Power Electronics is very much used in the PV system, the main use of power electronics in PV system is that it is used to convert the dc current from the solar panel into ac current which can be supplied to the grid and can be used for standalone load. Most important part is to extract maximum power from the solar panel [2]. M. Ciobotaru, R. Teodorescu, F. Blaabjerg presented paper in that it states that MPPT can be tracked down by using dc to dc converter and dc to ac converter [22]. In that paper, control of single phase single stage PV inverter is presented. In that paper, the control of active power flow and the MPPT and current control is implemented in single stage. Maximum power can be extracted from the solar panel, if the dc-link voltage of inverter is on the maximum power point voltage. So DC-link voltage control is used to control for tracking the MPP point voltage and this is also used to generate the current reference for current control [6, 13].

H. Haeberlin presented evolution of inverters for grid connected PV system, in that paper, there is the evolution of grid connected system from 1989 to 2001[22]. Firstly three phase grid connected inverter is introduced in that thyristor were used after that switches like MOSFET and IGBT used. In the grid connected system, for providing isolation, LF-transformer is used then HF-transformer is also used in DC to DC converter, these converter structure is used to extract maximum power also provide isolation between grid and the solar side. But at the year of 1995, a new inverter structure were developed which is not having transformer in the inverter structure. Without transformer in the inverter structure, the efficiency of the conversion of the inverter structure is increased up to 2%. In that paper, it is also described that between period 1988 to 1990, the European efficiency of grid connected structure was for 1-4 KW structure was 86%-90%. Later 90s the efficiency of the structure reached to 92%-94% as there is a saperation between the grid side and solar side. But now transformer-less inverter structure provides more efficiency and it also reduces losses in the structure.

Dr. Heribert Schmidt says a switching trick makes it possible to cut the losses of a series-production inverter in half and increase the efficiency from 96 to 98 percent [21]. The HERIC topology makes it possible to achieve a world-record efficiency of more than 99 percent. [21] Heric inverter structure provides better result compared to h bridge inverter family as it can provide the isolation and also it is having high conversion efficiency.

Roberto Gonzalez, Lopez,Pablo Sanchis, Gubia, Alfredo Ursua and Luis Marroyo presented paper in that they describe the Heric inverter,H-5 inverter and H-bridge inverter with bipolar modulation [11]. Yang, Bo, et al [1, 4] also describes the resonant circuit of single phase grid connected system and it also presented the condition to reduce the leakage current flowing in the grid connected system. This paper presented that the leakage current flowing in the grid connected system should be minimum. Heric inverter is the same as H-bridge but there is an AC bypass back to back switches which is used to provide isolation in the grid connected system. This paper is also presented that unipolar switching should be used in the Heric inverter as it provides better performance that by using unipolar switching the there is less current ripples and less switching losses as there is no double switching frequency component in the inductor. GU, Bin, et al [7] also describes the highly efficient and reliable single phase transformer less inverter for the solar power conversion and also reduce the leakage current in the structure in the non-isolated PV system. Yang, Bo, et al [4] describes the common mode leakage current flowing in the grid connected system. It also defines the conditions to reduce the flowing of the leakage current

Yongheng Yang, Wenjie Chen and Frede Blaabjerg presented Advanced Control of Photovoltaic and Wind Turbines Power Systems [2] paper that describes control scheme of grid connected inverter structure in that active power, reactive power, Vdc control can be controlled. In that paper, two type of control scheme is presented, first is double stage and second is single stage. In the double stage MPPT is implemented with DC to DC converter and in single stage inverter is only used to extract maximum power from the solar panel. In that control scheme as active and reactive power is controlled so that dq synchronously rotating reference frame is used, in that d axis is used to control the active power in the system and q axis can be used to control the reactive power in the grid connected system. For controlling of the active power, reactive power, Vdc control and MPPT in a single stage in a grid connected PV system, advance control scheme with synchronously rotating dq reference frames are used which gives better result in grid synchronization also. [2]

Sayed Ali Khajehoddin, Masoud Karimi-Ghartemani, Alireza Bakhshai, and Praveen Jain presents a power control method to control active power and reactive power in single phase grid connected system [10]. In that paper it has been discussed that to control active power and reactive power in the single phase grid connected system, dq synchronously rotating reference frame is used. If the grid connected PV system is 3 phase then it is easy to do transformation from abc axis to dq transformation. But as in single phase grid connected system, there is only one quantity, the transformation is done only from αβ axis to dq transformation, to make αβ axis from grid voltage and grid current, α axis is taken as same as grid current and grid voltage, but β axis is generated by shifting it 90º. After making αβ axis, it can simply convert it to dq transformation which can be used for controlling active power and reactive power in the single phase grid connected system.

The main issue of grid connected PV inverter is the harmonics in the injected current to the grid. The current harmonics in the injected current must be less than 5% as in standard IEEE1547. The current harmonics must be less and it should be synchronized with the grid voltage. The injected current must have unity power factor and at the grid side there should not be much deviation in the grid voltage and the grid frequency. Grid frequency deviation will create problems in the system and the utility grid. And it may cause many problems in the utility grid [1, 2].

CHARY, T. BRAHMA, and DR J. BHAGWAN REDDY [25] presented the designing steps and method to design the parameters of LCL filter and also gives advantages over other filter in the grid connected system. LCL filter provides better attenuation over its frequency range and it is very much useful to reduce the harmonics in the injected grid current and improve the power quality of the grid connected system. This paper also presents the advantage of using LCL filter over L-filter and LC-filter. By using LCL- filter in the grid connected system, the current harmonics in the injected current is reduced and the parameters and the size of inductor and the capacitor is also reduced.

1.3 ORGANIZATION OF THESIS

In this thesis, grid connected transformer-less inverter for solar power conversion is implemented. Heric inverter is used as transformer-less inverter structure, it is used to provide isolation in the grid connected PV system by using switches and it is also reduce the leakage current in the PV system. Single phase single stage grid connected Heric inverter is implemented in which active power and reactive power is controlled by using dq synchronously rotating reference frame. LCL filter is used in the PV system to eliminate harmonics in the grid current.

Chapter 1 gives the information about the renewable energy, photovoltaic energy and about inverter structure. It gives the introduction about grid connected transformer-less inverter and its benefits. It gives also the introduction of work which is carried out in this thesis.

Chapter 2 gives the introduction of solar cell, solar string and solar panel, its equivalent model and it also explains the maximum power point techniques. It also explains perturb & observe MPPT algorithm to extract maximum power from the solar panel.

Chapter 3 gives the introduction of transformer-less inverter structure. It also explains the advantage of Heric inverter in reducing the leakage current in the grid connected system. in that chapter, the resonant circuit of the grid connected transformer-less inverter structure is also discussed.

Chapter 4 gives the information about the control scheme of single phase single stage grid connected system. In this chapter active power control, reactive power control, dc-link voltage control is explained. It gives the basic control structure of grid connected system to control active power and reactive power.

Chapter 5 includes the simulation model of the single phase single stage grid connected Heric inverter. In this chapter, the simulation results of the single phase single stage grid connected Heric inverter is shown.

Chapter 6 includes the hardware implementation of the Heric inverter and results of working prototype of open loop Heric Inverter.

1.4 CONCLUSION

From the above discussion, it can be concluded that photovoltaic energy is the best available energy in the present time and it should be used properly so that the maximum energy from the solar panel cab ne used. The inverter structure of the grid connected system should be chosen as per requirements and the control scheme in the grid connected scheme is specific to the inverter structure. For improving efficiency in the inverter structure, the transformer-less inverter structure is used, it must have low leakage current and should provide isolation by using switches. dq synchronously rotating reference frame is used for controlling active and reactive power in the single phase grid connected system.

CHAPTER-2

SOLAR PANEL AND MAXIMUM POWER TRACKING

2.1 INTRODUCTION

Solar energy is the main source of energy in the present time and it is very important to use it properly. To get electrical energy, there is two important part: solar panel and inverter structure. Solar panel should be very highly efficient, reliable. There are lots of technologies developed to improve the efficiency of the solar cell so that solar panel can give maximum power and it can be easily converted to electrical energy. As there is a need of extracting maximum power from the solar panel, maximum power trackers are used, these tracker are used to extract maximum power from the system. There are lots of MPPT techniques developed to extract maximum power from the solar panel. Solar Panel is made of solar cell. These panels can be made of use of making solar string as in series or parallel. If these string is connected series in panel it is used to make for higher voltage and the voltage rating of the solar panel is increased and if the string are used in the parallel then the current rating of solar panel is increased and in both the cases the power rating of the solar cell is increased. From this solar panel, maximum power must be extracted so that the total energy is utilized.

2.2 SOLAR CELL

A solar cell is a photovoltaic device which converts energy from sun into electrical energy. It does it with the help of photovoltaic effect. Silicon is what is known as a solid state (semiconductor), meaning that it shares some of the properties of metals and sharing some of the properties of insulator, making it a main part in solar cell. Solar cell is a semiconductor like PN junction diode. The light coming from the sun is composed of photons. So whenever sunlight falls on the semiconductor, photons transfer their energy to the semiconductor material and it will lose electrons. It can be understand like that it ejects electrons from the valence band which then goes to the conduction band. When the energized electron is transferring from valence band to conduction band, it generates electrical current and leaves hole. So this generate an electro-motive force which in turn holes move in the opposite direction from electrons, thereby producing an electric current and converts solar energy into electrical energy.

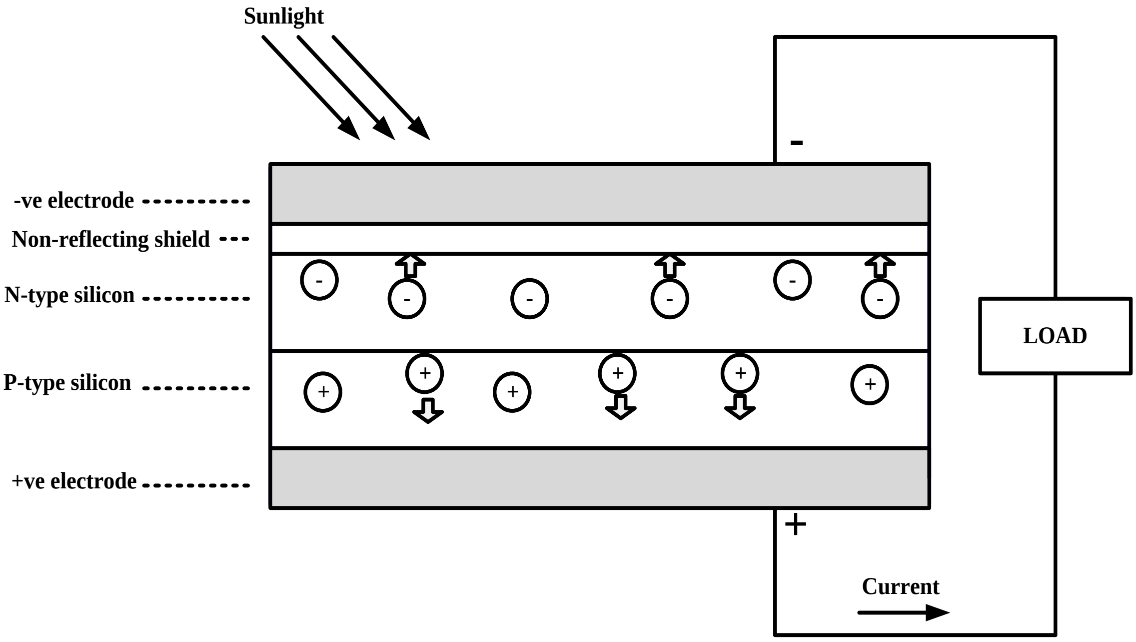


Figure 2.1: Photovoltaic phenomena in Solar Cell

2.2.1 MATERIALS & EQUIVALENT ELECTRICAL CIRCUIT

Solar cells are made up off semi- conductor materials like Silicon, Platinum or alloys like Cadmium Telluride. These materials are having characteristics to absorb sunlight and to convert it into electrical energy. There are three general families of PV Solar Panels. They are single crystalline silicon, poly crystalline silicon and thin film, which include amorphous silicon, CdTe and CIGS cell. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics which is having high efficiency than other two. Most of them have not yet been commercially applied and are still in the research or development phase.

As photovoltaic cell is used to generate electrical energy from solar insolation for that it is necessary to understand the behavior and the model of the solar cell. Photovoltaic cell can be represented as a current source as this cell is unidirectional so a diode is also added in parallel in solar cell. No solar cell is ideal so there will be losses in the solar cell so to represent losses in the resistance are added in the electrical model of the solar cell. Series Resistance Rs and Series Resistance Rsh describe the power losses due to unwanted resistance in the connecting bars, connections between modules and the converter and the filters and it is also describe the power loss due to the impurities in solar cell and lattice. The value of parallel resistance Rsh is high so it is not having influence on the solar cell characteristic.

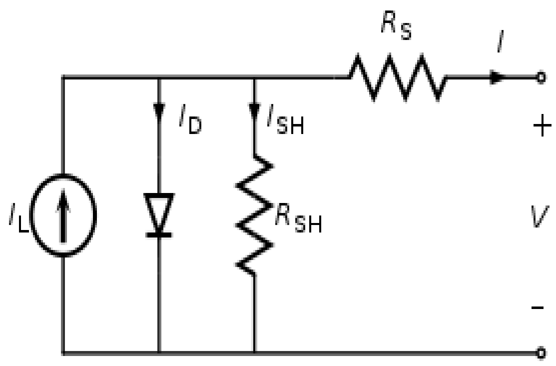


Figure 2.2 Equivalent Circuit of Solar Cell

- I_L represents the max short circuit current of the solar cell.
- Diode forms I-V characteristic of solar cell.
- Shunt resistor Rsh represents the leakage currents.
- Series resistance Rs represents the wiring and bars losses.

From the equivalent circuit, these are the two following equations:

I represents output current.

V represents output voltage.

Voc represents open circuit voltage.

$$I = I_L - I_0 \left\{ \exp\left[\frac{q(V + IR_S)}{nkT}\right] - 1 \right\} - \frac{V + IR_S}{R_{SH}}.$$

$$V_{OC} = \frac{kT}{q} \ln\left(\frac{I_{SC}}{I_0} + 1\right).$$

I & V : Cell Current and Voltage

Voc : Open Circuit Voltage of PV Cell (V)

I_L : Short Circuit Current (A)

T : Solar Cell temprature (ºK)

k : Boltzman‘s constant

q : Electron Charge (1.6*10-19)

I_0 : Reverse Saturation Current (A)

Rs : Series Resistance (Ω)

Rsh : Shunt Resistance (Ω)

2.3 I-V AND P-V CHARACTERISTICS

I-V and P-V characteristics are the two most important characteristics of a PV array and these characteristics are also very important for extracting maximum power from the solar array. These characteristics are very much depend upon atmospheric condition like temperature and irradiation. As the solar insolation and the operating temperature is changed, the I-V and P-V characteristics is also varies. There is only one point where the maximum power can be extracted which is called maximum power point (MPP), on the P–V curve. As in the solar cell equivalent model, the solar cell acts as a constant current source so that its characteristics is also constant up to maximum power point, after that point it will behave as an open circuit as in Fig 2.3. As the temperature and the irradiance is changing, the short circuit current is also changing, ant the operating point is also changing as in figure 2.3. So that the power of the PV array is also variable due to the changes in the conditions.as solar array should be working on the maximum power point condition so that maximum power can be extracted. The maximum power point is shown in fig 2.4 and fig. 2.5 with respect to voltage and the changing condition are temperature and irradiance. So maximum power point trackers plays a very important role in solar power conversion.

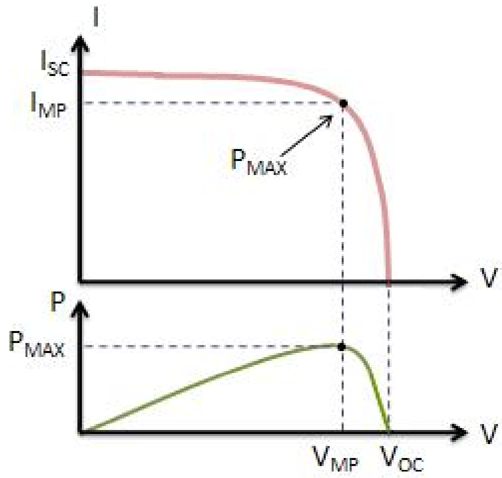


Figure 2.3: I-V and P-V characteristics of Solar cell

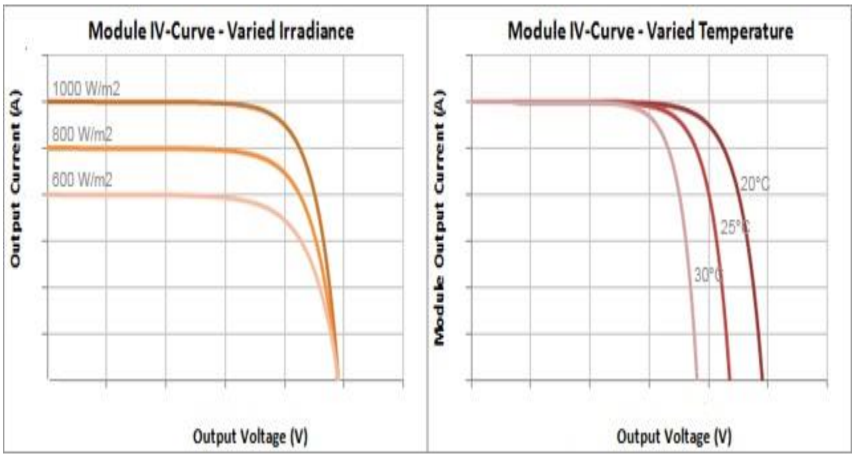


Figure 2.4 I-V curve with varying irradiation and temperature

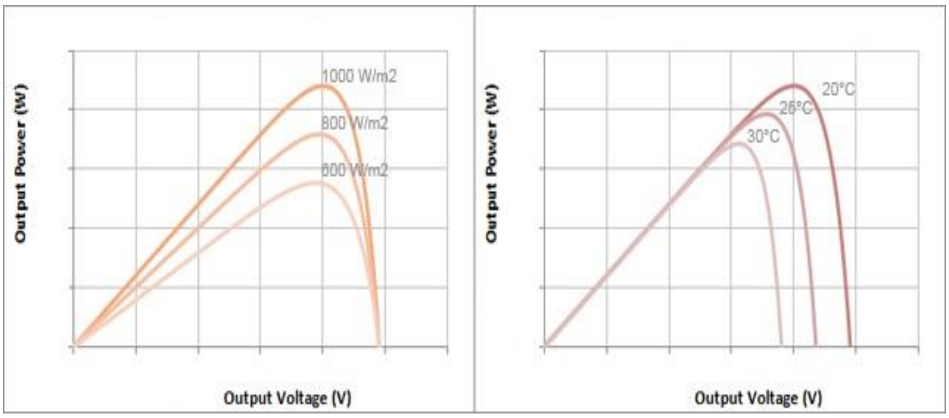


Figure 2.5 P-V curve with varying irradiation and temperature

2.4 APPLICATIONS

Solar power is gaining a lot of application due to its ability to produce electricity to remote areas in a clean and sustainable manner. Solar panel is used widely as the price of the solar cell is reducing and the new technology is developed to increase the efficiency, the application of the solar panel is also increased in two decades. Government is also giving subsidiary to the people to install it in the house. There are so many practical applications for the use of solar panels or photovoltaics in the commercial purpose. PV modules are mainly used in photovoltaic systems which is used in agriculture for irrigation, in the health sector and also medical sector. It is mainly used for the power generation as standalone system or grid connected system. There are some of the following applications where solar power system is widely used:

- Standalone PV systems
- Grid Connected PV system
- Roof-top Solar PV system
- Solar PV Pump
- Solar Vehicles
- Solar Power Station
- Solar Hybrid Power System

2.5 MAXIMUM POWER POINT RACKING

As we have seen in the characteristics that whenever there is any change in the atmospheric condition, there is also a change in the PV panel output. It is obvious that it is not required in the system so there is need to work in the maximum power of PV Panel. For working in the maximum power point solar PV system, there is need of tracking of maximum power in the solar system so that the system will work only in maximum power if there is any change in the atmospheric conditions. A MPPT device changes the operating point until it reaches the maximum power point where maximum power is extracted. For working at the maximum power point, there is a need of extraction of current and the voltage at which the maximum point occur. By using this converters, the maximum power from the solar panel can be easily extracted. PV system can be work on that MPP point so that maximum power coming from the PV system can be utilized.

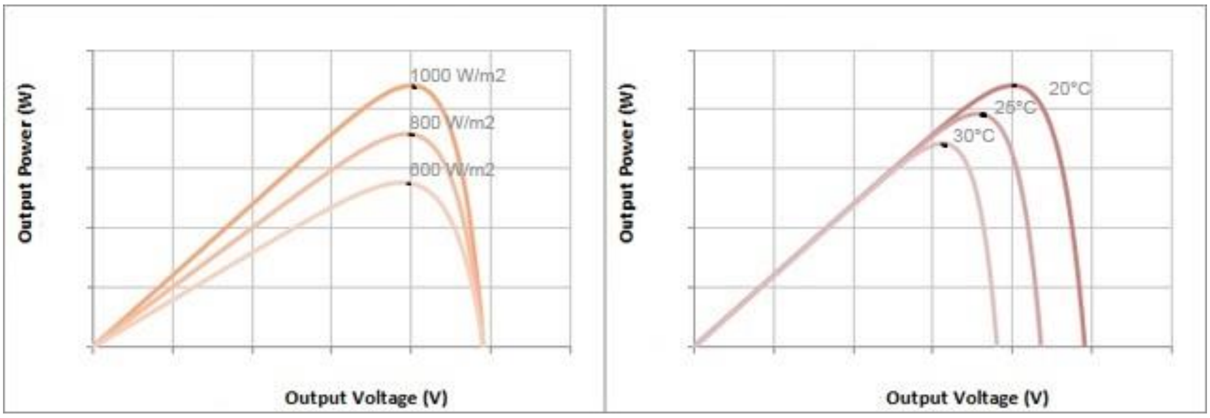


Figure 2.6 P-V curve with MPP Point varying irradiation and temperature

In that figure 2.6, it can be seen that if there is a change in the atmospheric condition such as irradiation or temprature. With these condtions, the characterstics of solar array is also changed and the maximimu power point is also changed. It can be seen in the different conditions in figure 2.6.

2.6 MPPT TECHNIQUES

There are many MPPT techniques developed which is used to take out maximum power from PV Panel. MPPT techniques is mostly used with power converters to take out maximum power. To take out maximum power, power converters as buck, boost, cuk etc. are used, these converters are used in two stage power conversion. MPPT techniques can be used in single stage power conversion and in that power converter is not needed, only inverter is sufficient to operate solar array at the maximum power point condition. MPPT control techniques is used for both stand alone and grid connected PV system. MPPT control techniques are as follows which is used to take out maximum power from the Photovoltaic panel.

1. Perturb and observe
2. Incremental conductance
3. Constant voltage
4. Look-up table method
5. Fuzzy Logic Technique

These are the five important MPPT techniques used to extract maximum power from the solar panel, in that Perturb and observe , incremental inductance are used very much in the PV system. Perturb & observe method in very simple to implement and it is also very good result.

Incremental conductance MPPT method is also very much used and its results are good, similar to perturb& observe method. In incremental conductance method, the MPPT controller measures the incremental deviation in PV panel current and voltage to estimate the DC-link voltage change. Constant voltage method is also used in extracting maximum power from the solar side, in that method the maximum power point voltage is fixed, if the irradiance is changing , there will not be much change in the maximum power point voltage, so in that method, the maximum power voltage is fixed in constant voltage method.

2.7 PERTURB AND OBSERVE TECHNIQUE

Perturb and Observe is very simple and uncomplicated technique to extract maximum power from the solar panel. This technique is also termed hill climbing method. This is worked on sensing the error between the voltage and the power at old point and calculate it and measure the maximum point. In that method the power is sensed and it is depends on the change of the power with respect to the voltage. So in this method, if the power increases or decreases, there will be deviation in the voltage if it is a single stage or deviation in the duty ratio if it is a double stage so that power in the system is constant. In that method, if there is any variation in the power, the operating voltage of the PV Panel is changed so that the maximum power from the PV Panel can be extracted. Perturb and observe is the most commonly used MPPT method because it can be easily implemented. The flowchart of this method is presented in the figure 2.7.

In that technique first output voltage and current of the solar panel is sensed and after that power at that instant is calculated. After calculating the power, the error between the power dP an the error between the voltage dV is calculated with respect to the previous instant. If the dP is zero then the voltage is fed to the dc link side of inverter. If it is not zero then there will be the increment or decrement in the voltage of the input side inverter. If dP is greater than zero and dV is also greater than zero then the dc link voltage will be incremented. Rest of the cases of dP and dV is shown in the table2.1. The voltage is varied as per condition as shown in Table 2.1.

dP	dV	Voltage variation (ΔVdc)
>0	>0	Increment
>0	<0	Decrement
<0	>0	Decrement
<0	<0	Increment

Table 2.1 Variation of Voltage with respect to dP and dV

The flowchart of Perturb and Observation MPPT technique is shown in Figure 2.7.

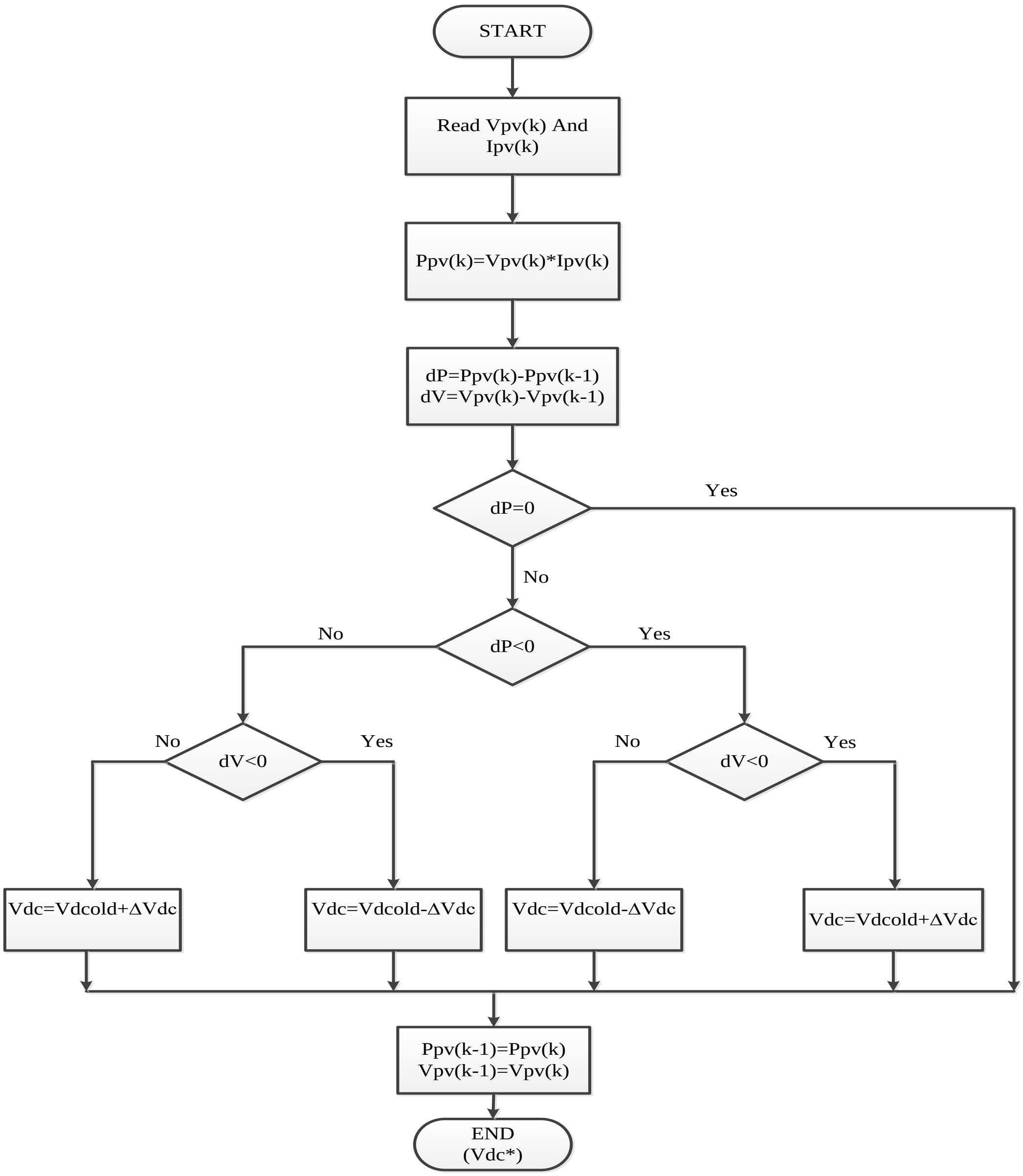


Figure 2.7 Perturb and Observe Flowchart

2.8 CONCLUSION

In this chapter, the equivalent circuit of the solar cell and nonlinear I-V and P-V characteristics have been discussed. As there is need of extracting maximum power from the solar cell, so for that purpose Perturb & Observe MPPT algorithm is discussed. There are lots of MPPT techniques as discussed in that Perturb & Observe method is mostly used MPPT technique. It is very easy to implement in Simulink. It is also very easy to implement in hardware. But there are also some disadvantages in that technique. It is having shadowing problem. Increment in voltage or duty ratio or step size should be chosen carefully so that there should be minimum oscillations.

CHAPTER-3

TRANSFORMERLESS INVERTER

3.1 INTRODUCTION

PV inverter is the main part of the solar power conversion. As the solar power conversion is totally depend on the efficiency. The main requirement of the PV system is that there should be less losses and power conversion efficiency should be very high. There are lots of structure used now a days. In that structure there can be a transformer or the structure without transformer. The advantage of the structure without transformer is that it is having high efficiency, low weight, low cost, easy to install. These PV structures also can also be made with or without DC to DC converter structure. By using single stage PV structure, the efficiency of the solar power conversion can be increased. There are the two following structures.

There are two way of designing of solar inverter. These are as follows:

1. PV Inverter with Transformer
2. Transformer-less PV Inverter

Most of the inverter structures are used with the transformer. The inverter structure with the transformer is having advantage that it provides isolation between the solar side and the grid side. It is very important for the safety purpose that there should be isolation between the input and output side. For that lots of inverter structure has been developed without transformer so that efficiency is improved and isolation is also taken care in that structures.

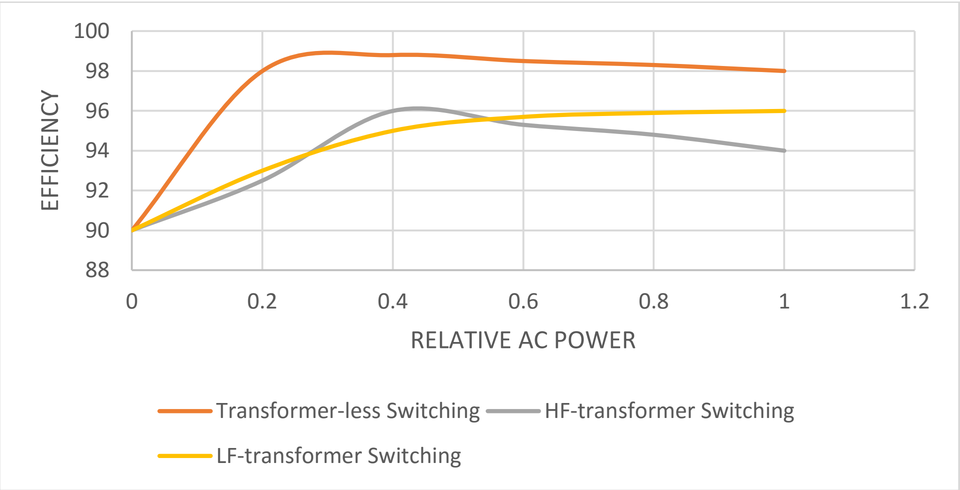


Figure 3.1 Comparison of Efficiency between Different Inverter Topologies

3.2 TRANSFORMER-LESS PV INVERTER

There are many transformer-less inverter structures which is used to offer high efficiency, high power conversion reliability. As there is no transformer in that structure, there is no provision of isolation between the input and the output side. If these transformer-less structures are used in the grid connected system, there may be a chance of flowing leakage current or common mode current in the system which can be create problem in the system. The main disadvantage of the structure is that it also decrease performance of the system.

3.2.1 COMMON MODE LEAKAGE CURRENT

Transformer-less Photovoltaic inverter is used due to low cost, compact size and it is also not tough to install. When these inverter structure are used in the grid connected system, as there is no transformer so there is no isolation between the solar side and the grid side. There may be a chance of flowing leakage current through the parasitic capacitance and the grid impedance in the PV structure. The measuring point of common mode leakage current is in Figure 3.2.

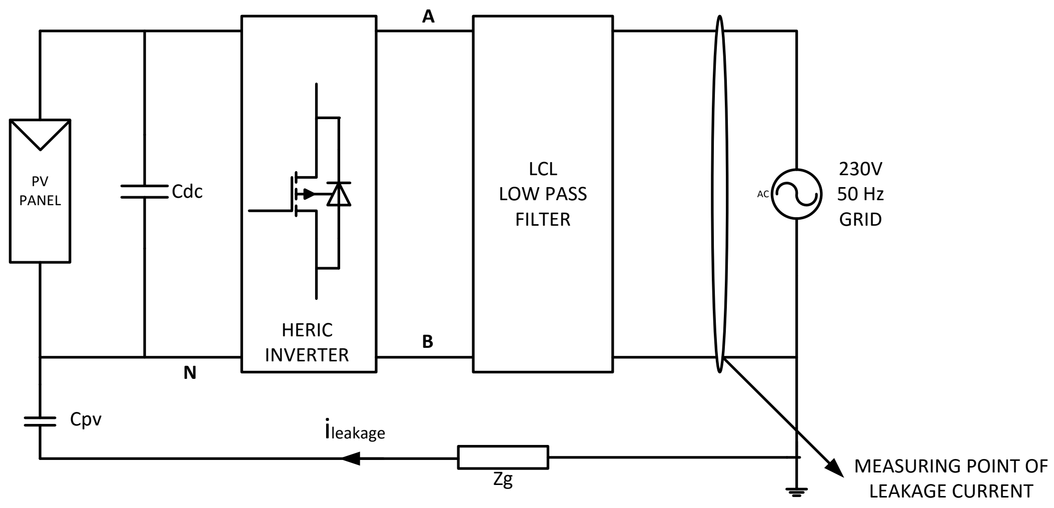


Figure 3.2: Measuring Point of Leakage current in a Grid Connected PV System

In Grid Connected transformer-less PV inverter, common mode leakage current is flowing through parasitic capacitance of solar panel (Cpv) and ground leakage impedence of the Grid, shown in Figure 3.2 where $i_{leakage}$ is the leakage current flowing through ground impedance Zg.

3.2.2 CONDITION TO ELIMINATE COMMON MODE LEAKAGE CURRENT

In the grid connected system, if the transformer-less inverter structure is used, there is no galvanic isolation between the PV array side and the grid side. Due to this, it may form a resonant circuit. This resonant circuit in the transformer-less photovoltaic inverter structure may induce leakage current. The equivalent resonant circuit of Grid Connected photovoltaic system has been presented as depicted in Figure 3.3 where Cpv is the parasitic (stray) capacitance La and Lb are the filter inductors, i_{cm} is the leakage current, Vecm is equivalent common mode voltage, Vcm is the common mode voltage, Vdm is the differential mode voltage.

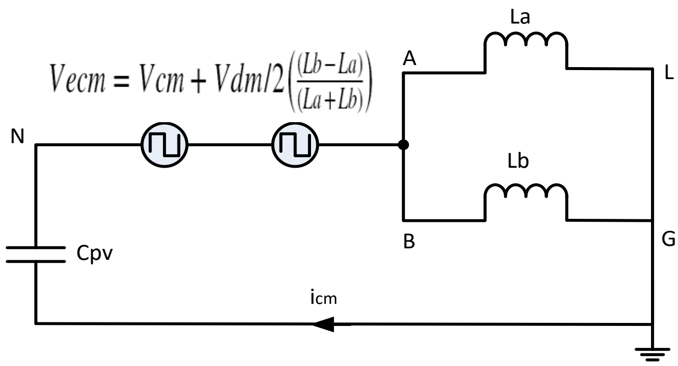


Figure 3.3: Equivalent common mode resonant circuit

Equivalent Common mode resonant voltage, $Vecm = Vcm + Vdm/2(\frac{Lb-La}{La+Lb})$

Common mode voltage $Vcm = (VAN + VBN)/2$

Differential mode voltage $Vdm = VAN - VBN$

In the full bridge H bridge inverter family including H-5 inverter, Heric inverter, H-6 inverter, filter inductor La and Lb is chosen same. So that, the equivalent common mode resonant voltage is equal to the common mode voltage as shown in the Figure 3.4

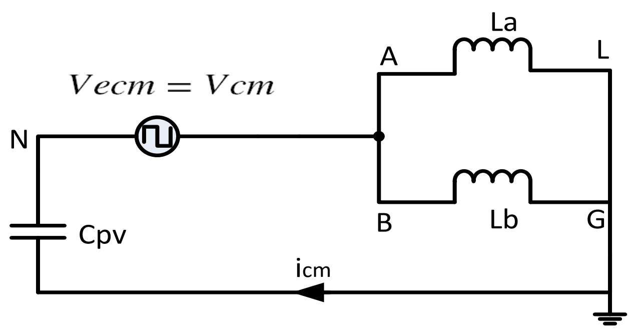


Figure 3.4: Equivalent Common Mode Resonant Voltage for H bridge family

As in the above figure 4.3 it is shown that common mode leakage current is flowing through parasitic capacitance Cpv and ground of grid. As most of H bridge inverter family filter inductor is taken is of same value so that leakage current flowing through parasitic capacitance is due to common mode voltage.

Common mode leakage current, icm $= \frac{d}{dt} Vcm$

From that equation, condition of eliminating common mode leakage current is only met when common mode voltage is constant.

$$Vcm = \text{Constant}$$

$$i_{cm} = \frac{d}{dt}\text{Constant}$$

$$= 0$$

Transformer less inverter topology is chosen like that in that topology common mode voltage is constant so that leakage current flowing in the grid connected PV system is zero.

3.3 TRANSFORMER-LESS PV INVERTER TOPOLOGY

Transformer less inverter topology has been divided into two group families.

1. H-bridge
2. Neutral point clamped (NPC)

3.3.1 H-BRIDGE FAMILY TRANSFORMER-LESS PV INVERTER

H-Bridge family is very important family inverter structure in power electronics converters. It is the first strategy that is very popular and can be used for DC to DC converter and DC to AC converter. It is a very versatile inverter structures and it is the first inverter structure which used force commutated switches for conversion. These inverter structure can be used as half bridge and the full bridge converter structure. These are having very good performance and conversion efficiency. There are following topologies under this family:

1. Basic Full Bridge Inverter
   i) Bipolar (BP) modulation
   ii) Unipolar (UP) modulation
   iii) Hybrid modulation
2. H-5 Inverter
3. Heric Inverter
4. H-6 Inverter

5. Refu Inverter
6. Full Bridge Zero Voltage Rectifier (FB-ZVR)

3.3.2 NPC FAMILY TRANSFORMER-LESS INVERTER

The Neutral Point Clamp is very important and versatile topology and it can be used as half bridge and full bridge inverter structure. It is also having advantage of lower stress on the semiconductor switches. By using these topologies structure dV/dt stress on the switches can be reduced. There are following NPC topologies:

1. NPC Half Bridge Inverter
2. NPC Full Bridge Inverter
3. Conergy NPC Inverter

3.4 HERIC INVERTER

HERIC (highly efficient and reliable inverter concept) inverter topology is patented by Sunways which is very highly efficient and it is also very reliable. It is belongs to the H bridge inverter family. In HERIC inverter structure, it is same as full h bridge but there is some difference that it is also a back to back two switches in the AC side. The AC bypass are used to provide two main functions:

1. During the zero voltage state, it prevents the reactive power exchange between solar side and grid side.
2. During zero voltage state, it isolates the solar side and grid side.

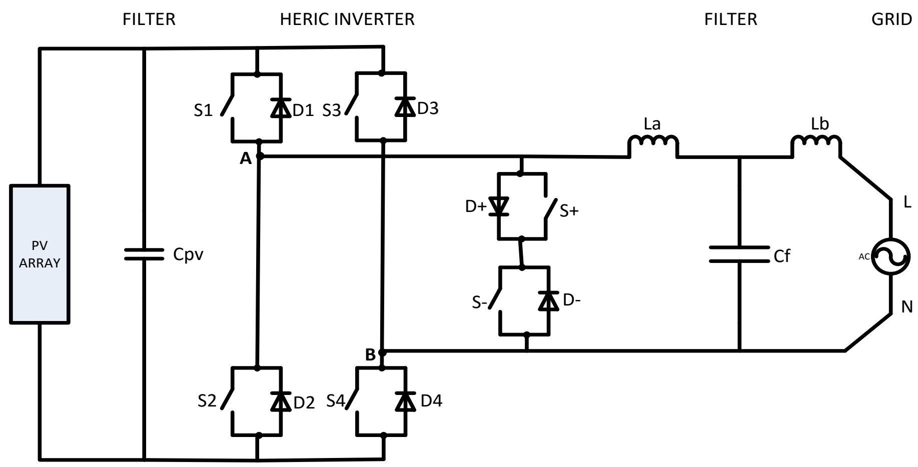


Figure 3.5 Heric Inverter

3.4.1 SWITCHING STATES OF HERIC INVERTER

Heric Inverter is having 6 switches. Switching pulses for the HERIC Inverter is generated by unipolar switching, by using this the stress between the switches can be reduced. S1-S4 and S2-S3 are switched at high frequency by comparing modulating signal with respect to high frequency carrier signal. S+ and S- are switched at grid frequency by comparing modulating signal with respect to ground. So S+ is on for +ve grid current and S- is on for –ve grid current. By using these switching, there is no connection between Solar Panel DC side and AC Grid side at zero voltage state. The switching state pulses is shown as follows:

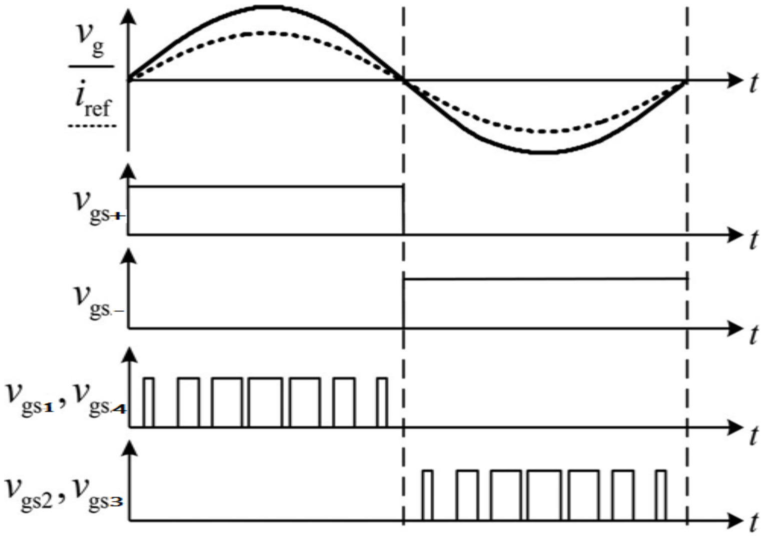


Figure 3.6: Heric Inverter Switching States

In Heric Inverter, at one time 2 switches are switched on at high frequency and one switch is switched on grid frequency for +ve half of the current. As in the Heric inverter topology AC bypass switches are used so that at the zero voltage state there is no connection between solar side and grid side and there is no reactive power exchange between the solar side and the grid side hence the efficiency of the inverter structure is improved. Electromagnetic interference in that topology is also reduced.

3.4.2 SWITCHING STATES OF HERIC INVERTER FOR GENERATING +ve CURRENT

For generating +ve current in the Heric Inverter, three switches are switched on, in that two switches are switched on high switching frequency and one switch is switched on grid frequency. S1 and S4 are switched on the high switching frequency and S+ is switched on the grid frequency. In generating +ve current, there will two states, first is when all the three switch is ON, V_{AB}=Vpv and second is zero voltage state. At zero voltage state only one switch is on.

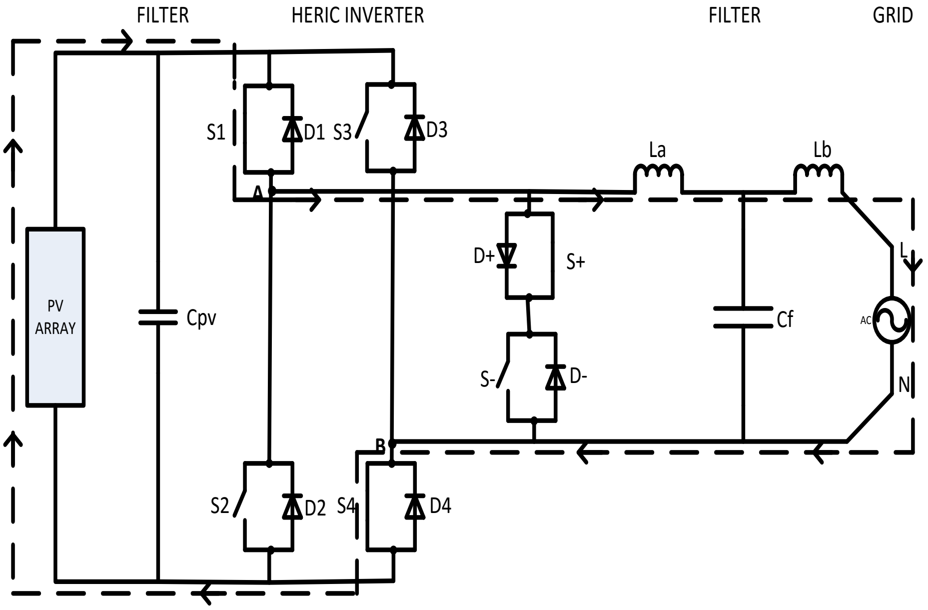


Figure 3.7 Switching States of Heric Inverter in Case of Generating +ve current

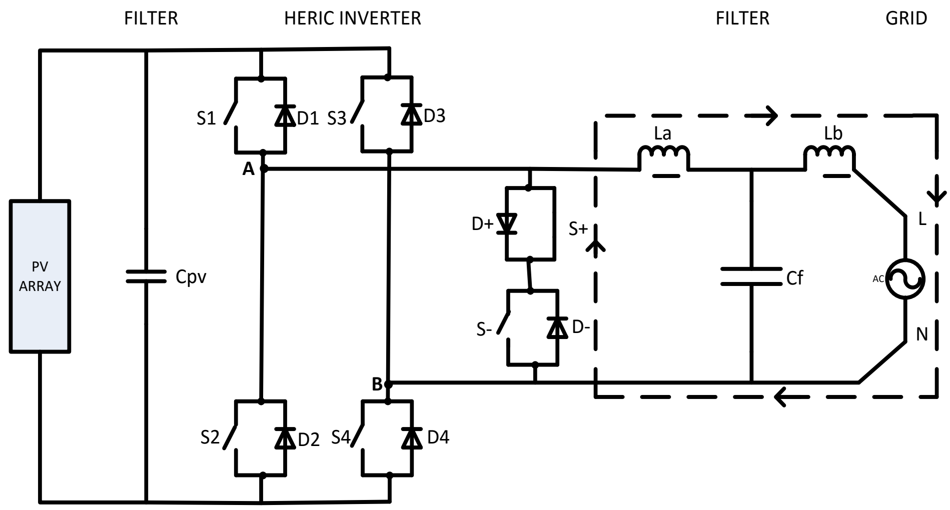


Figure 3.8 Switching States of Heric Inverter in Case of Generating +ve current

There are two voltage level state, first is when V_{AB} =Vpv and zero voltage state V_{AB} =0. The direction of current is shown for both the state in Figure 3.7 and Figure 3.8.

3.4.3 SWITCHING STATES OF HERIC INVERTER FOR GENERATING -ve CURRENT

For generating -ve current in the Heric Inverter, three switches are switched on, in that two switches are switched on high switching frequency and one switch is switched on grid frequency. S2 and S3 are switched on the high switching frequency and S- is switched on the grid frequency. In generating -ve current, there will two states, first is when all the three switch is ON, V_{AB}= -Vpv and second is zero voltage state. At zero voltage state only one switch is on.

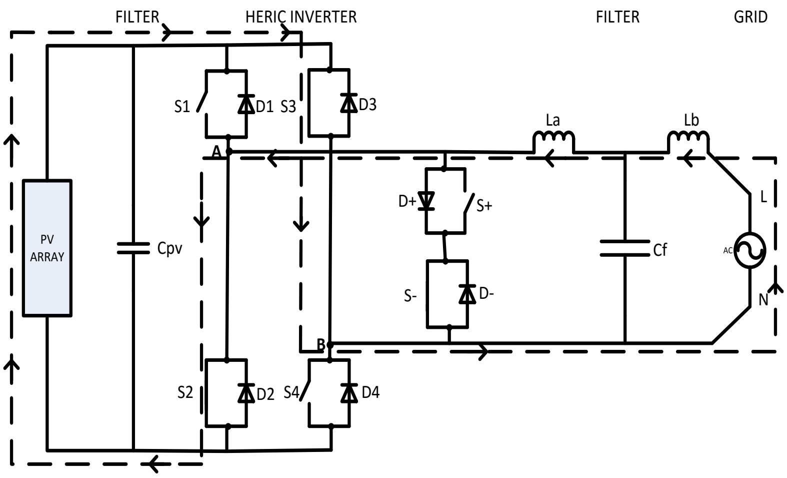


Figure 3.9 Switching States of Heric Inverter in Case of Generating -ve current

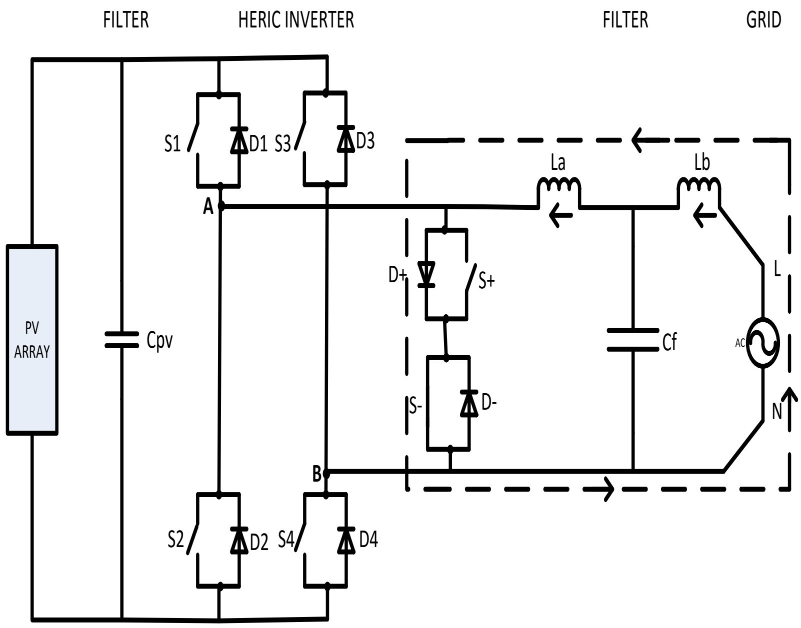


Figure 3.10 Switching States of Heric Inverter in Case of Generating -ve current

There are two voltage level state, first is when V_{AB} = -Vpv and zero voltage state V_{AB} =0. The direction of current is shown for both the state in Figure 3.9 and Figure 3.10.

3.4.4 COMMON MODE VOLTAGE AND LEAKAGE CURRENT IN HERIC INVERTER

HERIC inverter topology is mainly using uniponar modulation technique so that it is having less strss than bipolar switching.

Its common-mode leakage current i_{cm} generated by the parasitic capacitance (C_{PV}) between the photovoltaic array and earth is:

$$icm = Cpv\frac{d}{dt}Vcm$$

The common-mode voltage Vcm is:

$$Vcm = (VAN + VBN)/2$$

If now the common mode voltage is constant than there will no leakage current in the inverter structure.

In this topology as voltage is controlled by the four switches S1-S4 and two switches is used to bypass the voltage and used to provide isolation in the structure. As in the structure it can be seen that if the upper switch is ON then the V_{AN}=V_{AB} and if the lower switch is ON then the voltage V_{BN} is zero. To understand the common mode voltage in the heric inverter structure it is divided into two part. First is for +ve voltage, during the +ve voltage state S1 and S4 is ON and S+ is also ON. So the V_{AN} is V_{IN} and V_{BN} is zero so the common-mode voltage applied is:

$$Vcm = Vin/2$$

Now in the –ve voltage state as S2 S3 and S- is working, in the previous case VAN is input voltage and V_{BN} is zero but now in that case V_{AN} is start to decrease and VBN is going to start increase.it will stop to increase when the diode of S- switch will ON. And this will create a bypass legg for the current flow. Now in that state V_{AN} is zero and V_{BN} is V_{IN} so that common mode voltage in both of the cases is VIN/2 which is a constant for both conditions. The common mode voltage at –ve state:

$$Vcm = Vin/2$$

So in the negative state V_{AN}=0 and V_{BN}=$V_{IN.}$

So by using Heric Inverter topology, common mode voltage in the grid connected PV system is constant, common mode leakage current in the system is reduced. Due to this, there will be reduced Electromagnetic Interference.

3.5 CONCLUSION:

In this chapter, the transformer-less inverter structure is discussed. As there is no isolation between the solar side and the grid side so there may be a resonant circuit in the PV structure. Due to flowing leakage current in the Grid connected PV system, Heric inverter structure is used. This structure provides isolation by adding two switches at the AC side as it will create isolation at the time zero voltage state. In that chapter, the resonant circuit of the structure and the leakage current flowing path is also discussed. In that the condition of reducing common mode leakage current is also discussed. Heric inverter provides the better inverter structure for grid connected PV system.

CHAPTER-4

CONTROL STRUCTURES OF GRID CONNECTED PV SYSTEM

4.1 INTRODUCTION

Grid connected PV inverters are very much used in the recent times and the control scheme of the grid connected system should be specific that it should control the grid side and the PV panel side. In the control scheme, there should be active power control, reactive power control, dc link voltage control, current control at the grid side and at the PV Panel side there must be maximum power is extracted from the panel side. Grid synchronization is the main part of the scheme that the injected grid current and the grid voltage must be synchronized. The control scheme of grid connected PV system is different for single stage and two stage. In the two stage system, one DC to DC converter is also used which is mainly used to extract maximum power but if single stage grid connected system is used then in that control scheme with basic grid controls MPPT is tracked by using modulation index of the inverter structure controlled so that the maximum power can be extracted.

4.2 GENERAL CONTROL STRUCTURES OF TRANSFORMER-LESS INVERTER

There are lots of variety of PV inverter topologies present so the control structure should be also specific for that PV inverter. Control structure can be double stage or single stage. The control structure of single stage PV inverter is shown in the figure 4.1. In that figure all the generic control has mentioned for the grid connected single stage PV inverter. Current controller is the main control part of the control scheme of the grid connected transformer-less PV inverter structure. Its main function is to control the injected current and to improve the power quality of the system. There are lots of studies has been developed for extracting phase angle from grid voltage and many methods has been developed for that, some methods are as Zero-Crossing Method, Filtering of Grid Voltage, Phase Locked Loop (PLL) Technique.

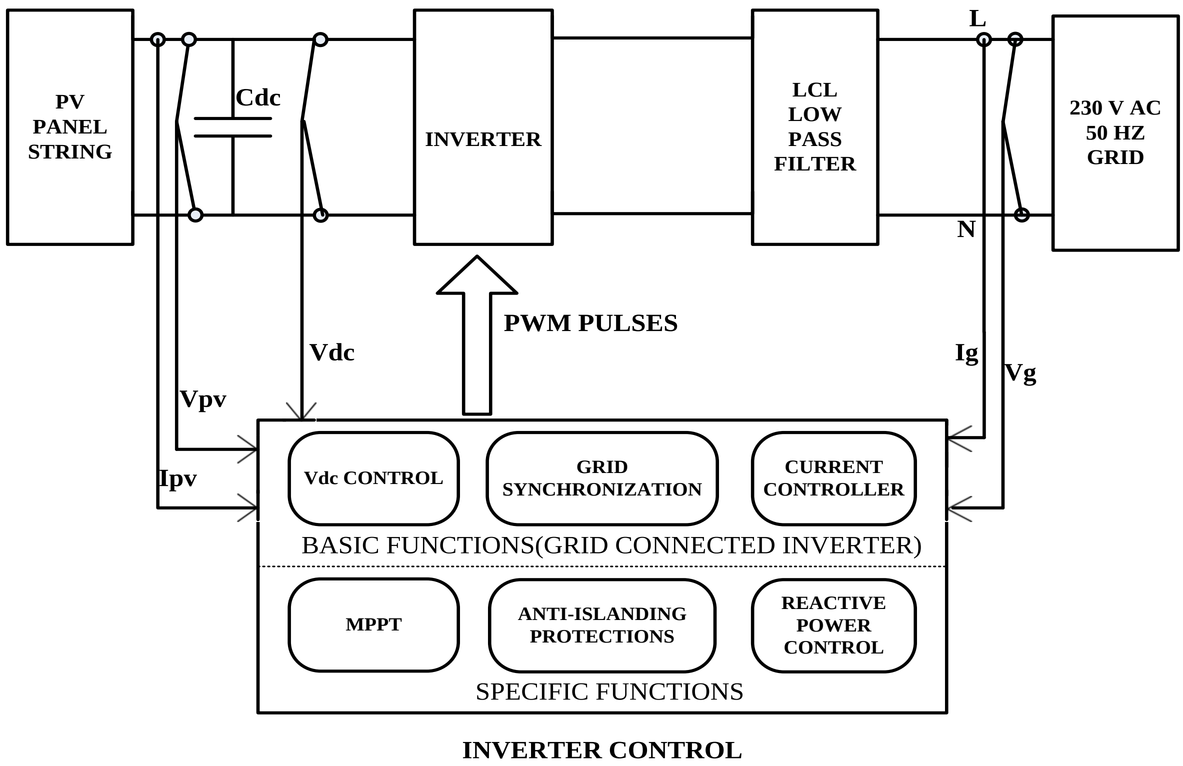


Figure 4.1: General Control Structures of Transformer-less Inverter

1. Basic functions – common for all grid-connected inverters

Grid current control

- THD limits imposed by standards
- Stability in the case of large grid impedance variations

DC voltage control

- Adaptation to grid voltage variations
- Ride-through grid voltage disturbances

Grid synchronization

- Operation at the unity power factor as required by standards
- Ride-through grid voltage disturbances

Reactive Power Control

- Reactive Power (Q) compensation
- Load reactive power supplied by the DC link side.

2. PV specific functions – common for all PV inverters

Maximum power point tracking (MPPT)

- Very high MPPT efficiency during steady state (typically > 99 %)
- Fast tracking during rapid irradiation changes (dynamical MPPT efficiency)
- Stable operation at very low irradiation levels
- Anti-islanding (AI), as required by standards (VDE 0126, IEEE 1547.)

Grid monitoring

- Synchronization
- Fast voltage and frequency detection

4.3 CONTROL OF SINGLE-PHASE SINGLE STAGE PHOTOVOLTAIC SYSTEMS

Control structure of the single phase PV systems should be like that it should control the PV side and the grid side requirement. The function of the control structure of single stage single phase photovoltaic system can be as follows:

- The most important part of the control scheme is that it should track the maximum power from the solar panel. This is the PV side controlling.
- Control of the active power delivered to the grid
- Control of the reactive power exchange with the grid
- THD of injected current is less than 5% and high efficiency.
- Grid Synchronization.

4.4 CONTROL SCHEME OF SINGLE PHASE SINGLE STAGE GRID CONNECTED TRANSFORMER-LESS PV INVERTER

To control single phase single stage Heric inverter, there is a two part, PV side controller and grid side controller. In the grid side, there is a need of controlling of active power and reactive power, it is good to use synchronously rotating reference frame dq controller to control the active power and reactive power separately in the single phase single stage inverter. There are the following control loop are used in close loop control of single phase single stage PV Inverter. In single phase single stage grid connected Heric inverter, control scheme has to control input side, PV panel side and grid side.

Control scheme of Heric Inverter has following task:

- Extract maximum power from PV panel.
- Grid Synchronization
- DC-link voltage control
- Grid current should be injected at unity power factor
- Injected grid current THD < 5%, Standard IEEE1547
- Common mode leakage current < 30 mA, Standard VDE 0126
- Reactive power flow control.

To get these condition to be satisfied, dq synchronous rotating reference frame is used. By using dq synchronous rotating reference frame, there is a separate provision to control the active power and reactive power. If there is no need of controlling of reactive power, reference q axis current is to be taken zero.

In this control scheme, dc link voltage controller is used to generate the d axis reference current. To generate it, there is a need of comparison of reference voltage and the input dc link voltage. Reference voltage Vdc is determined by using perturb and observe MPPT algorithm, in that PV panel voltage Vpv and Current Ipv is sensed. By using MPPT technique reference voltage of dc link voltage is set like that it will work on the maximum power point and extract maximum power from the solar panel in all the atmospheric conditions. After comparing it, it is fed to the PI controller which is used to generate d axis reference current. In that control scheme, reactive power is not controlled so q axis reference control is taken as zero. So d and q axis reference current is generated by this method as shown in Figure 4.4.

PLL is used for Grid synchronization and to extract frequency (wt) from grid voltage so that the grid current which is injected into the grid is having same frequency as same as grid voltage as shown in Figure 4.4.

The main part of the control scheme is to make synchronously rotating dq current and voltage from the single phase grid current Ig and grid voltage Vg. To get dq axis voltage Vdq and dq axis current Idq from Vg and grid current Ig, first single phase quantity is changed to αβ axis. Grid current Ig and grid voltage Vg is fed to orthogonal signal generator, in that block α axis current or voltage is taken same as grid current or voltage and to get β axis current or voltage is taken by shifting the grid current and voltage by its ¼ cycle. After getting αβ axis current and voltage, by using park transformation it is converted to dq axis current Idq and voltage Vdq as shown in Figure 4.3.

$$\begin{bmatrix} d \\ q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \cdot \begin{bmatrix} \alpha \\ \beta \end{bmatrix}$$

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \cdot \begin{bmatrix} d \\ q \end{bmatrix}$$

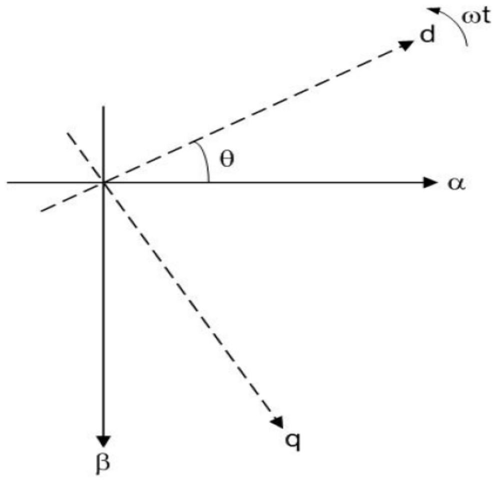


Figure 4.2 dq and αβ Frames

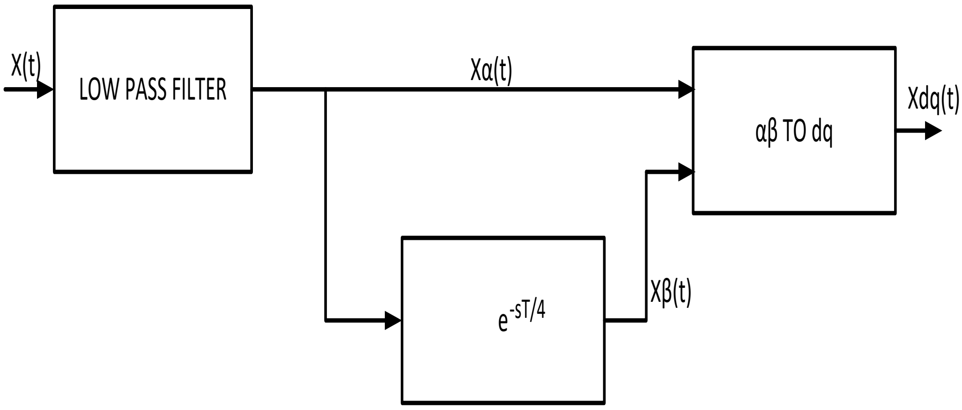


Figure 4.3 Single phase signal to dq axis signal

After getting Idq and Vdq, then inner current control controller is used, in this reference dq axis current Idq* and actual Idq is compared which is fed to PI controller. This inner current control is used to improve the grid current quality. The output of this PI controller is added to feed forward voltage as shown in Figure 4.4. The output after addition is given to the modulating signal generator where dq axis is converted to αβ axis and which will give modulating signal. After getting this, by using unipolar technique of PWM, PWM pulses is generated by comparing modulating signal and carrier signal as shown in Figure 4.4. This is the control scheme of grid connected Heric Inverter in which dc link voltage of input side of inverter, active power and inner grid injected current and reactive power is controlled.

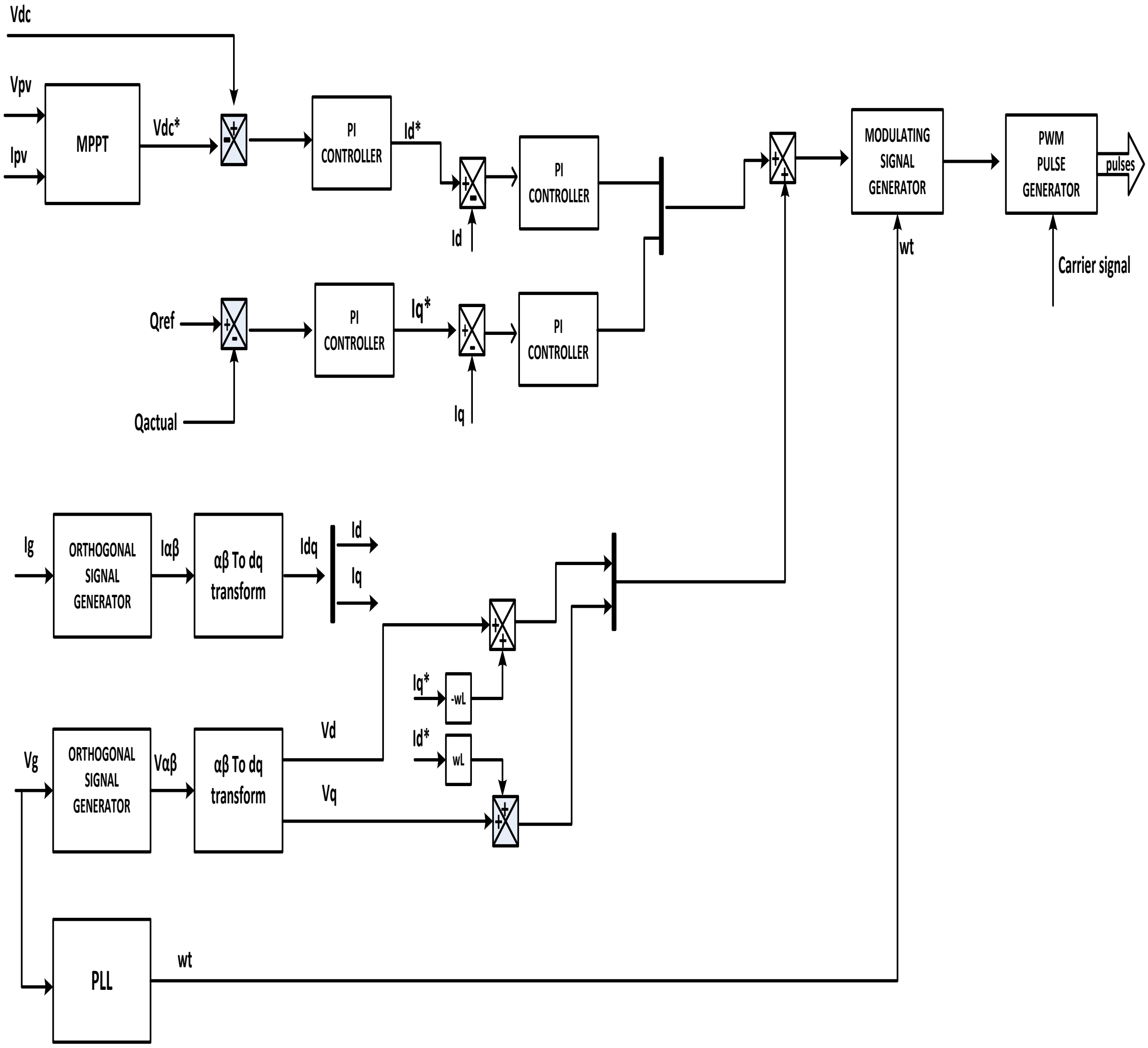


Figure 4.4 Control Scheme of Grid Connected Heric Inverter

4.5 AC SIDE LOW PASS FILTER

The ac side low pass filter is used to reduce harmonics in the injected grid current which is comprised of high order harmonics caused due to switching of heric inverter. There are many combination of low pass filter which can be used to reduce harmonics so that third harmonic distortion in the injected grid current can be minimized. These are the most used low pass filter combination:

4.5.1 L-FILTER

The L filter is very much used filter and simple filter. It is a first order filter. L-filter is also having 20db/decade attenuation over its frequency range. This type of filter is used for the inverter to remove the harmonics produced by the switching of the semiconductor switches. L-filter is shown in figure 4.5.

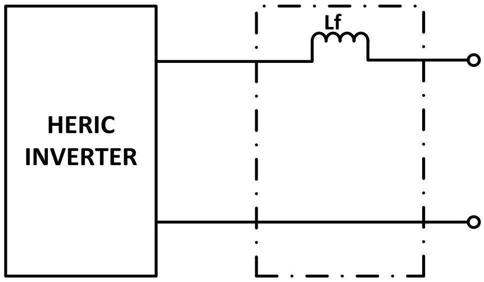


Figure 4.5 L-Filter

4.5.2 LC-FILTER

LC–filter is a second order low pass filter. LC filter as shown in Figure 4.6 is having better damping factor than L- filter. It gives better performance than L-filter to improve the power quality of grid current and remove the harmonics in grid current due to high switching frequency. It is very easy to design and it removes the harmonics in the injected current. LC-filter is having 40 db/decade over its frequency range. By choosing good damping factor the performance of LC filter can be improved.

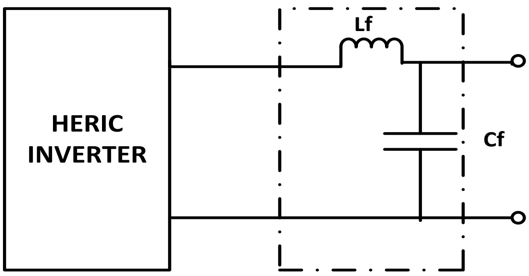


Figure 4.6: LC Filter

4.5.3 LCL-FILTER

LCL-filter is a third order filter with 60dB/decade of attenuation over its frequency range. It is having a better damping factor than L and LC type of filter. It is mostly used filter to remove harmonics in the grid current and to improve quality of the grid current. It also provides the better decoupling and damping factor than any other filter. It is very good for grid connected system. LCL filter is having very good ripples which is very helpful in removing the harmonics in the injected grid current. The parameters of LCL filter as shown in figure 4.7 is chosen correctly and wisely because it may create problem in the system and can be induce harmonics in the injected current. L1 is the inverter side inductance and L2 is the grid side inductance and Cf is the filter capacitance. In series with the capacitor filter Cf , resistance Rf is also connected to provide damping.

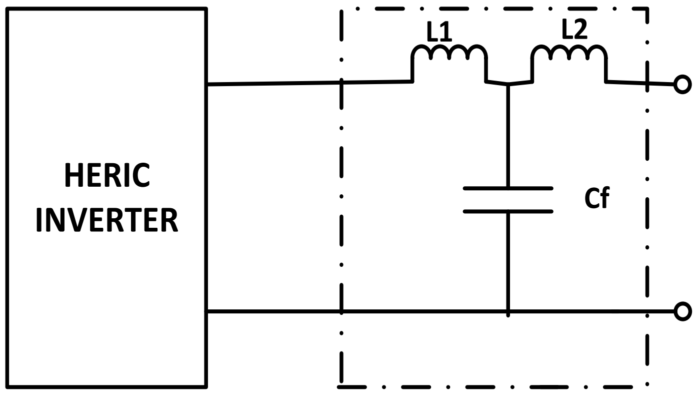


Figure 4.7: LCL Filter

4.5.4 LCL-FILTER DESIGN PROCEDURE

LCL filter is very important filter used in grid connected system to eliminate harmonics from the injected current. The design of the LCL filter should be very effectively and wisely. In the designing process, some factors should be taken care as current ripple, maximum grid current, the switching frequency. The reactive power is also very much affecting the LCL filter. For damping factor, a series resistance with the filter capacitor is also designed in the LCL filter. The algorithm of LCL filter designing is shown in figure 4.8.

The following parameters are needed to design LCL parameters: Vn- single phase RMS voltage (inverter output), Pn- rated active Power, Vdc -DC link voltage, fg- grid frequency ,fsw- switching frequency, fres- resonance frequency. The base impedance and base capacitance are defined in the base value are:

$$Zb = Vn^2 / Pn$$

$$Cb = 1 / WgZb$$

Where

$$Imax = Pn\sqrt{2} / Vn$$

$$L_1 = Vdc / 6fsw\Delta I_{Lmax}$$

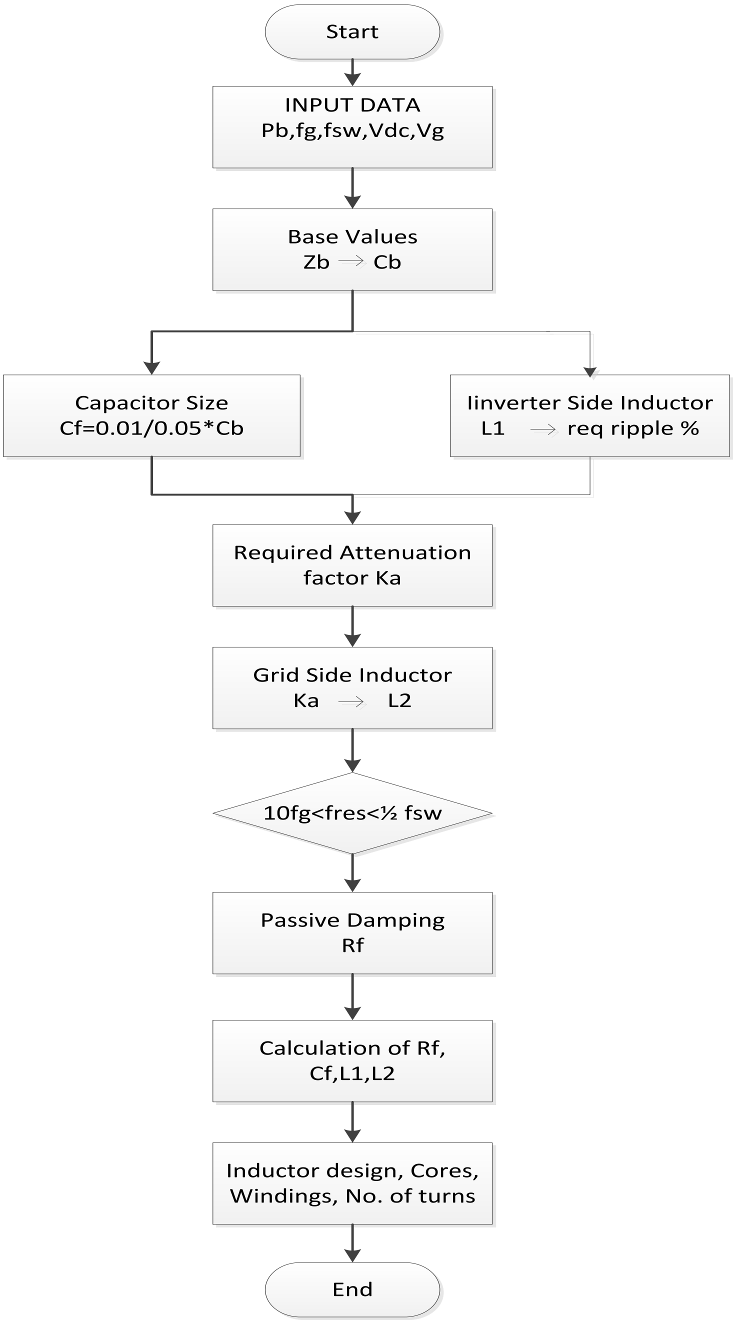


Figure 4.8: LCL Filter Parameters Design Calculation

If it is assumed that the maximum power factor variation in the grid is 5% then filter capacitance cab be calculated. So the filter capacitance can be calculated as $Cf= 0.05Cb$

It can be observed in the maximum peak to peak ripple in DC to AC inverter is in m=0.5, then

$$\Delta I_{Lmax}= Vdc/ 6fswL_1$$

Where L_1 is the inverter side inductor, it is assumed that 10% ripple current of the rated current for the design parameters is given by:

$$\Delta I_{Lmax}=0.1\ Imax$$

The LCL filter should reduce the injected current ripple to 2%. The desired attenuation in this filter is 20%. After calculating the value at the inverter side, for calculating the value at the grid side is desired attenuation is selected. Grid side inductor can be calculated by this formula:

$$L2 = \sqrt{(1}/Ka^2) + 1/CfWsw^2$$

Ka is the desired attenuation in the filter.

r is the ratio between the inductance at the grid side and inductance at the inverter side.

$$L_2 = r\ L_1$$

By using this relation, choosing different value of r , the transfer function of the LCL filter can be easily designed. In series with the filter capacitor a series resistance is also added, it is added for the damping. The value of filter resistance is one third of the impedance of the filter capacitance at the resonance frequency. The resonance frequency should be chosen wisely. It resonance frequency is not in the range then it may create problem in the filter damping. :

$$w_{res} = \sqrt{\frac{L1+L2}{L1L2Cf}}$$

$$10fg < fres < 0.5fsw$$

The filter resistance can be calculated by this formula:

$$Rf = \frac{1}{3wresCf}$$

This is the step by step procedure to get the parameters of LCL filter. By using this algorithm and procedure, the parameters of LCL filters can be easily calculated, so that harmonics in the grid current can be reduced and third harmonics distortion is reduced.

4.7 CONCLUSION

In this chapter, Control scheme of single phase single stage Grid connected transformer-less invertee is discussed. As in that active and reactive power is controlled for that purpose dq synchronously rotating reference is used, in that method d-axis is used to control the active power flow in the grid connected system and the q-axis is used to control the reactive power flow in the system.

CHAPTER-5

SIMULATION AND RESULTS

5.1 Simulation Model Components

The simulation model consists of 6 main parts:

1. PV Panel
2. MPPT Algorithm
3. Heric Inverter
4. Inverter Control
5. LCL Filter
6. Grid and Load

1. PV Panel

The PV Panel used in this simulation is a used defined block.

Datasheet of Solar Panel

Number of cells in Series=11

Number of cells in Parallel=1

Maximum Power of one module=185.625

Total power of Panel=2041.875

Open circuit voltage of one Module=44.5

Open circuit voltage of Panel=489.5

Maximum power voltage=412.5

Short circuit current of 1 module=5.4

Current at maximum power=4.95

Shunt resistance Rsh=182.1671Ω

Series resistance Rs=.25684 Ω

Temperature coefficient of Isc (%/deg.C)=.03922

Temperature coefficient of Voc (%/deg.C)=-.3964

PV Panel is modelled in the matlab Simulink. I-V and P-V characteristics of solar panel is shown in figure. These characteristics are at the varying irradiance and constant temperature. The maximum power at 1000W/m2 irradiance and 25ºC temperature is 2041 W. The maximum power at 800 W/m2 irradiance and 25ºC temperature is 1640 W as shown in figure 6.1.

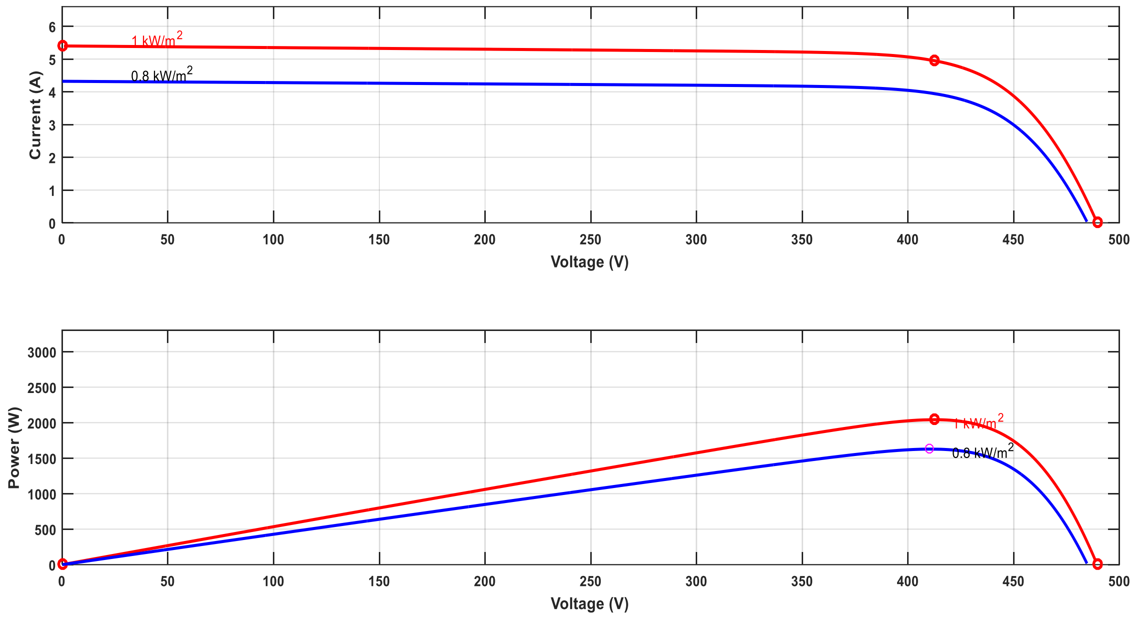


Figure 5.1 I-V & P-V curve of solar panel at Different Irradiance

2. MPPT Algorithm

As if there is any change in the atmospheric condition such as irradiance and temperature, there is a change in maximum power of the solar panel. MPPT algorithm is used to extract the maximum power from the solar panel.

In the figure 6.1, at temperature 25ºC and 1000 and 800 W/m2 irradiance, there is a change in the maximum power of the solar panel. But there is not much change in maximum voltage at which maximum power is getting. So by using Perturb & observe Algorithm, the maximum voltage is determined at which maximum power is extracted.

3. HERIC Inverter

Simulink Model of Heric Inverter is shown in figure 5.2.

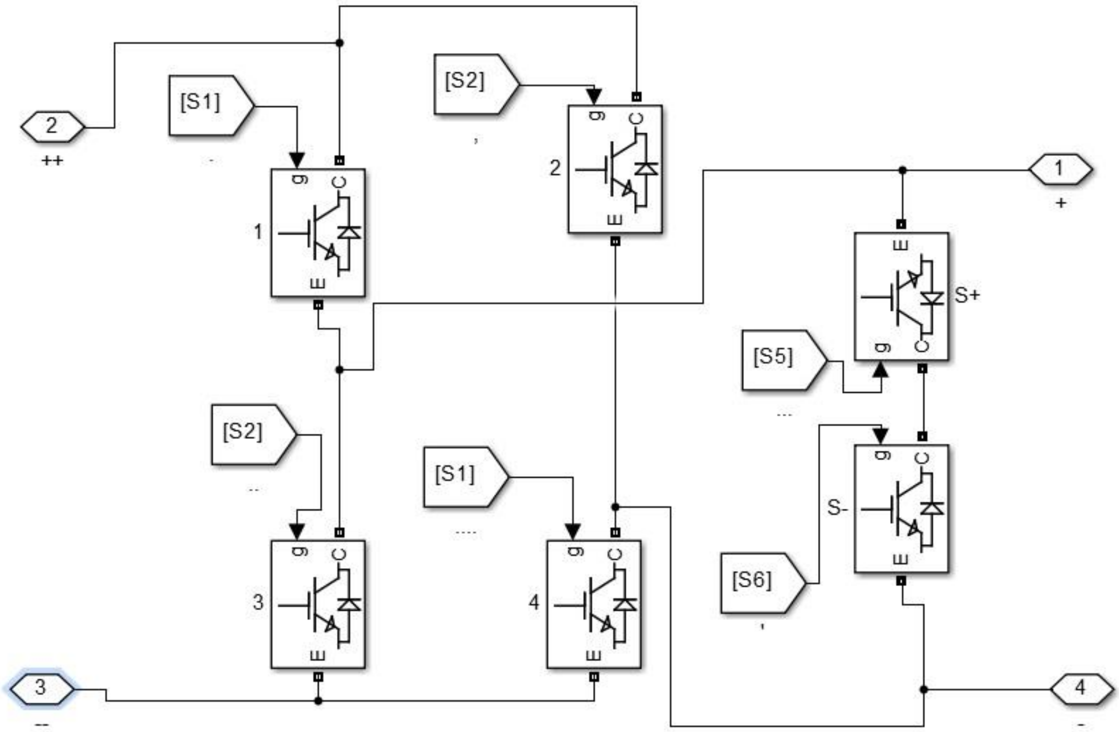


Figure 5.2 Simulink Model of Heric Inverter

The Simulink model of switching of Heric inverter is shown in figure 5.3. In that figure there are 6 switches to fire. For that this unipolar method is used. S5 is used as S+ and S- is used as S6. S1, S2, S3, S4 are fired at high frequency and S+ and S- are fired at grid frequency. In that modulating signal from the inverter control of the system and it is compared with the carrier wave which is having 10KHz switching frequency. The switching Simulink model is shown in the figure 5.3.

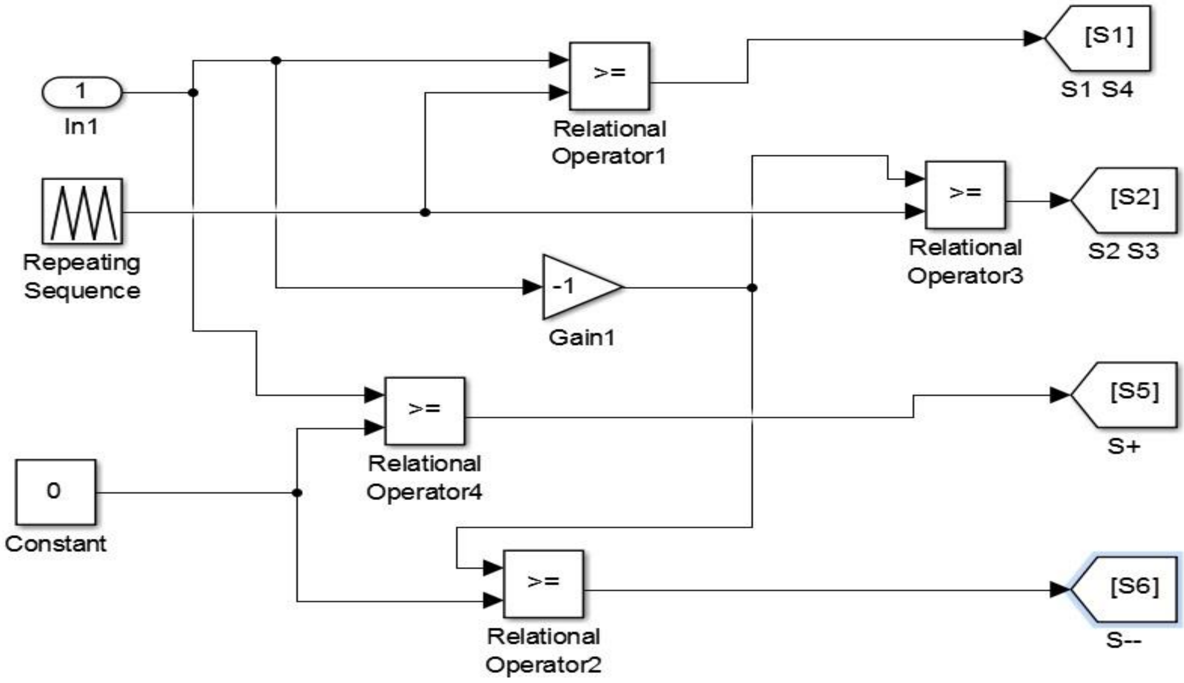


Figure 5.3: Simulink Model of Switching Pulses of Heric Inverter

4. Inverter Control Scheme

Inverter control is the main block of the transformer-less inverter. It is used as current control. It can be used as reactive power control as discussed in 4.4. Inverter control has been having these main blocks:

1. MPPT algorithm

2. Grid synchronization (PLL) and single phase quantity to dq reference frame current and voltage generation

3. Vdc control

4. Reactive Power Control

4. Current Control

5. Modulating signal Generator

The Simulink model of inverter control is shown in figure 5.4 with all the blocks as mention above.

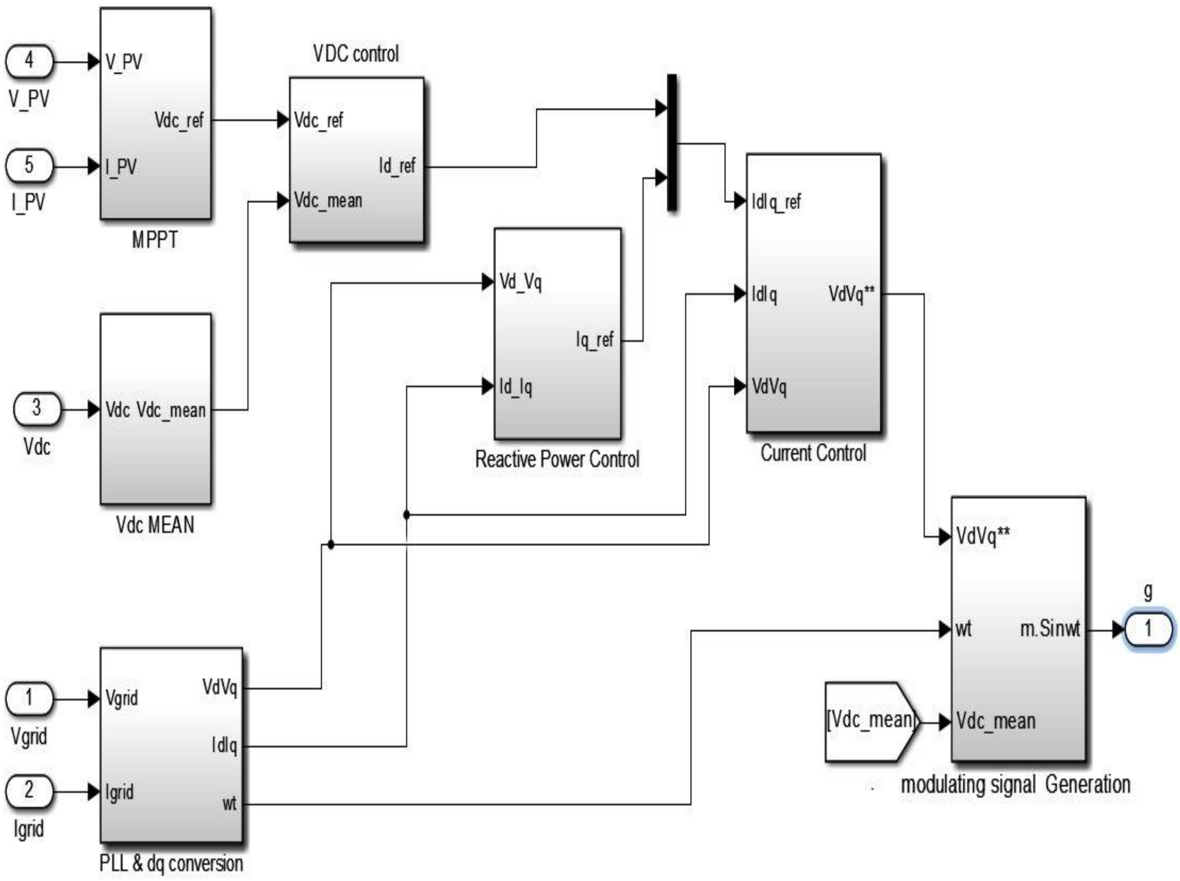


Figure 5.4 Simulink Model of Inverter Control

5. LCL Filter

LCL filter is mostly used filter to remove harmonics in the grid current and to improve quality of the grid current. It also provides better decoupling between the filter and the grid impedance and lower current ripple across the grid inductor. The designing of LCL filter is discussed in 4.6.4 by using this method the parameters of LCL filter is calculated. To reduce the leakage current, the inductance is provided in both leg by dividing it equally.

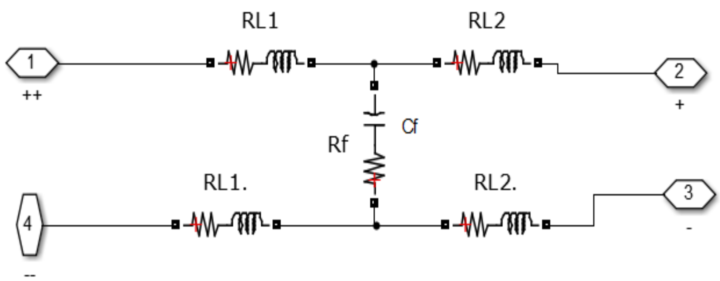


Figure 5.5 Simulink Model of LCL filter

6. Grid Connected Transformer-Less Inverter

As grid connected PV system is having more advantages than stand-alone system. The Simulink model of transformer-less structure Heric inverter is shown in figure 5.6. Rg is the earth resistance connected between stray capacitance and grid. RL load is used in that structure. There should be power balance between input power entering to the grid, load and Grid.

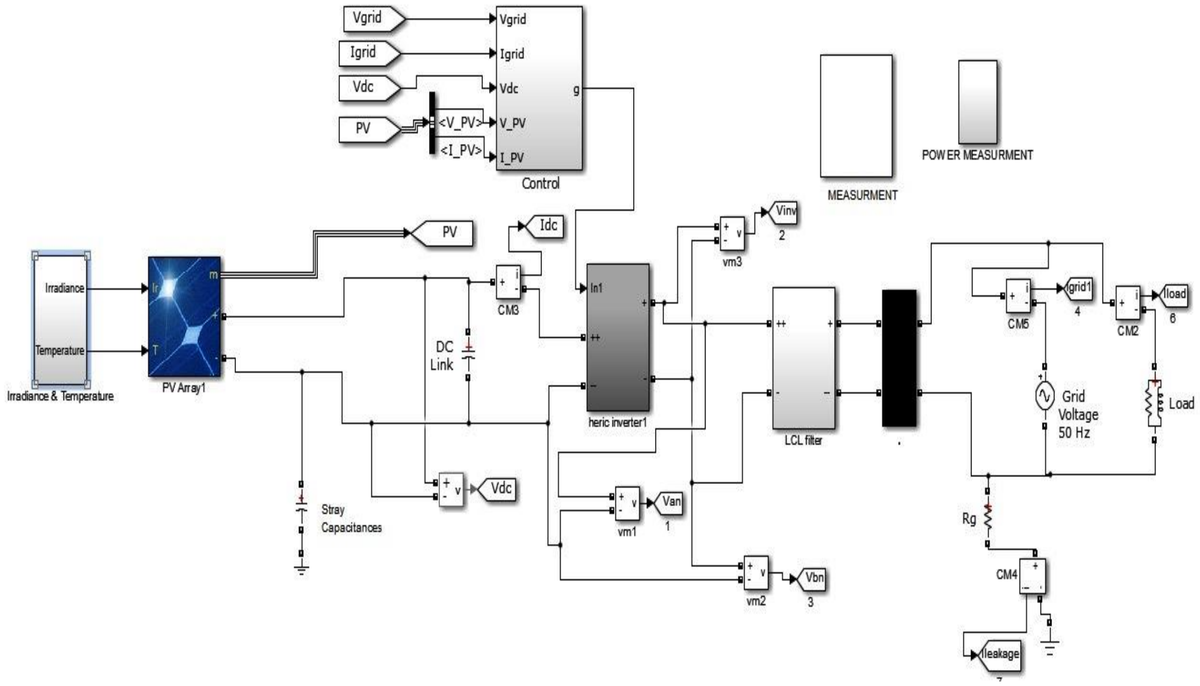


Figure 5.6: Grid Connected Heric Inverter

5.2 SIMULATION RESULTS

5.2.1 Simulation results for Active Power Control

To control only active power in the grid connected system, as there is no reactive power control so that reactive power control current reference is taken zero. The simulation results for active power control in grid connected system is as follows:

5.2.1.1 AT 1000 W/m^2 & 25°C

5.2.1.1.1 Irradiance, Voltage and Power at Dc Solar Panel Side

In the DC side the maximum power should be extracted from the solar panel and for that DC link voltage should operate at maximum power point voltage.

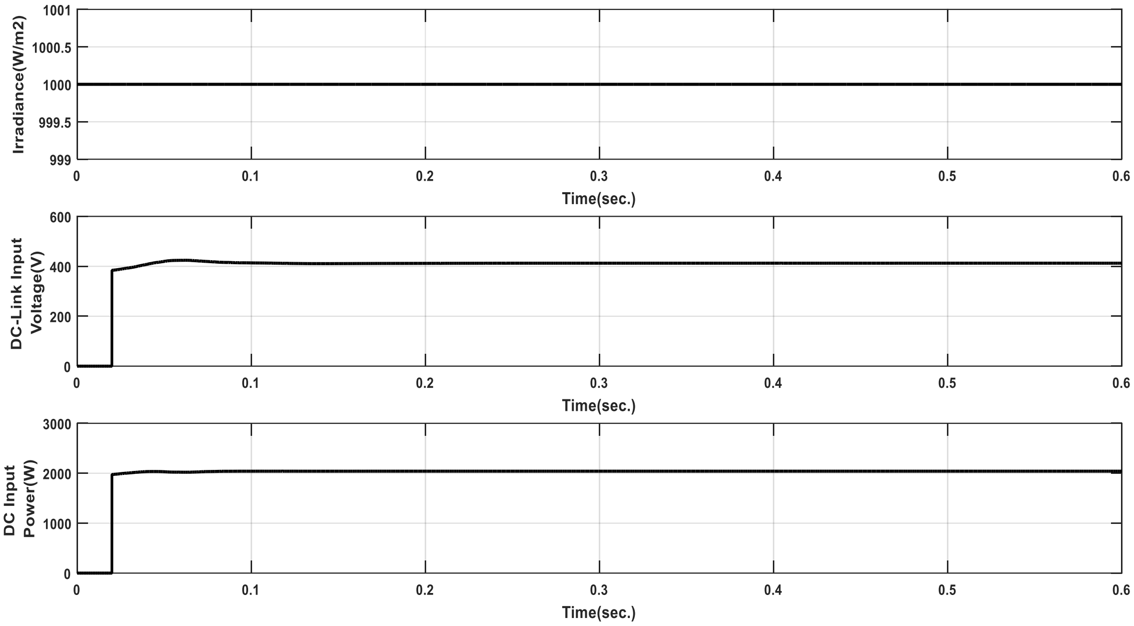


Figure 5.7: DC variation of PV system

In that figure 5.7, it can be seen that it is extracting the maximum power at 1000 irradiance at maximum power point voltage.

At in the figure 5.7 it can be seen that at 1000w/m2 and 25ºC temperature, the maximum voltage at MPP point is 410 and the maximum power of the solar panel is 2040 W. So maximum power 2040 W is coming from the solar side to the input of the Heric inverter.

5.2.1.1.2 Current and Voltage Entering To the Grid (Injected Current and Grid Voltage)

Current and voltage entering to the grid as shown in figure 5.8 should follow some conditions; that is it should have THD less than 5% and current and the voltage is synchronized and maximum power from the solar panel should be extracted.

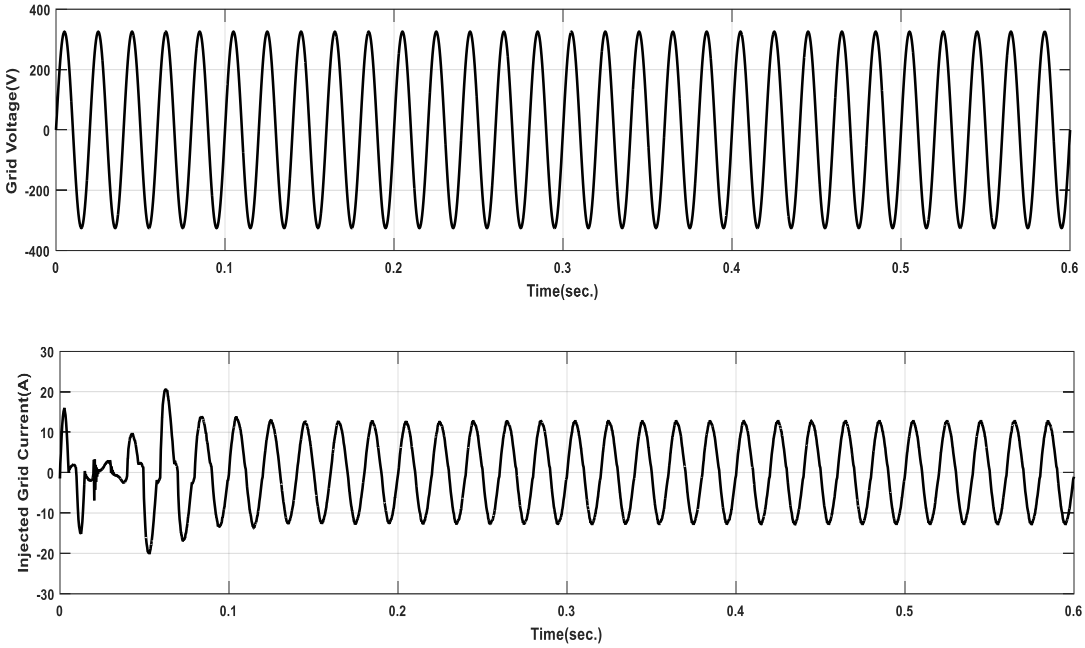


Figure 5.8: Voltage and current entering to the Grid

RMS value of current entering to the grid=8.79 A

RMS value of voltage entering to the grid=230V

Total Active Power entering to the grid (Injected Power) = 8.79*230

=2021.7 W

Maximum Power of Solar Panel at 25ºC and 1000 W/m^2 =2041 W

So maximum power is extracted from the panel. And the injected grid current and grid voltage are synchronized.

5.2.1.1.3 FFT Analysis of Injected Grid Current

The current entering to the grid should be less than 5% THD. In the simulation result at 1000 W/m2 and 25º C, the current THD is 3.54%. Fast Fourier transform (FFT) analysis of the injected current is shown in the figure 5.9.

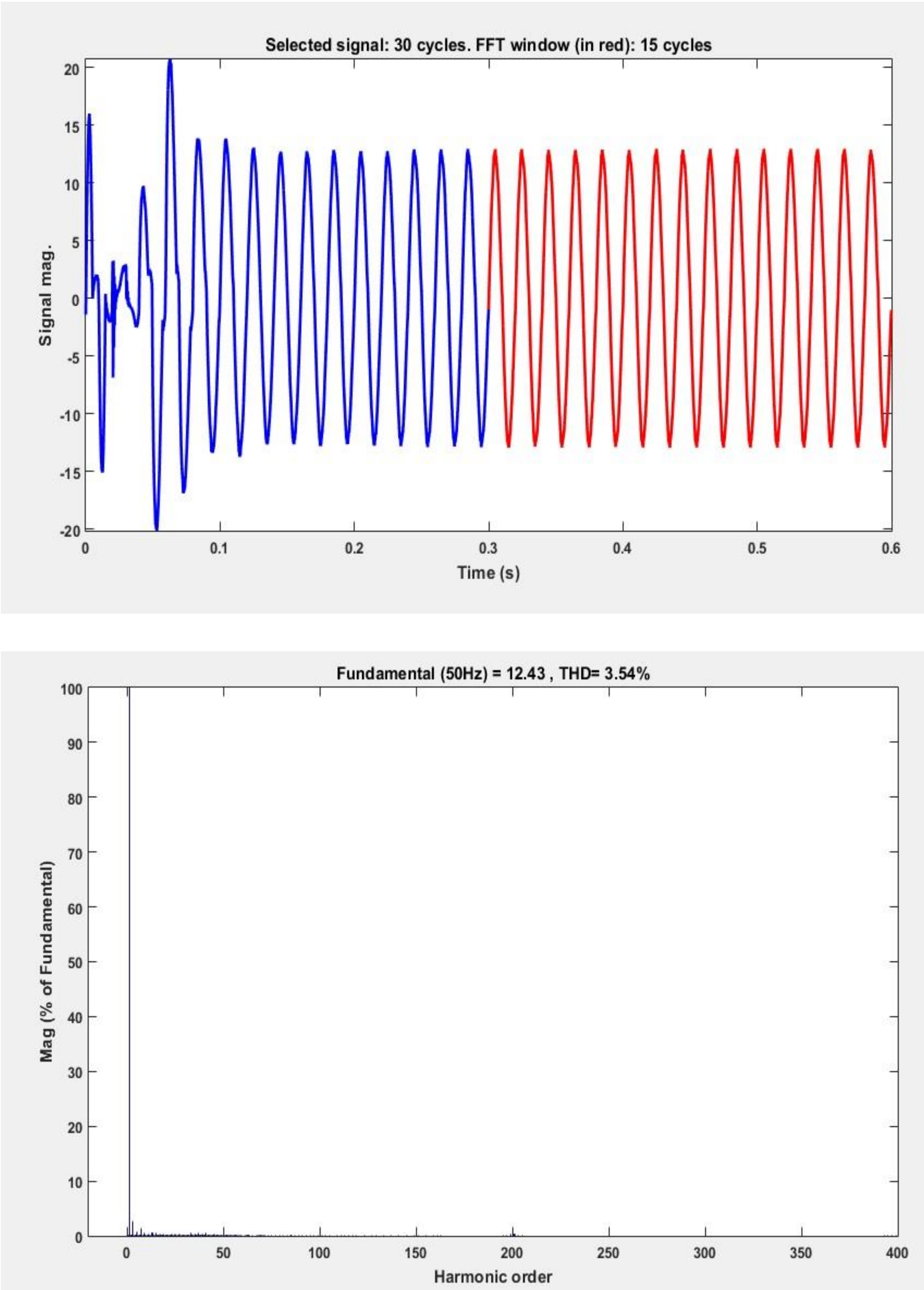


Figure 5.9: FFT analysis of current

5.2.1.1.4 Leakage Current in Heric Inverter Structure

As there is no galvanic isolation between solar panel and grid in transformer-less inverter structure, there may be chance of flowing leakage current in PV system. This leakage current should be less than 30mA according to German standard VDE 0126-1-1. The leakage current is depend on parasitic capacitance. It should be as minimum as possible. The value of parasitic capacitance is taken as for simulation result is 5nF. The simulation result of leakage current in transformer-less Heric inverter is shown in figure 5.10. For 1000 irradiance the leakage current flowing in the system is 1.67mA.

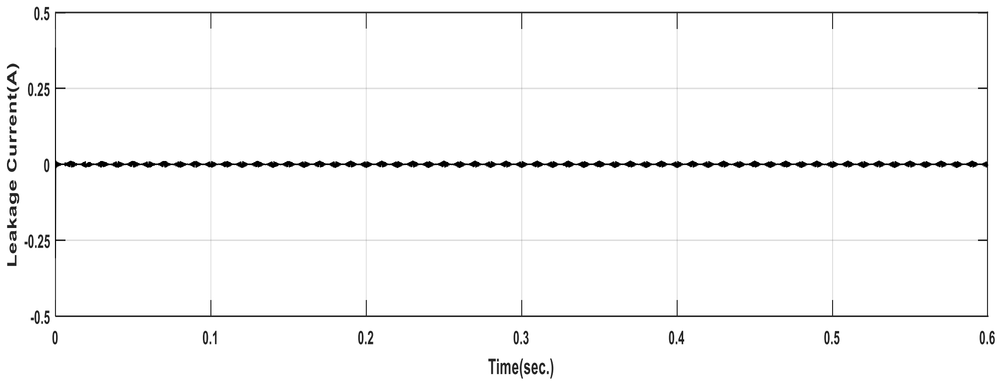


Figure 5.10: Leakage Current in PV structure

5.2.1.1.5 Active Power Balance between Solar Panel, Grid and Load

Active load=3000 W

If there is any load is connected in grid connected system, if the load is taken as 3000 W then maximum power is supplied the PV panel and rest the power is supplied by the grid. In the figure 5.11 it can be seen that 2020W is supplied by the solar Panel and the rest the 980W is supplied by the grid

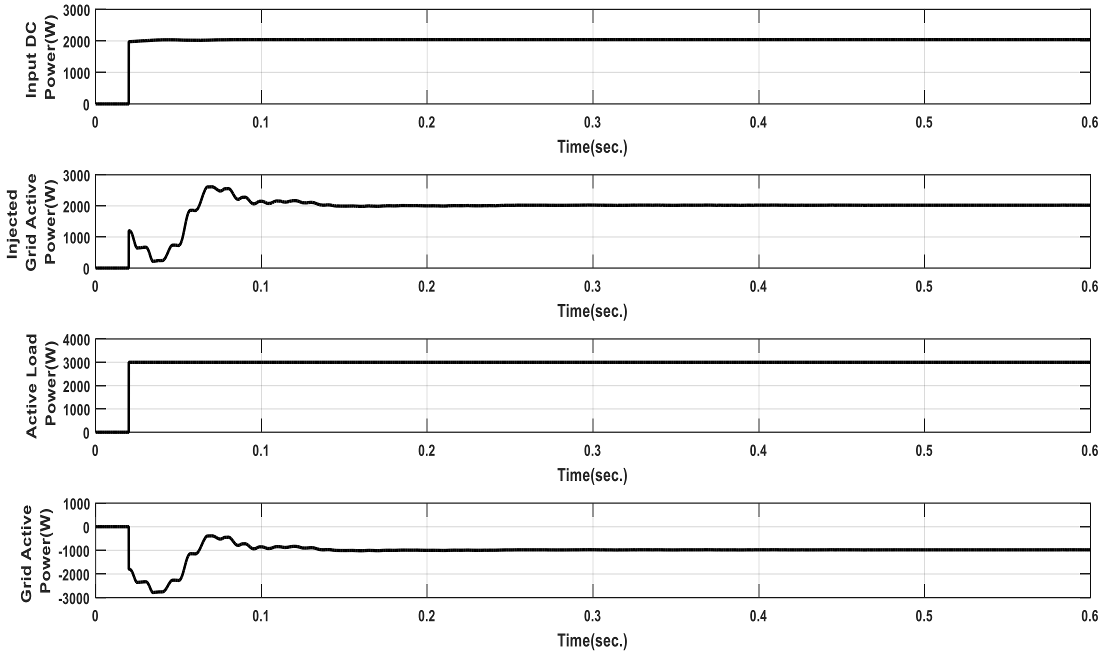


Figure 5.11: Power flow in Transformer-less inverter PV system

.5.2.1.2 At 25ºC Temperature and Varying Irradiance W/M^2

5.2.1.2.1 Irradiance, Voltage and Power at Dc Solar Panel Side

If there is any change in the atmospheric conditions; irradiance or temperature, maximum power should be extracted from the solar panel. To extract the maximum power from the solar panel, dc link voltage of inverter should be at maximum power point voltage. The input side parameters of solar panel is shown in figure 5.12. In that figure it can be seen that at time .6 sec. the solar irradiance is changing from 1000W/m2 to 8000 W/m2.

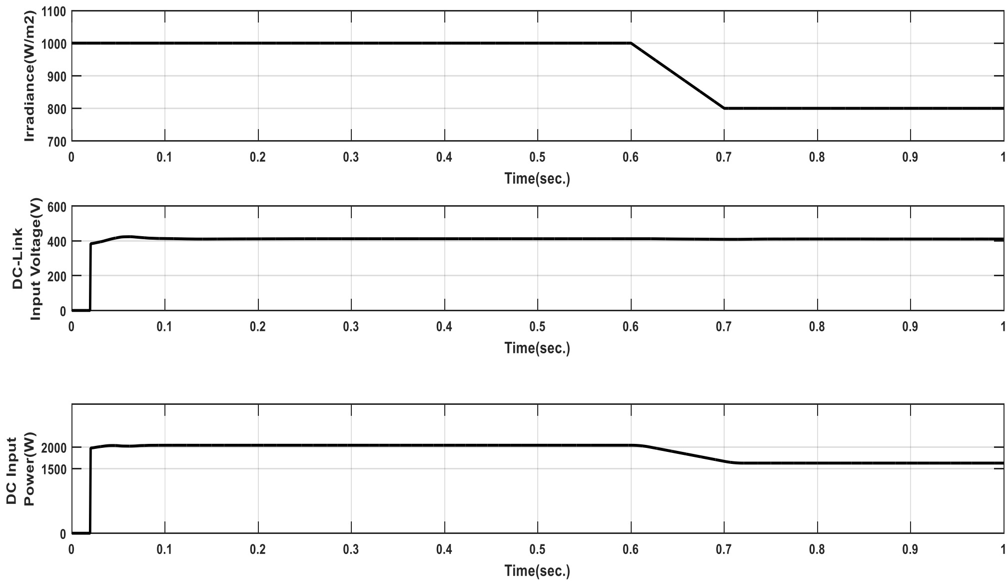


Figure 5.12: DC variation of PV system

5.2.1.2.2 Grid Voltage and Injected Grid Current

Current entering to the grid should be sinusoidal and the THD of the current should be less than 5%. The entering power of the grid should having high efficiency. When the irradiance is varied the voltage is same and the current RMS is decrease. It can be seen in the figure 5.13 that at time .6 irradiance is changed from 1000W/m2 to 800W/m2.

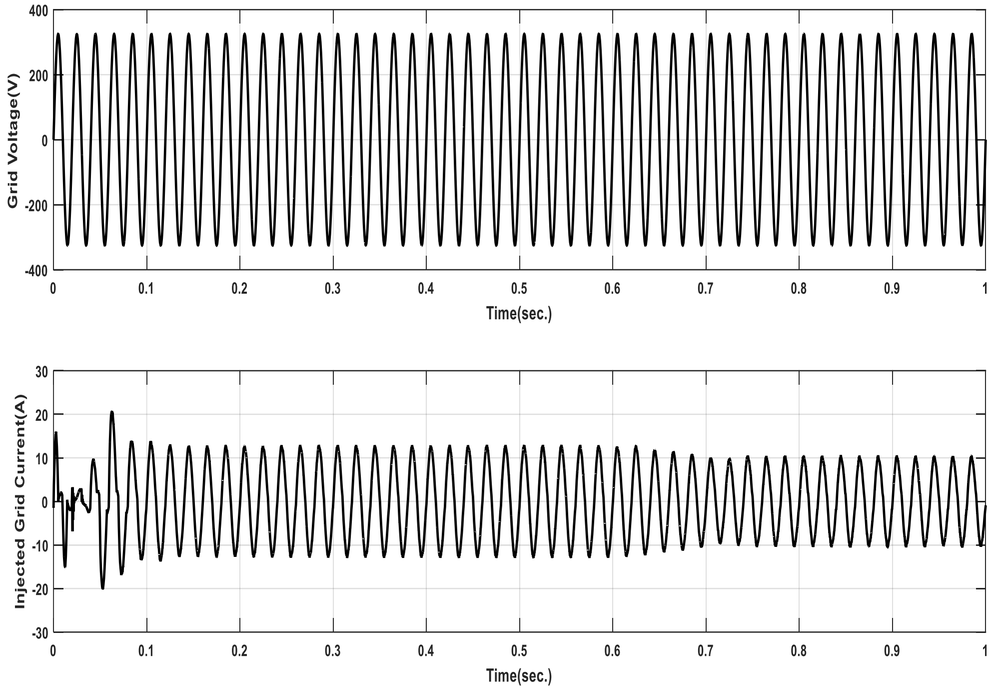


Figure 5.13 Grid Voltage and Injected Grid Current

RMS value of current entering to the grid for 1000W/m2 Irradiance=8.79 A

RMS value of voltage entering to the grid=230V

Total Active Power entering to the grid (Injected Power) at 1000W/m2 = 8.79*230

=2021.7 W

Maximum Power of Solar Panel at 25ºC and 1000 W/m^2 =2041 W

RMS value of current entering to the grid at 800W/m2=7.01 A

RMS value of voltage entering to the grid=230V

Total Active Power entering to the grid (Injected Power) = 7.01*230

=1613 W

Maximum Power of Solar Panel at 25ºC and 800 W/m^2 =1640 W

So the maximum power is extracted from the solar panel at different atmospheric conditions.

5.2.1.2.3 FFT Analysis of Injected Grid Current

FFT analysis of the injected current at the time of irradiance 1000 W/m^2 is shown in figure 5.14. THD of the current is 3.54%.

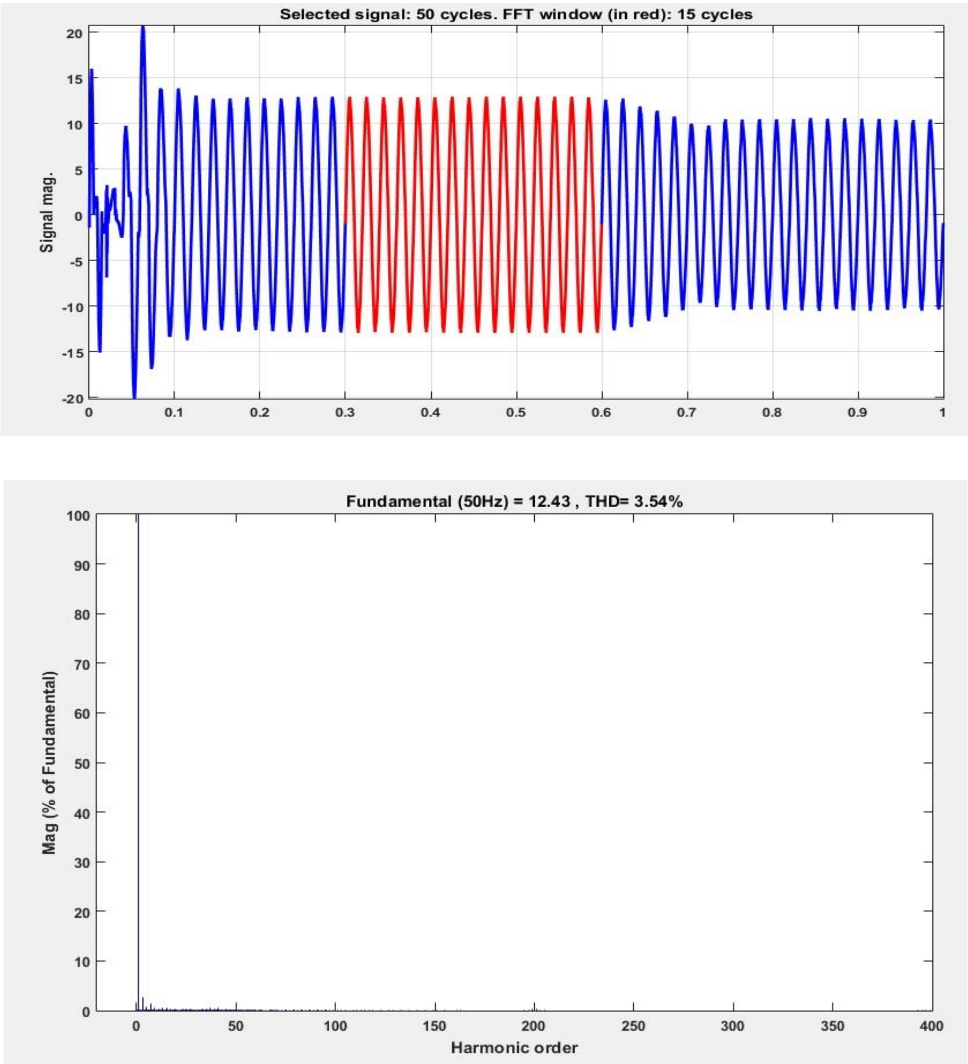
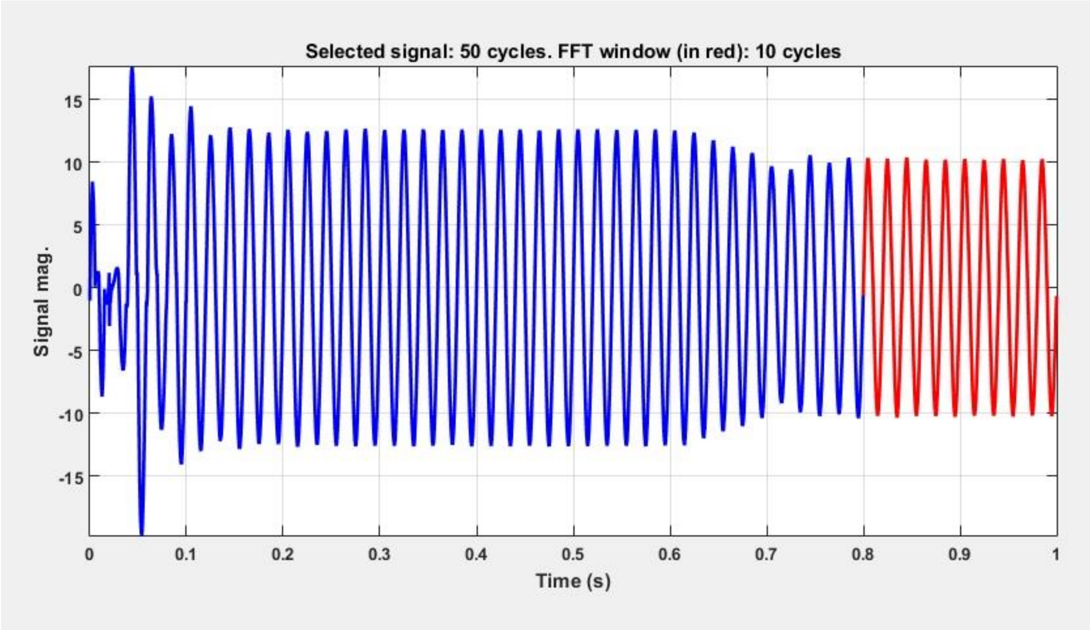


Figure 5.14: FFT analysis of current at 1000 W/m^2 irradiance

FFT analysis of the entering current to the grid at the time of irradiance 800 W/m^2 is shown in figure 5.15. THD of the current is 3.65%.



(a)

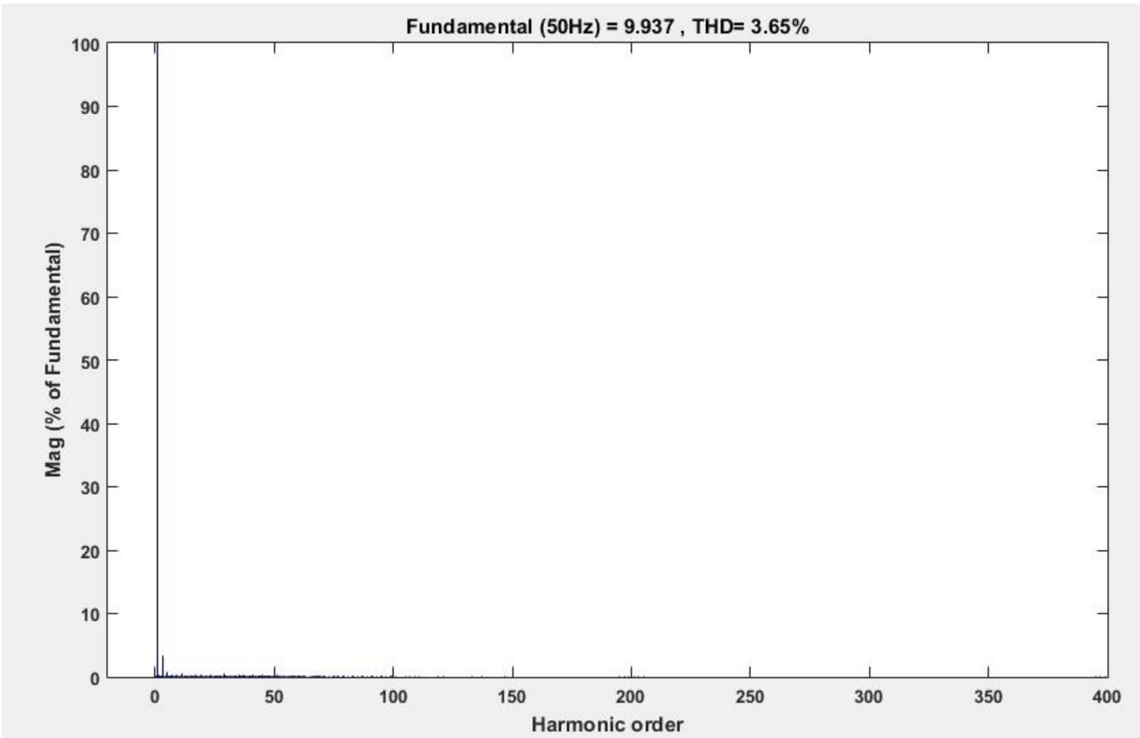


Figure 5.15 (b): FFT analysis of current at 800 W/m^2 irradiance

5.2.1.2.4 Leakage Current in Heric Inverter Structure

This leakage current flowing in PV structure should be less than 30mA according to German standard VDE 0126-1-1. The value of parasitic capacitance is taken as for simulation result is 5pF as shown in figure 5.16. For 1000 irradiance the leakage current flowing in the system is 1.67mA.

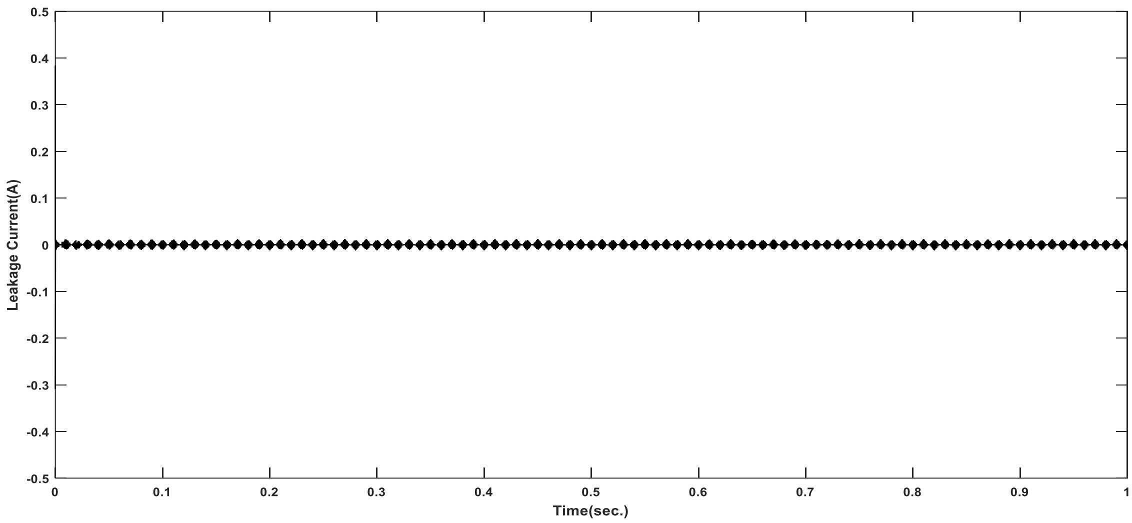


Figure 5.16: Leakage Current in PV structure

5.2.1.2.5 Active Power Balance between Solar Panel, Grid and Load

There must be power balance between grid, load and input dc power. As the irradiance changes, the dc power is also changes so the power entering to grid side is also changes. But if load is taken as more than the DC load then the remaining load power is supplied by the grid. This power balance can be seen in the figure 5.17. In that load power is taken 3000 W. so remaining load power is supplied by the grid.

If the active load power is less than the supplied Solar PV power, the extra power which is not consumed by the load is fed to the grid so that the extra power is not wasted and it can be utilized. It can be seen in the figure 5.18. Load power is taken 1000 W and extra power is supplied to the grid.

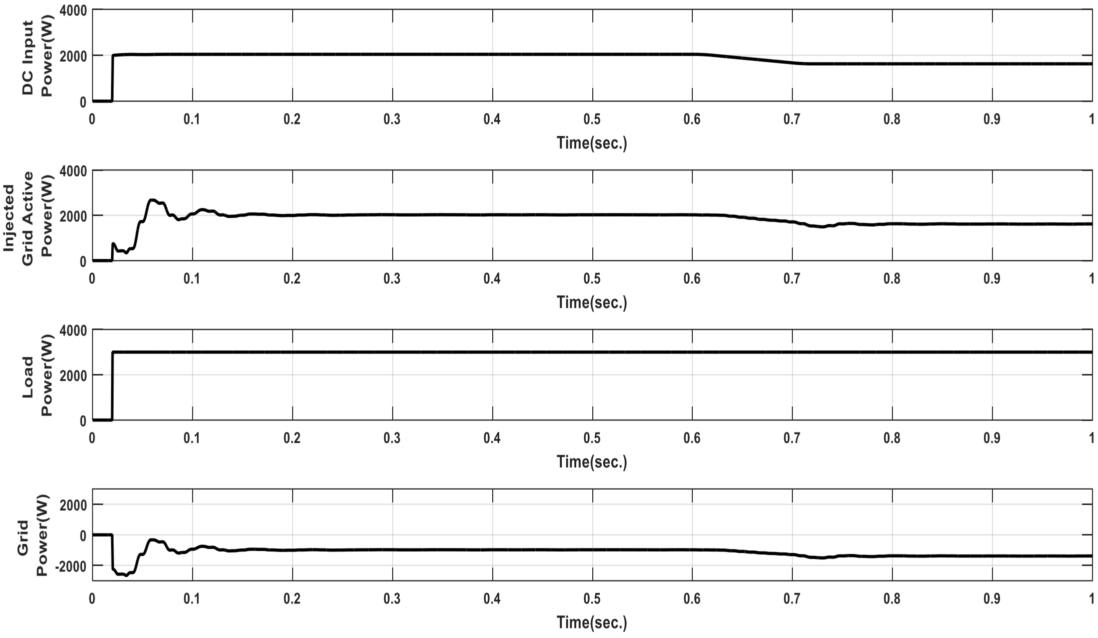


Figure 5.17: Power flow in Transformer-less inverter PV system at 3000W Load

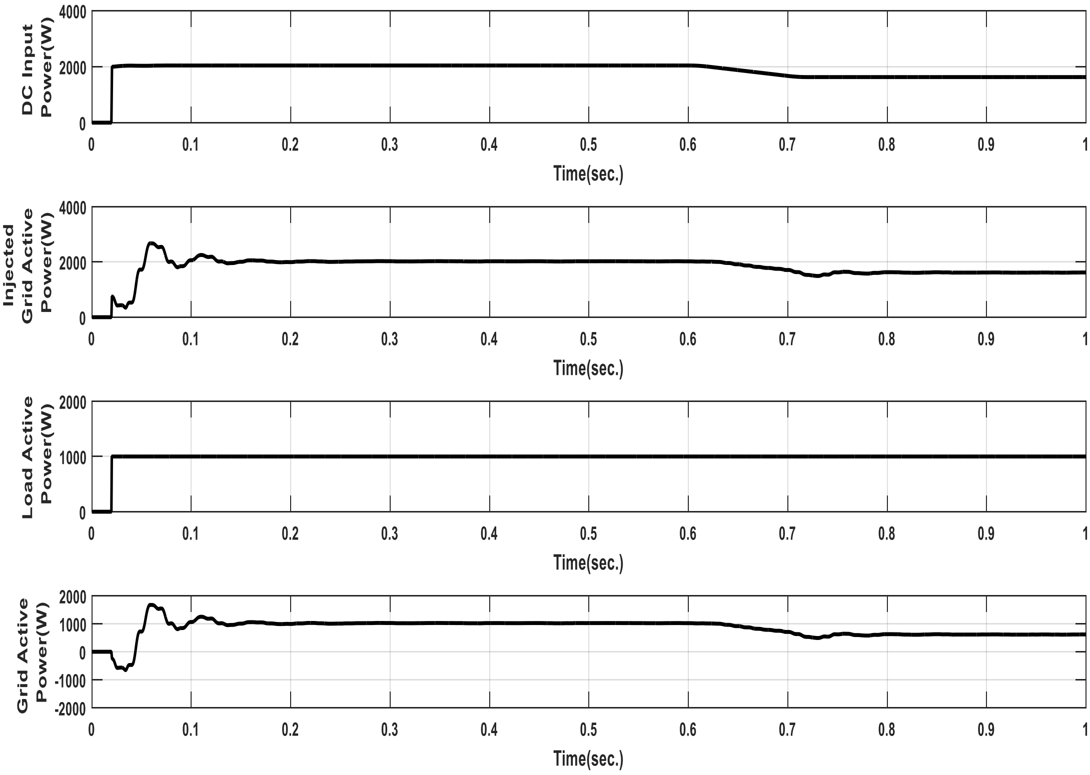


Figure 5.18: Power flow in Transformer-less inverter PV system at 1000W Load

5.2.2 Simulation results for Active Power Control and Reactive Power Control at 25ºC Temperature and Varying Irradiance W/M^2

In the Grid connected system, there should be active and reactive power control in the system. In that control scheme, reactive power controller current is generated. In that control scheme, the reactive power requirement of load is supplied from the solar panel so that no reactive power is taken from the grid.

5.2.2.1 Irradiance, Voltage and Power at DC Solar Panel Side

If there is any change in the atmospheric conditions; irradiance or temperature, maximum power should be extracted from the solar panel. To extract the maximum power from the solar panel, dc link voltage of inverter should be at maximum power point voltage. The input side parameters of solar panel is shown in figure 5.19. In that figure 5.19 it can be seen that at time .6 sec. the solar irradiance is changing from 1000W/m2 to 8000 W/m2.

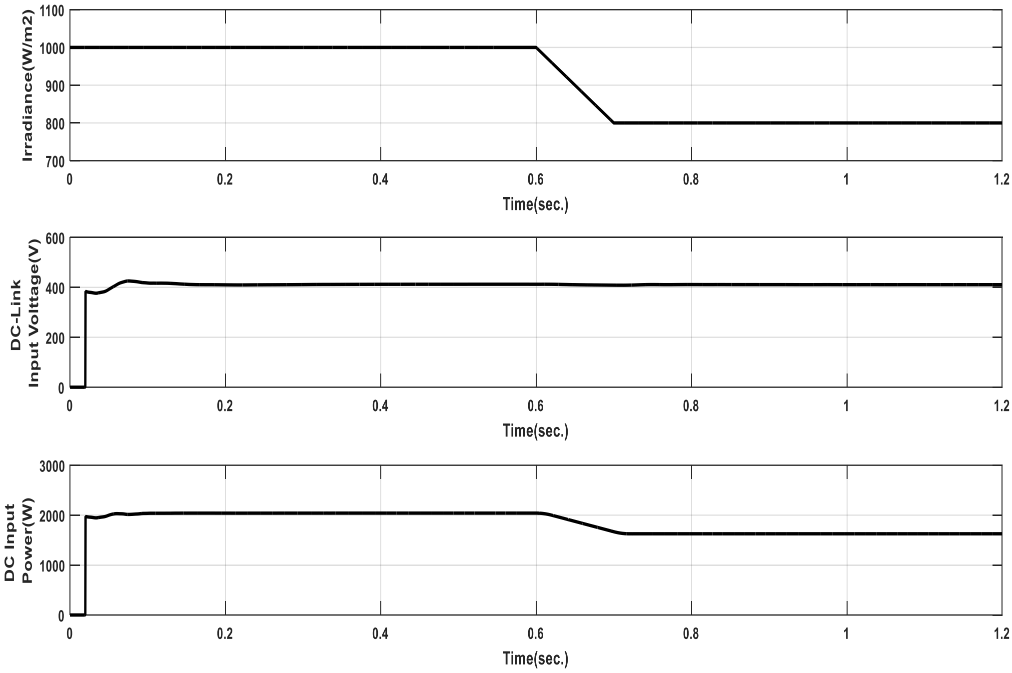


Figure 5.19: DC variation of PV system

5.2.2.2 Grid Voltage and Injected Grid Current

Current entering to the grid or injected grid current should be sinusoidal and the THD of the current should be less than 5%. The entering power of the grid should having high efficiency. When the irradiance is varied the voltage is same and the current RMS is decrease as at the time of .6 sec the solar irradiance is changing from 1000 W/m2 to 800 W/m2 the current RMS value is also changed as shown in figure 5.20.

RMS value of current entering to the grid for 1000W/m2 Irradiance=8.99 A

RMS value of voltage entering to the grid=230V

Power Factor at inverter output current and grid voltage=.975

Total Active Power entering to the grid (Injected Power) at 1000W/m2 = 8.99*230*.975

=2016 W

Maximum Power of Solar Panel at 25ºC and 1000 W/m^2 =2041 W

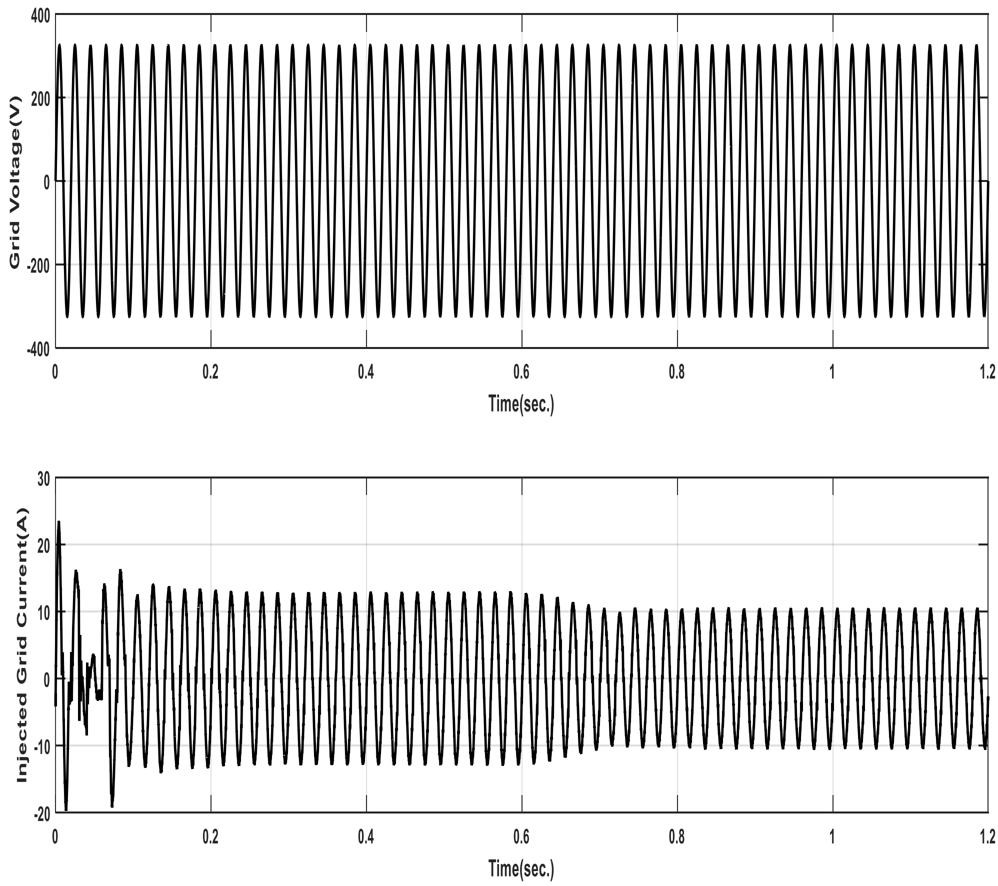


Figure 5.20 Grid Voltage and Injected Grid Current

RMS value of current entering to the grid at 800W/m2=7.261 A

RMS value of voltage entering to the grid=230V

Power Factor of Inverter output current and grid voltage=.9629

Total Active Power entering to the grid (Injected Power) = 7.261*230*.9629

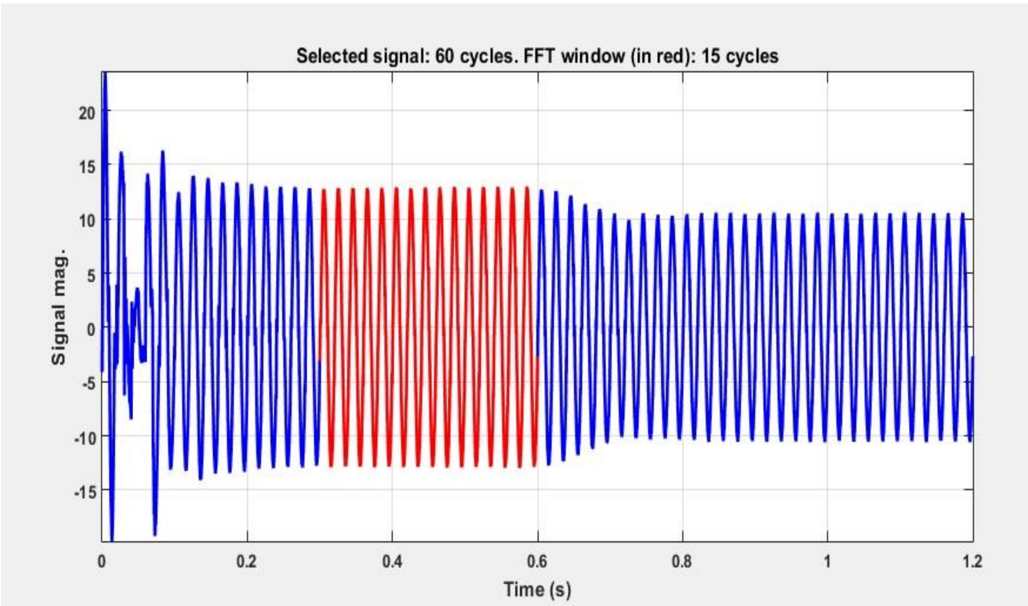
=1608.7 W

Maximum Power of Solar Panel at 25ºC and 800 W/m^2 =1640 W

So the maximum from the solar panel at different irradiance.

5.2.2.3 FFT Analysis of Injected Grid Current

FFT analysis of the injected current at the time of irradiance 1000 W/m^2 is shown in figure 5.21. THD of the current is 3.97%.



(a)

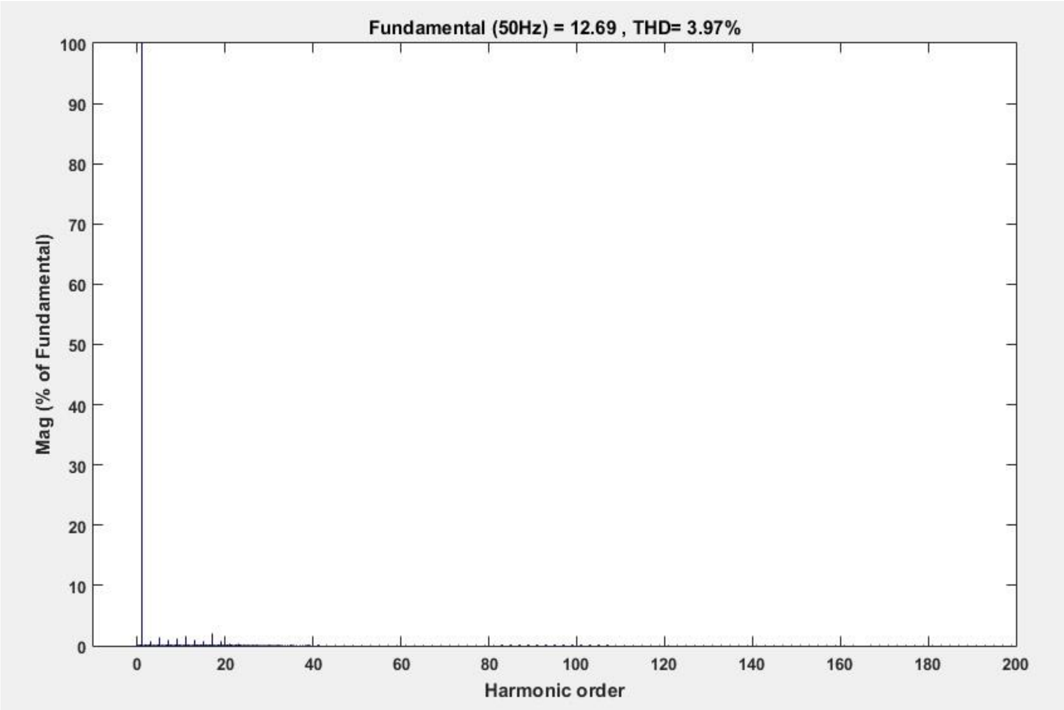
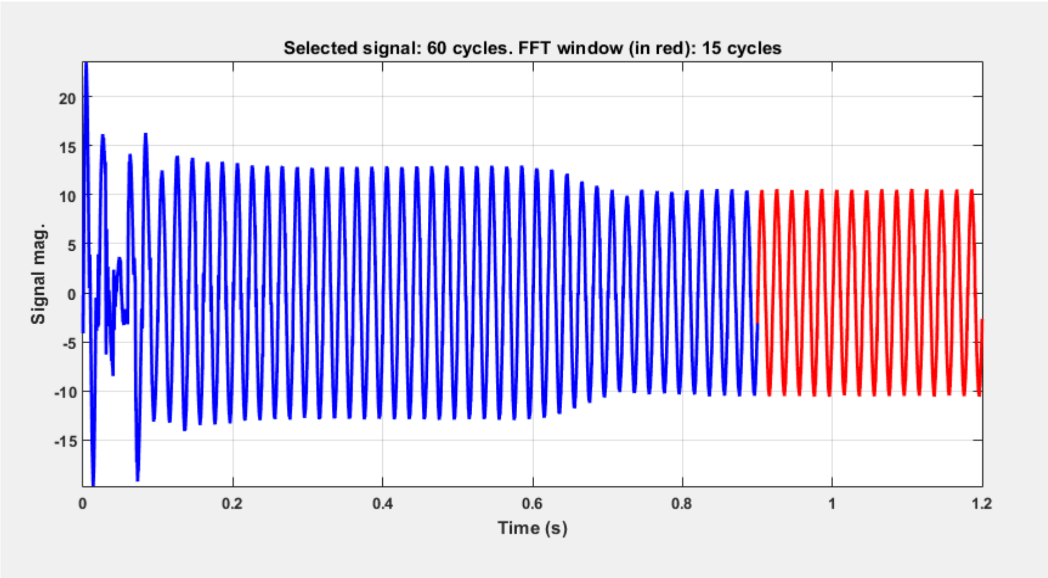


Figure 5.21 (b): FFT analysis of current at 1000 W/m^2 irradiance

FFT analysis of the injected current at the time of irradiance 800 W/m^2 is shown in figure 5.22. THD of the current is 4.10%.



(a)

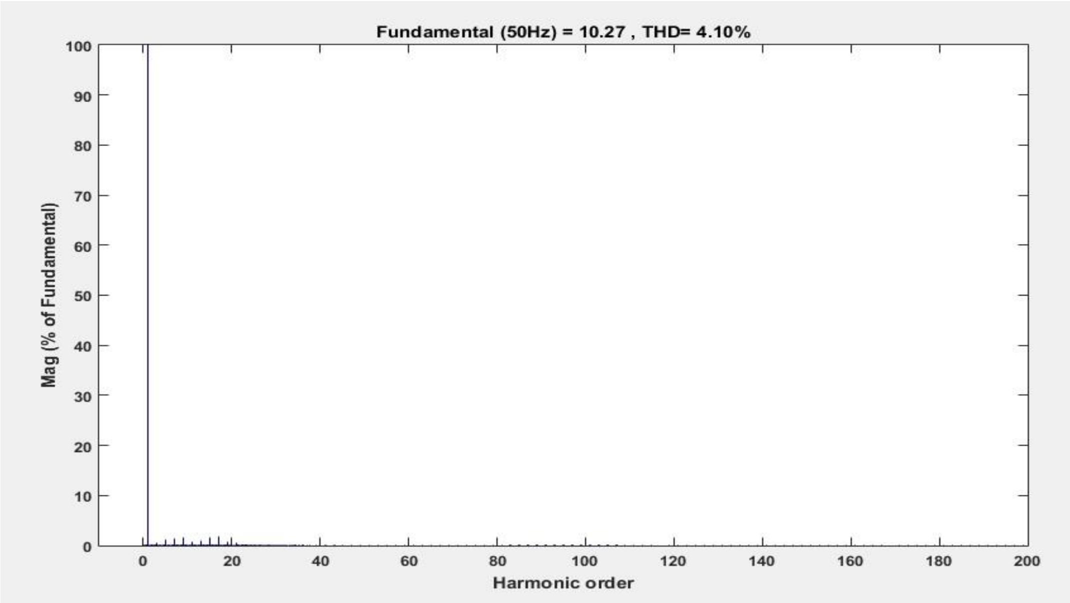


Figure 5.22 (b): FFT analysis of current at 800 W/m^2 irradiance

5.2.2.5 Active Power Balance between Solar Panel, Grid and Load

There should be active power and reactive power balance between the grid, solar panel and load. In the system, the active load power is taken 600 W so that load active power is supplied by the solar side and the extra power is supplied to the grid. In the system at .6 sec irradiance is changing so the DC input power and the injected grid power is also changed. So if the injected power is changing, the load power is supplied from the solar side and the remaining power is supplied to grid as shown in figure 5.23.

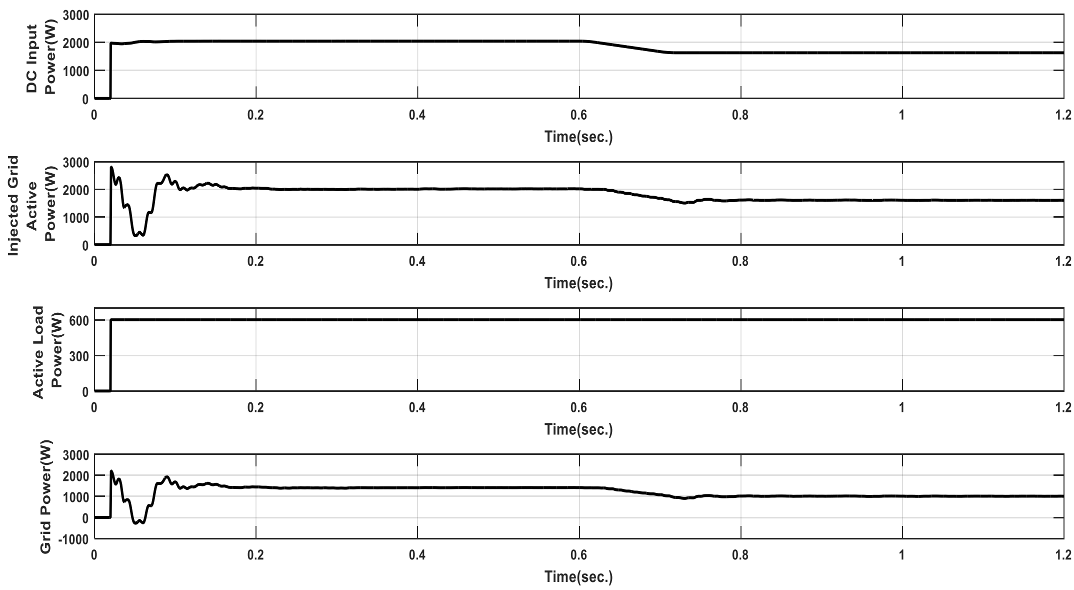


Figure 5.23: Active Power flow in Transformer-less inverter PV system

5.2.2.5 Reactive Power Balance between Solar Panel, Grid and Load

Reactive Power is very important part in the control scheme, in that scheme the required reactive power by the load is supplied by the solar panel and no reactive power from the grid side is taken, only active power is given to the grid. In that system load reactive power is 450 VAR, which is supplied by the solar side and no reactive power is taken from the grid side. In the figure 5.24 it can be seen that if the irradiance is also changing at .6 sec. the reactive power of load 450VAR is supplied by the solar side.

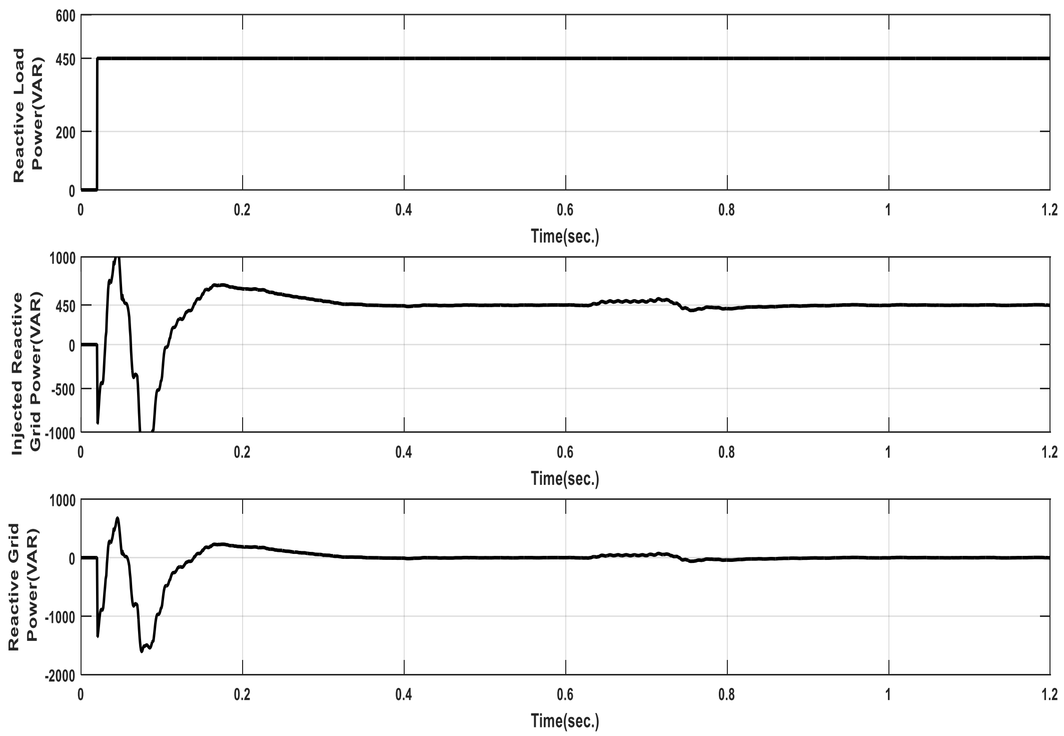


Figure 5.24: Reactive Power flow in Transformer-less inverter PV system at 450VAR

To understand reactive power properly one more reactive power load requirement is taken, In that system load reactive power is 375 VAR, which is supplied by the solar side and no reactive power is taken from the grid side. In the figure 5.25 it can be seen that if the irradiance is also changing at .6 sec. the reactive power of load 375VAR is supplied by the solar side.

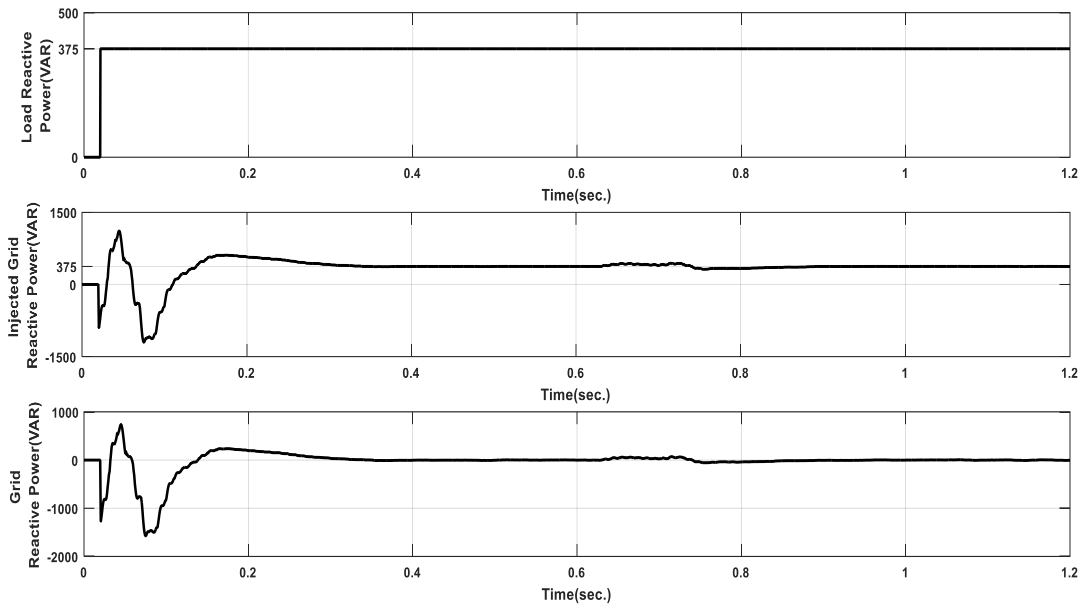


Figure 5.25: Reactive Power flow in Transformer-less inverter PV system at 375 VAR

CHAPTER-6

SYSTEM HARDWARE DEVELOPMENT

6.1 INTRODUCTION

This chapter involves hardware layout of Heric inverter and various circuits, current sensor, voltage sensor etc. FPGA has been used to generate the firing pulses for switches of inverter and sense the real time current and voltage from Hall Effect current and voltage sensor. For inverter action MOSFET switches is used. The block diagram of complete experimental setup is shown below.

6.2 FPGA

FPGA stands for Field Programming Gate Array. Various companies produces FPGA. For this project Xilinx's Spartan-3E kit is used. Programming language used in FPGA is Verilog and VHDL. Here VHDL is used. It stands for Very large scale integrated circuits Hardware Description Language. To write code ISE (integrated software development) design suite 14.7 software is used. Unlike another controller FPGA uses HDL which describe the hardware on the board. Some key component and feature of Xilinx XC3S500E Spartan-3E

- 50 MHz on board clock oscillator.
- Two-input, SPI-based Analog to Digital Converter (ADC) with programmable-gain pre-amplifier
- 2-line,16-character LCD screen
- Xilinx 4 Mbit Platform Flash configuration PROM
- 64 MByte (512 Mbit) of DDR SDRAM, x16 data interface, 100+ MHz

.6.3 POWER CIRCUIT DEVELOPMENT

Power circuit development of total hardware system consist inverter switches circuits, regulated power supplies and Current and Voltage sensor circuit. Each of the six switches in heric two level inverter have their gate driver circuit and snubber circuit. The regulated power supplies i.e. +15V, -15V, +12V, -12V and +5v are required for providing biasing to various circuits like pulse amplification and isolation circuits using regulator IC's 7815, 7915, 7812, 7912 and 7805 for +15V, -15V, +12V, -12V and +5v respectively. And the sensors circuits (voltage and current) are required to sense real time voltage and currents which is used as feedback in considered control schemes.

6.3.1 HERIC INVERTER CIRCUIT

Fig.6.1 shows the power circuit of a Heric Inverter.

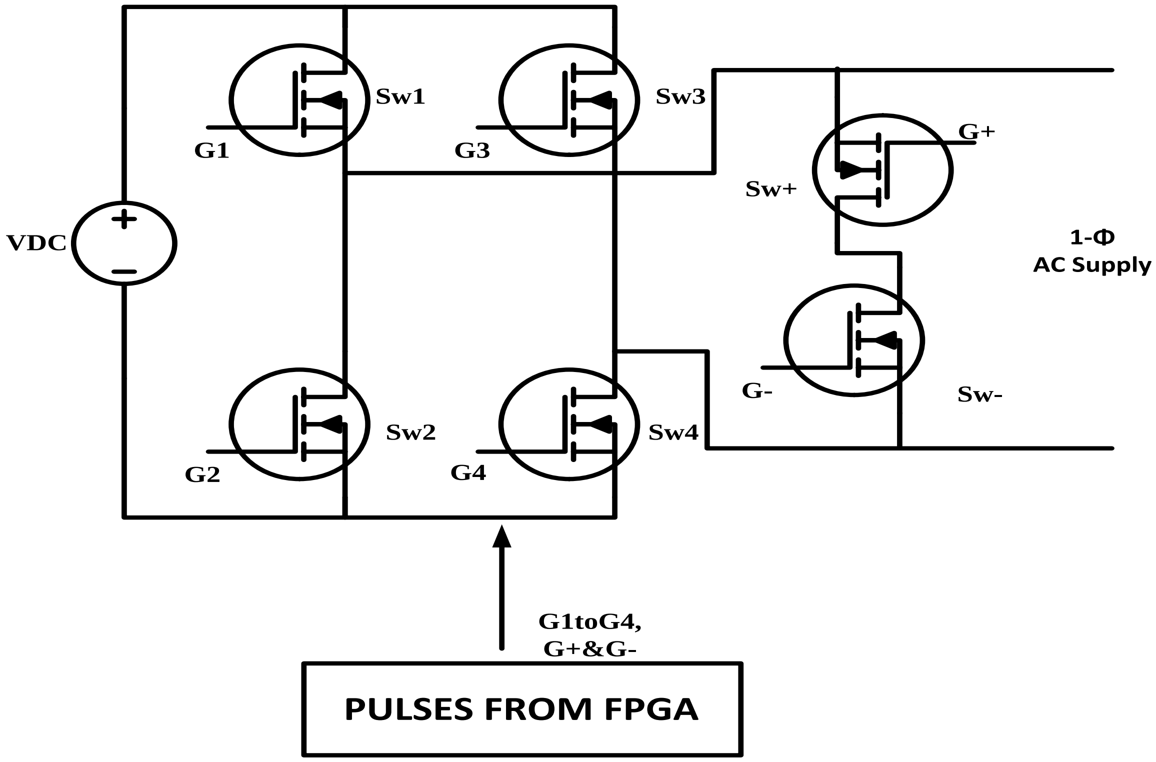


Fig.6.1 Power Circuit of Heric Inverter

Specifications:-

- MOSFET – IRFP 460 (500v, 20A).
- Drain to source voltage (V_{dss}) = 500v
- Source to drain resistance during on period ($R_{DS(on)}$) = 0.27Ω
- Rated drain current (I_D) = 20A

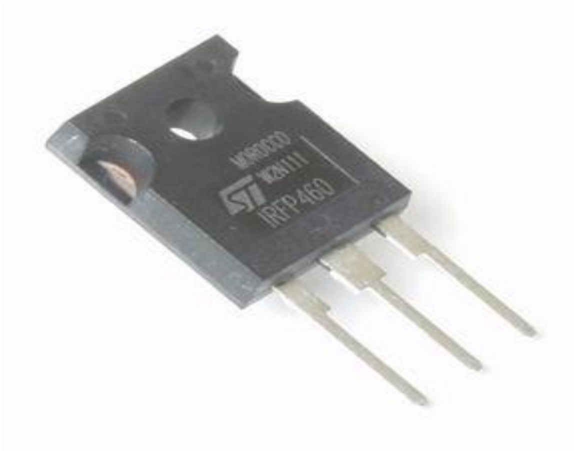


Figure 6.2 MOSFET used in the Heric Inverter

Each MOSFET switch consists of an inbuilt anti-parallel freewheeling diode. No forced commutation circuits are required for the MOSFET's because these are self-commutated devices (They turn on when the gate signal is high and turn off when the gate signal is low). The load inductance restricts large di/dt through MOSFETS; hence turn off snubber is required for protection. RCD (Resistor, Capacitor and Diode) turn off circuit is connected to protect the switch against high dv/dt and is protected against power voltage by connecting MOV (Metal Oxide Varistor).

6.3.1.1 Snubber Circuit (Protection of MOSFETS)

Since power handled by the prototype circuit is less (up to 10A), RC snubber circuit has been used for protection of main switching device . Switching high current in short time gives rise to voltage transients that could exceed the rating of the MOSFET. Snubbers are therefore needed to protect the switch from transients. Snubber circuit for MOSFET is shown in Fig.6.3.The diode prevents the discharging of the capacitor via the switching device, which could damage the device due to large discharge current. An additional protective metal oxide varistor (MOV) is used across each device to protect against over voltage across the device.

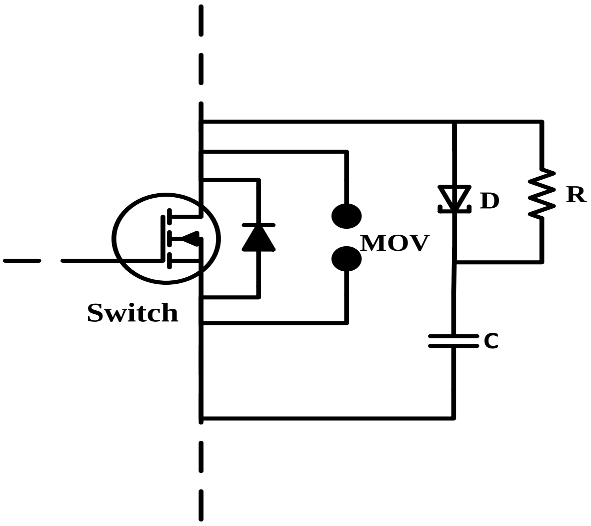


Figure 6.3 Snubber circuit for MOSFET protection

Components

- Capacitance : 0.1µF,1000v
- MOV (Metal oxide Varistor): 320v
- Diode- IN5408
- Capacitor, C = 0.1µF
- Resistor, R= 0.1kΩ,5w

6.3.1.2 Driver Circuit (Pulse Amplification and Isolator)

The pulses obtained for a frequency more than 5 kHz is found to have a variation from the ideal square shape. So, for this particular driver circuit using MCT2E optocoupler, the switching frequency of inverter is limited to less than 5 kHz. So, in order to obtain better switching pulses for higher frequencies, a new driver circuit based on HCPL 3101 IC was developed and tested. The circuit diagram of the new driver circuit is as shown in the Fig 6.5.

Figure 6.4 Firing Pulses of Driving Circuit Using MCT2E

The pulse amplification circuit for MOSFET is shown in figure 6.4.The optocoupler HCPL301 provides necessary isolation between the low voltage isolation circuit and high voltage power circuit. The”pulse amplification circuit is provided by the output amplifier transistor 2N2222. When the input gating is +5v level, the transistor saturates, the LED conducts and the light emitted by it falls on the base of the phototransistor, thus forming its forming its base drive. The output transistor thus receives no base drive and remains in the cut-off state and a +12v pulse (amplified) appears at its collector terminal.

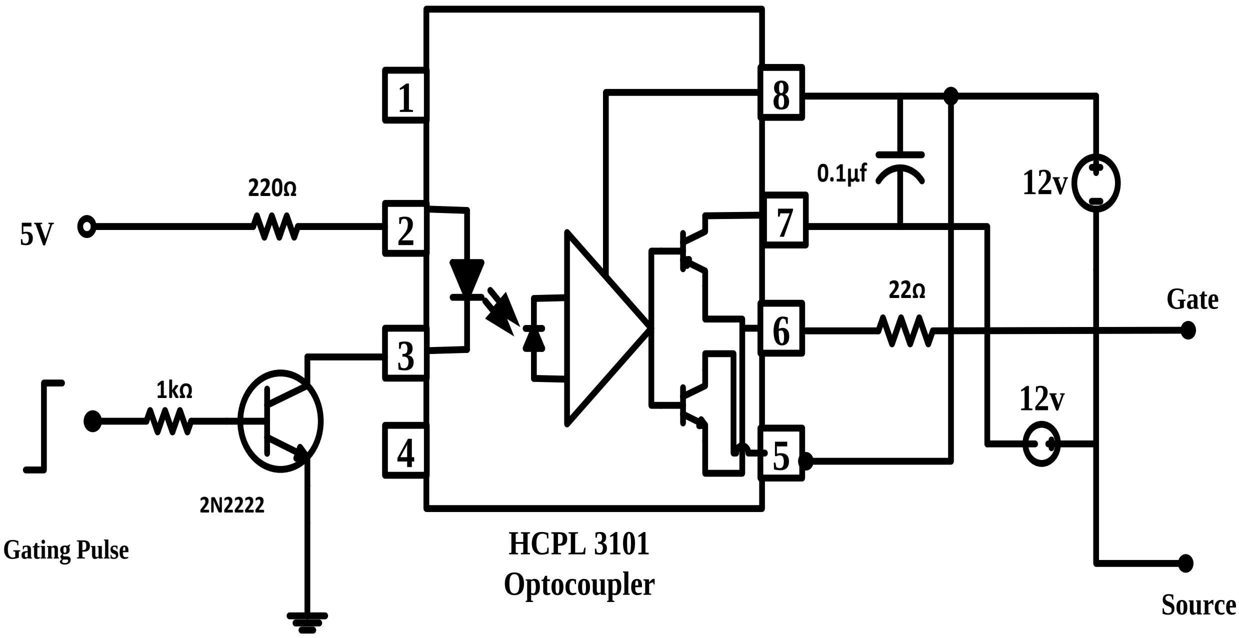


Figure 6.5 Pulse amplifier and Isolator circuit

The Full layout of Driver circuit and protection circuit required for switches is shown in Fig.6.5.

6.3.2 Power Supplies

For providing biasing, DC power supplies are needed in the isolation amplifier, driver circuit and op-amp. For making DC power supplies voltage regulator (7812, 7912, 7805, and 7905) are used.

The circuit diagram of the DC power supplies is as shown in following figures below (Fig 6.6 a, b and c).

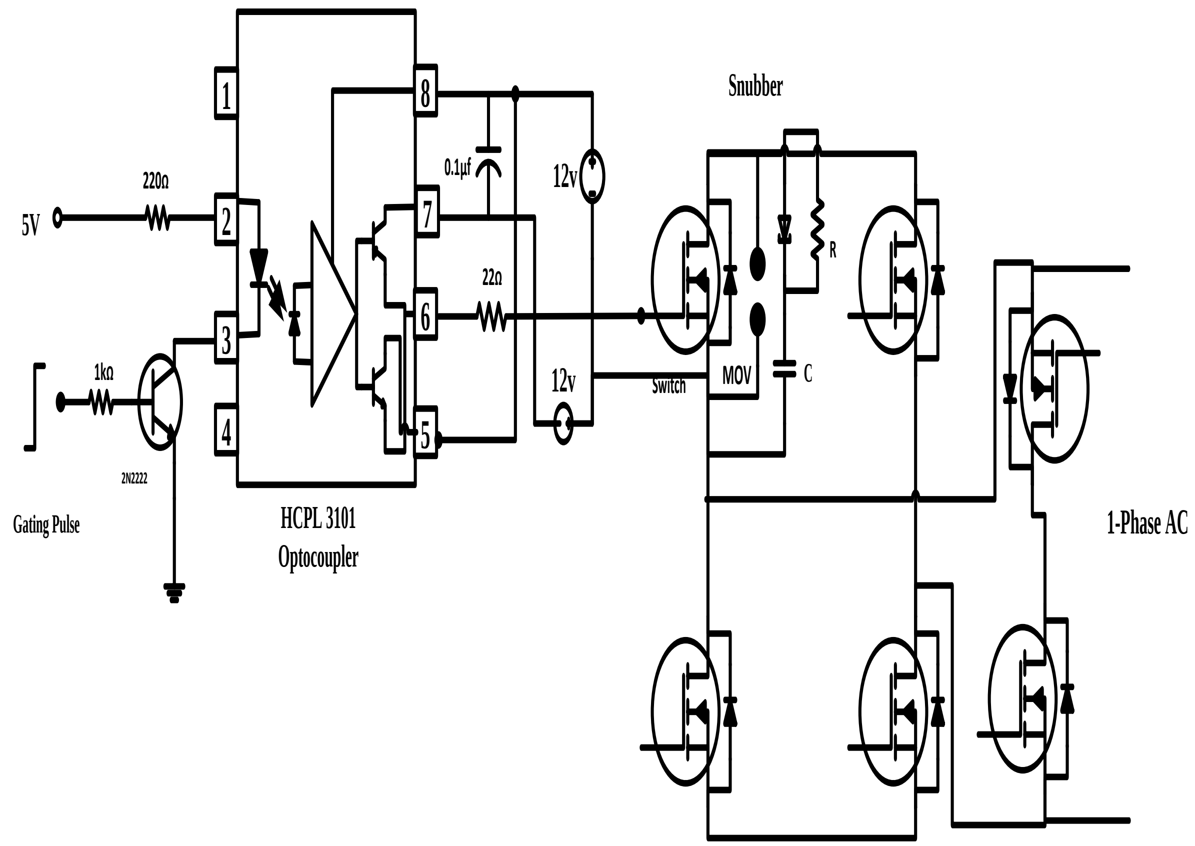
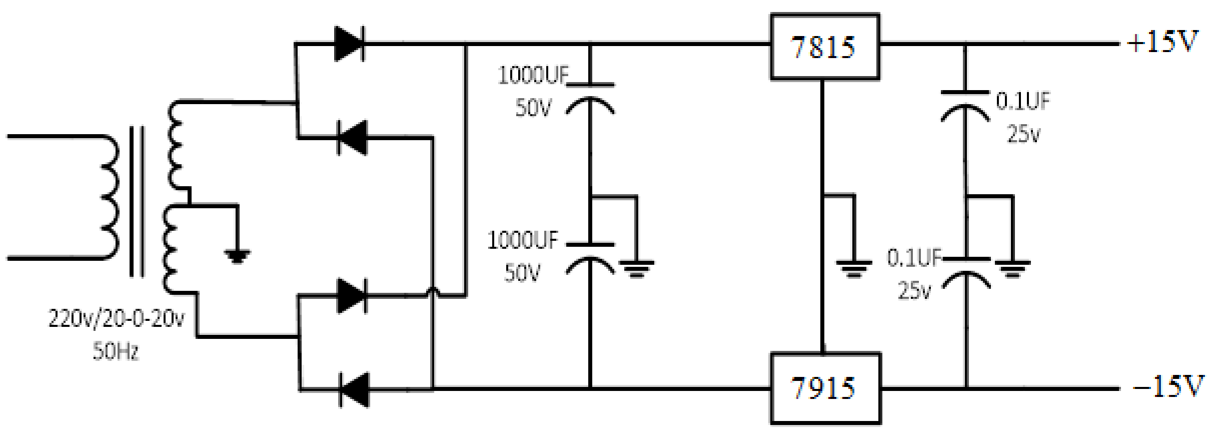
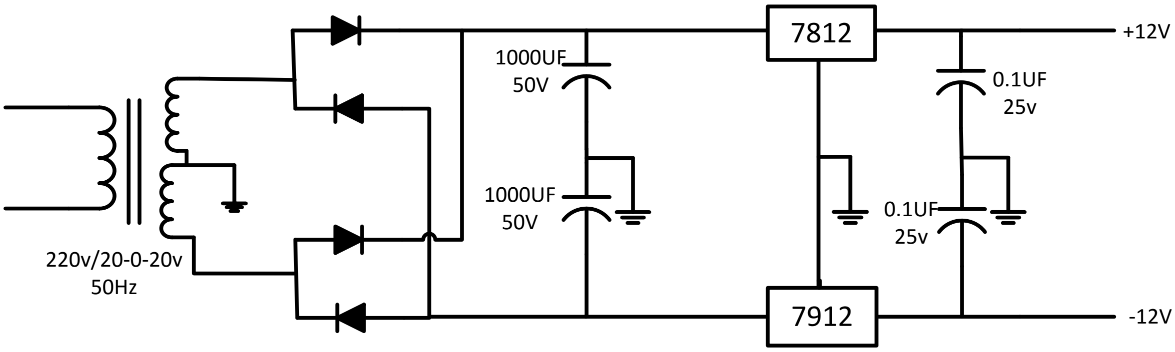


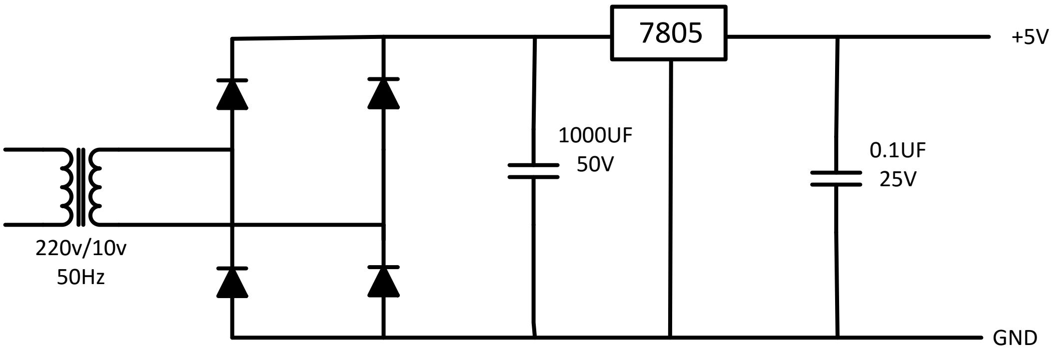
Figure.6.6 Full layout of Driver circuit and protection (snubber) circuit required for switches



(a)



(b)



(c)

Figure 6.7 Connection diagram for power supplies (a) +15V, 0, -15V (b) -12V, 0, +12V and (c) +5V.

6.3.3 CURRENT AND VOLTAGE SENSOR

6.3.3.1 Current Sensor

The current sensor circuit is based on Hall Effect current sensors using TELCON HTP25. HTP25 is a closed loop Hall Effect current transformer which can measure currents upto 25A. These current sensors provide galvanic isolation between high voltage power circuit and the low voltage control circuit and require a nominal supply voltage of the ±12V to ±15V. It has a transformation ratio of 1000:1 and the output resistance of the current sensor is scaled properly. The voltage input to the buffer circuit is calculated by the equation. Thus the voltage is scaled properly with the scalar circuit.

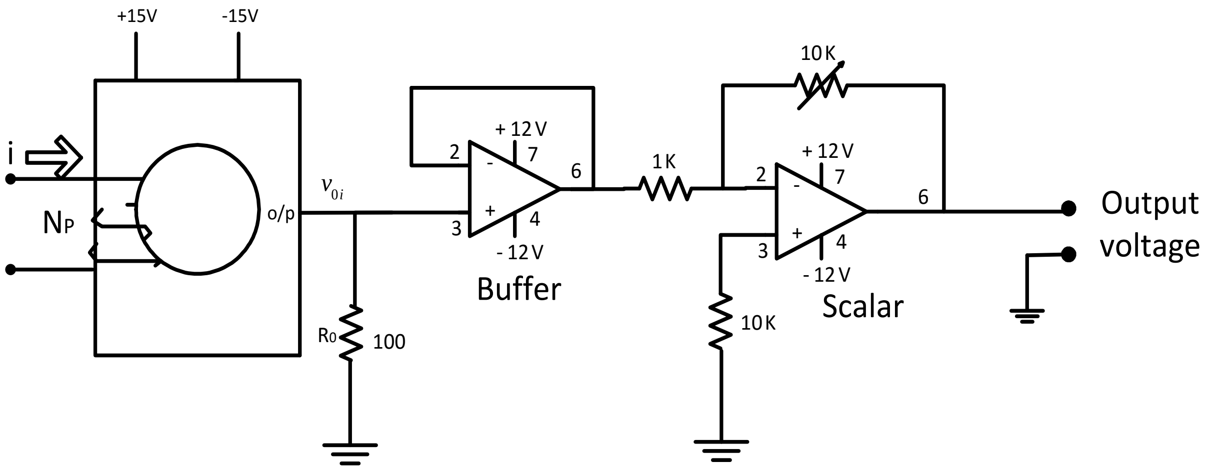


Figure 6.8 Current sensor circuit

6.3.3.2 Voltage Sensor

The AD202JN is an isolation amplifier in the present experimental setup. It has good accuracy and wide bandwidth. It consumes less power and is small in size. The power circuit voltage which is in the range of ±500 V is converted into ±5V range. Voltage to be sensed is applied between pins 1 and 2 through a voltage divider circuit. Output is sensed between pins 19 and 18. This is fed to a buffer circuit for impedance matching. Output of buffer is scaled by using a scalar buffer circuit which is basically an inverting Op-amp and is varied by using a pot.

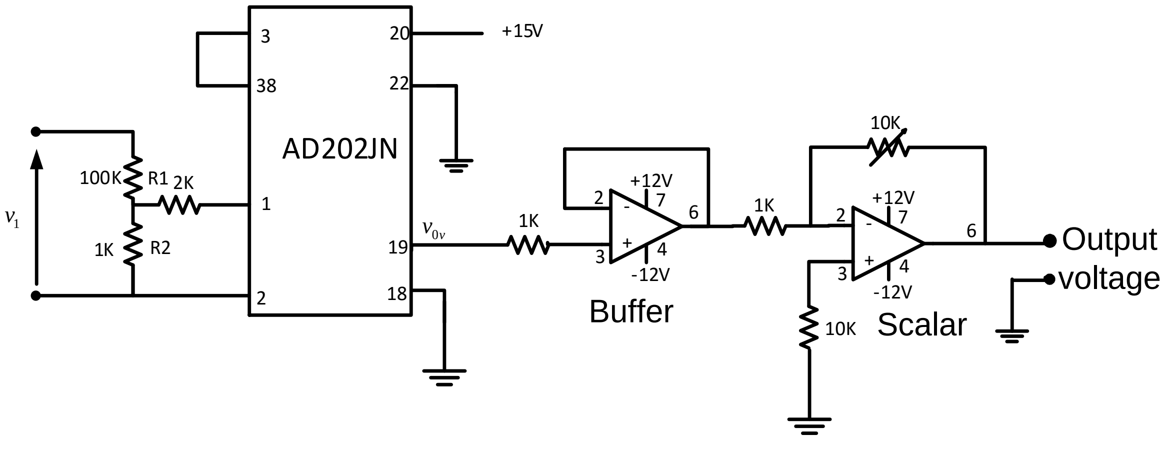


Figure 6.9 Voltage sensing circuit

6.4 OPEN LOOP HERIC INVERTER

6.4.1 HARDWARE SETUP OF HERIC INVERTER

In the hardware of Heric inverter, there are six switches and in that the switching pulses pf the MOSFET is given by FPGA.

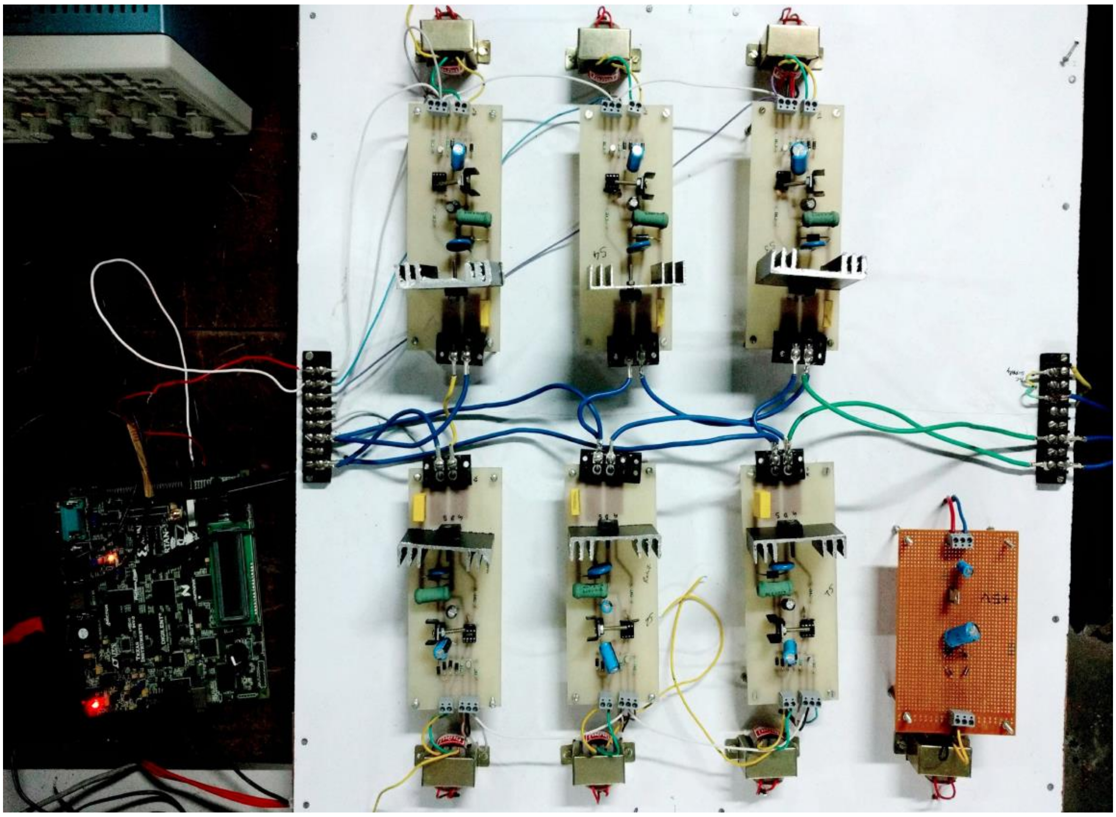


Figure 6.10 Hardware of Heric Inverter

6.4.2 OPEN LOOP HERIC INVERTER SWITCHING PULSES

Heric inverter is having 6 switches and the switching states as discussed in 3.4.1. In the switching of Heric inverter 2 switches are switched at the grid frequency and other are switched at the high frequency. The result of the switching states of open loop Heric inverter is shown in figure. In that result, it can be seen that 1 and 2 pulses are for S+ and – which is used to switch at the grid frequency and 3rd one is used to switch S1 & S4 and last 4th is used to switch S2 & S3. All the four switches are switched at the high switching frequency.

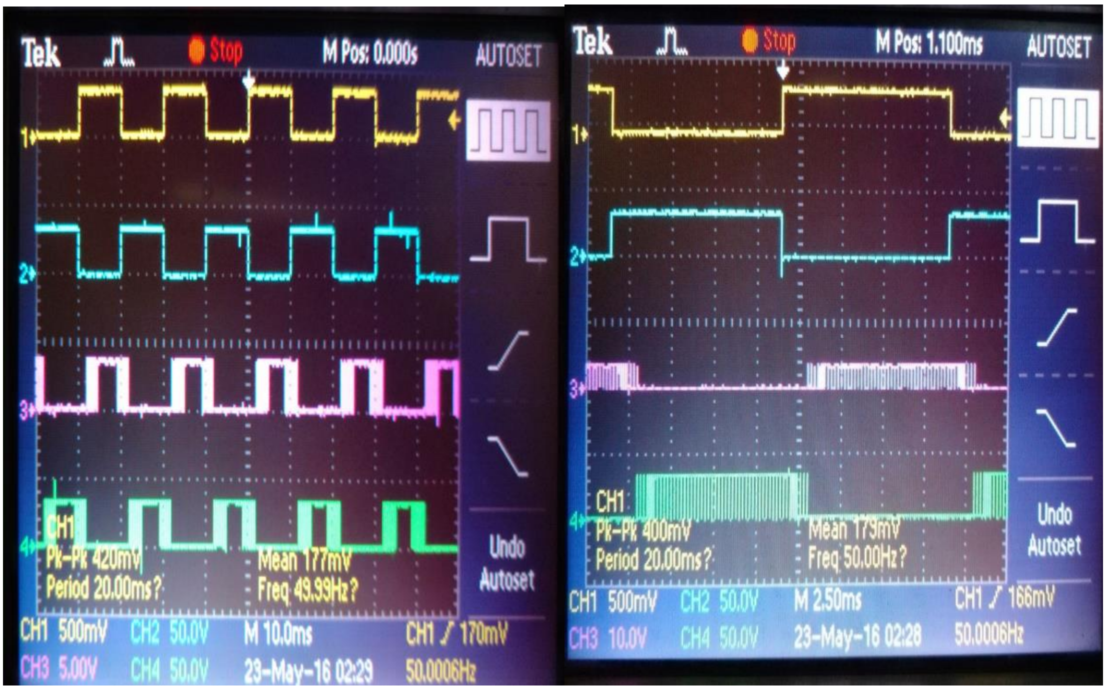


Figure 6.11 Switching States Of Heric Inverter

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION

To meet the imperative demand of a clean and reliable electricity generation, more efforts have been made on the integration of solar energies. In respect to single stage single phase PV inverter, the control strategy has been discussed in order to control active power, reactive power in the grid connected system. To improve the efficiency in the grid connected system, PV inverter without transformer is used, in that structure to provide isolation in the grid connected system, the switching of the grid connected system should be proper. Control scheme in grid connected Heric inverter has been implemented and the all the condition in the grid connected system is met as per standard. As the PV inverter structure is transformer-less, the leakage current is also reduced by using Heric inverter.

Transformer-less Heric inverter is having high efficiency and by using this structure, the leakage current in the grid connected PV system. In that structure, the efficiency and the reliability of the system is very high and it is very easy to install. The advantage of that structure is that in that reactive power can be controlled and the maximum power from the solar side can be easily extracted. Single phase single stage grid connected Heric inverter is implemented.

7.2 FUTURE SCOPE

Transformer-less PV inverter is very much used in the grid connected system, the efficiency and reliability of the structure is very much high. It is mostly used for the rating of 1KW-5KW. There are lots transformer-less inverter structure developed in that common mode voltage in the grid connected system is constant so that the common mode leakage current flowing in the grid connected system is reduced in that structure. MPPT is used in the single stage single phase inverter, in that partial shedding condition is also included so that the practical implementation of the system can be implemented. At present condition, solar inverter is disconnected from the grid when any condition changes at the grid side. Thus a control scheme should be developed and investigated to make inverter operate between grids and solar at the time of islanding mode so that it should not be disconnected at the time of islanding.

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APPENDIX

1. Perturb & Observe Algorithm

The Matlab function code of Perturb & observe algorithm is as follows:

```
D=PandO (Param,Enabled,V,I);

% Param Input

Vint=Param(1); Initial Value of Vdcref

Vmax= Param(2); maximum value of Vdcref

Vmin= Param(3); Minimum value of Vdcref

deltaV= Param(4); Increement value used

persistent Vold Pold Vdcold;

datatype= ‘double’;

if isempty (Vold)

  Vold=0;

  Pold=0 ;

  Vdcold=Vint;

end

P=V*I;

dV=V-Vold;

dP=P-Pold;

if dP~=0 & Enabled~= 0

   if dP<0

      if dV<0

         Vdcref = Vdcold+deltaV;

     else

     Vdcref=Vdcold-deltaV;

     end

  else

     if dv<0

        Vdcref=Vdcold-deltaV;

     else
```

```
        Vdcref=Vdcold+deltaV;
        end
      end
else
Vdcref=Vdcold;
end
if Vdcref>=Vmax | Vdcref<=Vmin
  Vdcref=Vdcold;
end
Vdcold=Vdcref;
Vold=V;
Pold=P;
```

2. The parameters of LCL filter

RL1: R1=10*10^{-3} Ω & L1= 3*10^{-3}H

RL2: R2=10*10^{-3} Ω & L1=1*10^{-4}H

RC: Rf=1.2 Ω & Cf= 10*10^{-6} F

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CHAPTER-1 INTRODUCTION AND LITERATURE REVIEW 1.1 INTRODUCTION With the rise in energy costs many people have been searching to alternative sources of renewable energy.

10**One of the important energy sources** available in **the**