

Modelling, Control and Simulation of DC Micro-grid for meritime applications

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Certificate

We accept the work contained in this report as a confirmation to the required standard for the partial fulfillment of the degree of BE (EE).

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Dedication

We dedicate this report first and foremost to Almighty God who has been right there from the beginning to this point. We specially dedicate it to our parents for their support and compassion toward us during course of engineering. Furthermore, we want to dedicate it to lecturers for their continual support in a project.

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First and foremost we like to thank *ALLAH ALMIGHTY* who gave us the strength, power and health for finishing this project.

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We thanks to faculty of *BAHRIA UNIVERSITY* for the queries and suggestions raised during various phases of the project. Their opinions helped in adding new dimensions to our project.

We sincerely appreciate the contribution of all my lab-mates for all the help and support. If there were times when we got stuck, Discussion with one among them that helped me a lot.

We have been very lucky indeed to have always had the full encouragement and support of my parents in all my endeavors. My heartiest gratitude and love to them.

Abstract

Nowadays, modern Reefer ships are using renewable energy sources for e.g. (PV, Wind, Fuel Cell, etc.,) to meet their energy demand along with fossil fuel(s). The concept of an electric powered ship is not something new. Power electronic converters are required for the integration of renewable sources and loads within the micro-grid. One of the key differences between the terrestrial micro-grid and the maritime one is that it is an islanded micro-grid. World is facing energy crises badly, especially in Pakistan. Pakistan has a lot of renewable energy sources available. To increase the efficiency multi energy system is recognized, because most of the losses are based on conversion like heat energy to electrical energy conversion and electrical energy to heat energy. The conventional method of electricity generation is very expensive and also not effective this system depends on many factors. Now there is a big advancement in renewable energy sources which are very cost effective. Renewable sources provide clean energy where is no pollution and also these sources are free. Solar based energy generation system is very famous in Pakistan and is of very cost effective. Wind power generation system introduced and working fine for power generation. Multi sources integration with grid is the main factor in which we can reduce the losses and also provide extra energy to WAPDA. Inverter plays vital role in renewable energy resources, because lower the losses efficient the complete system. Grid connection give more advantage to renewable energy systems because some time renewable energy sources are not available or less power available from these sides so we shift ourself or share the resources with grid.

Key Words: Reefer Ship, Photovoltaic (PV) system, (THD Total harmonic distortion), (MPPT), Maximum power point tracking , Sinusoidal pulse width modulation (SPWM). (SVPWM) Space Vector PWM, Terrestrial Microgrid.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The main focus of this thesis is to analyze the performance of multi-source energy conversion system because energy produce from non-conventional sources are very expensive and they require periodic maintenance. Pakistan has a lot of GOD gifted energy resources like solar and wind, these resources require less periodic maintenance cost and need one time investment. The problem in renewable energy conversion system is that it requires a very highly efficient inverter which has a very low THD (total harmonic distortion). the three-phase inverter which we are going to design will have a very low THD and is of highy efficient. multi sources of renewable energy conversion system is connected in parallel to cover the load capacity. These sources provide renewable energy and inverter will convert the three-phase voltage with 50Hz frequency. These sources have variable output so we will design a voltage stabilization circuit to maintain the output voltage. this circuit can be buck boost converter which work under the required mode automatically and provide us the fix output voltage. A battery system will connect to provide the backup if the sources are not available [4]. A three-phase inverter which we will design is based on 6 IGBT and it require only 6 pulses from microcontroller. The IGBT require 12V at the gate so e will use voltage amplifier at the output of inverter.

The main focus of this research is on multi energy system in which we study about renewable resource of energy generation system. From last few decades world is facing energy crises badly and in Pakistan there is a lot of energy crises in which industry and academia and research organizations all suffer. Solar based energy solution is the low-cost source of energy generation system in this paper author

focus on renewable sources and its effective utilization [1]. The smart grid control system mechanism has been discussed in this paper for smart cities a new concept that has been implemented, the control of smart grid is very important and also it is useful for peoples because electricity cost increases day by day [2]. The free energy resources can be recovered and can be reused for products, multi-source energy system can combine to get a small grid system in which the grid is connected and also the grid can be used stand alone [3]. A multicriteria approach is used to for multi-source energy system. In this approach author propose multiple criteria for multi-source energy system [4]. Data analytics tell the pattern of previous load profile and open data and open software both are useful for researchers to analyze the load profile of smart grid and can tell the load forecast [5]. There are some drivers required for multi energy system like voltage stabilization circuit for solar based systems, buck boost converter for wind-based system and some driver circuits are required for the conversion of heat

energy into electrical energy [6]. One major factor which control of energy system or grid control system, there are many techniques available but some are very effective and some of them are not efficient [7]. Micro grid operation and its control technique is very important for complete system, the operation analysis and periodic monitoring of grid is very important and grid connected system can be used more effective way [8]. Energy storage is the main issue we cannot store energy, if we want to, we need to bear much cost to store the energy [9]. Scheduling is very important factor for multi energy system [10].

1.2 Background, Scope and Motivation

For renewable energy system there are many sources available like solar which is the most famous and cost effective source of energy conversion system, on second wind based power generation. Wind is also a very famous source of energy. The problem in that sources is that first we need to stabilize the voltage and then we need to convert it into DC if it is not already in DC. For solar case it is available in DC and for wind we must convert it into DC and combine the sources using DC bus. Our conventional loads are AC so we must convert DC to AC and for this purpose we need to design an inverter which frequency is 50Hz and 3 phase voltage. For efficient inverter design we need to reduce the losses of inverter.

There are many techniques available, the main technique for inverter switching is PWM , SPWM and SVPWM. These techniques are used for the switching of IGBT. The most famous technique is SVPWM. The main problem in inverter is total harmonic distortion. Our objectives are to reduce THD and also maintain the voltage and frequency.

1.3 The Proposed System

Our proposed system is based solar , wind and hyrdo power generation which are connected in parallel and three phase inverter would invert DC to AC.

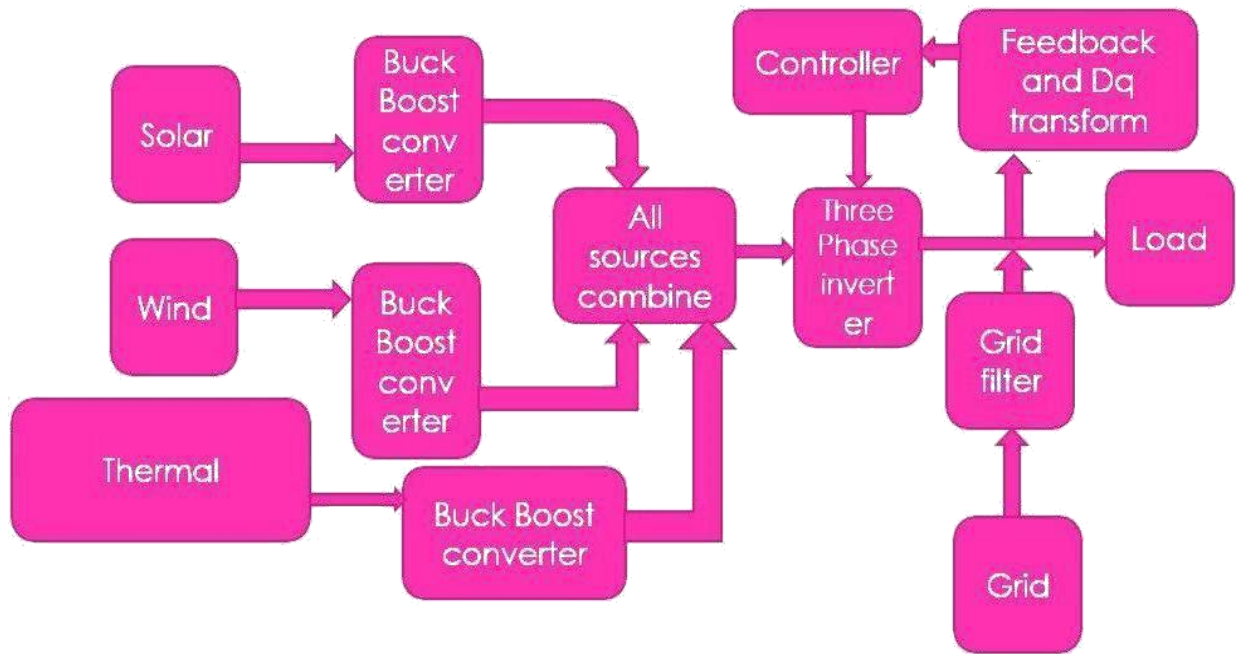


Figure 1.1 Block diagram of whole system.

1.4 Solar Module

Conventional source of energy conversion system is very expensive and require periodic maintenance, solar is the best and low-cost renewable energy source in which there is only onetime cost and there is very less maintenance cost in which a middle man can also afford for its basic use. In Pakistan solar is almost available for 12 hours a day.

1.5 Solar Cell equivalent model

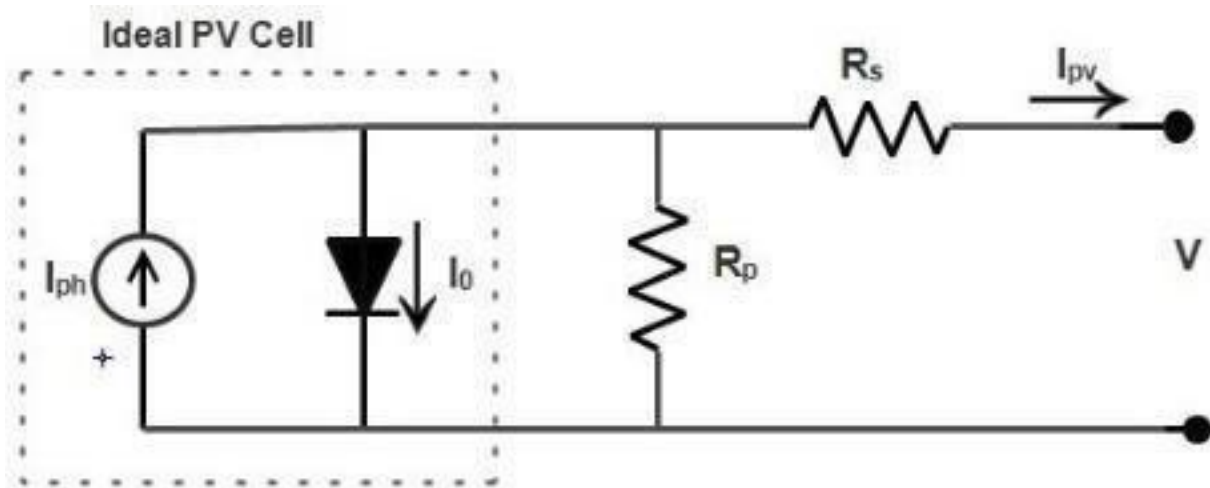


Figure 1.2 Internal Circuit of solar

For solar cell current factor is main factor which determine the power of solar cell and resistance tell the capacity. The equation of solar cell is as follows.

$$I_{ph} = [I_{scr} + K_i(T - 298)] \quad (1.1)$$

The short out current of sun based cell is meant by I_{rs} and it tends to be determined by utilizing the accompanying condition

$$I_{rs} = I_{scr} / \exp \frac{q_0 V}{k T} \quad (1.2)$$

Sun oriented cell has V_{oc} which is the most extreme voltage of sun based board. The yield current of sunlight based cell is definid as

$$I_o = I_{rs} [T] * \exp] \quad (1.3)$$

The reference temperature is defined as T_r and I_{pv} can be calculated as follow

$$q(V_{pv} + I_{pv})$$

$$I_{pv} = N_p * I_{ph} - N_o * I_o [\exp \{ R_s \} - 1] \quad (1.4)$$

The point where no load is associated with the cell then this is called open circuit.

1.6 Matlab/Simulink Model of PV

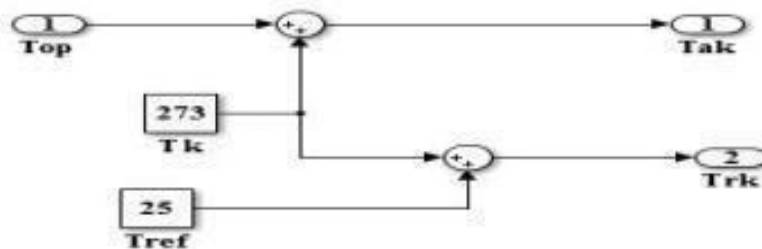


Figure 1.3 Simulink model of PV

Solar panel is based on temperature and irradiance. The top defined the temperature of solar panel and T_{ref} is the reference temperature.

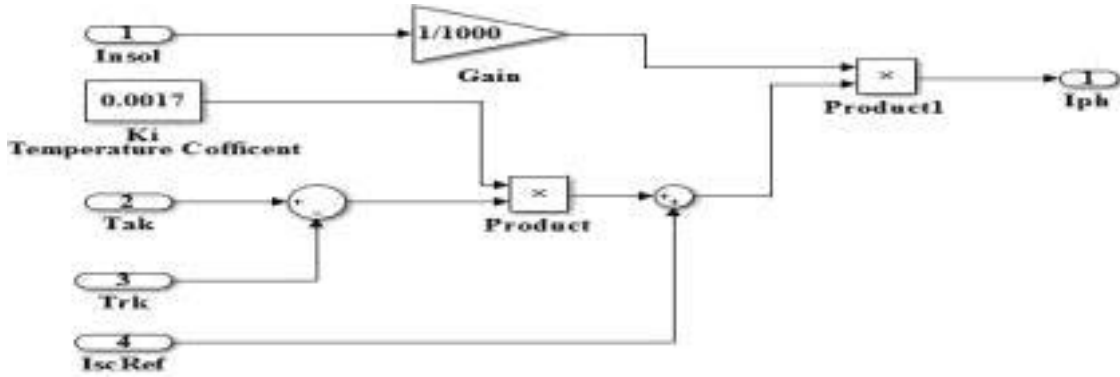


Figure 1.4 solar panel internal circuit

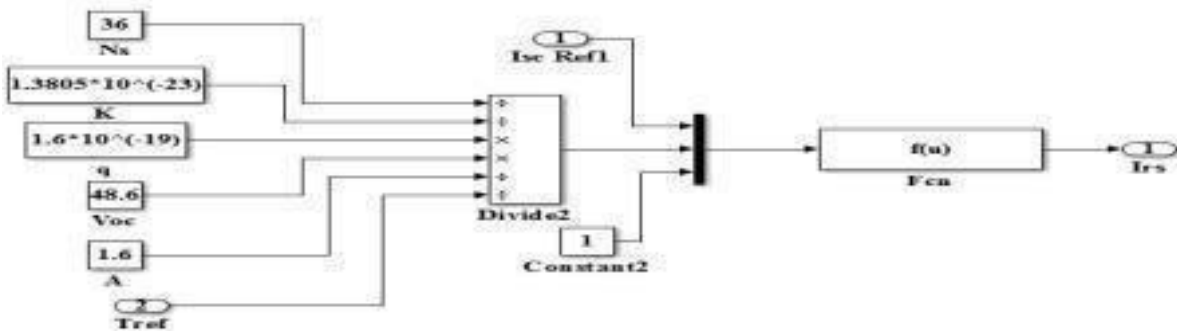


Figure 1.5 saturation current of PV module

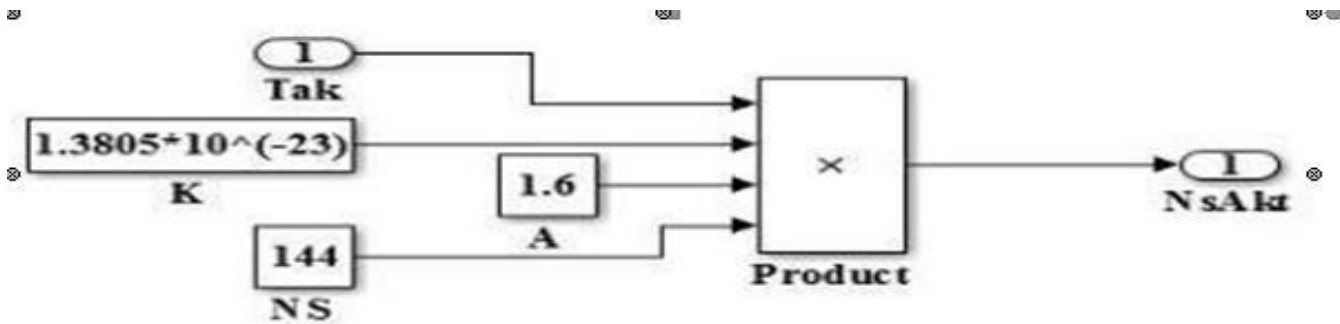


Figure 1.6 NsKTak product

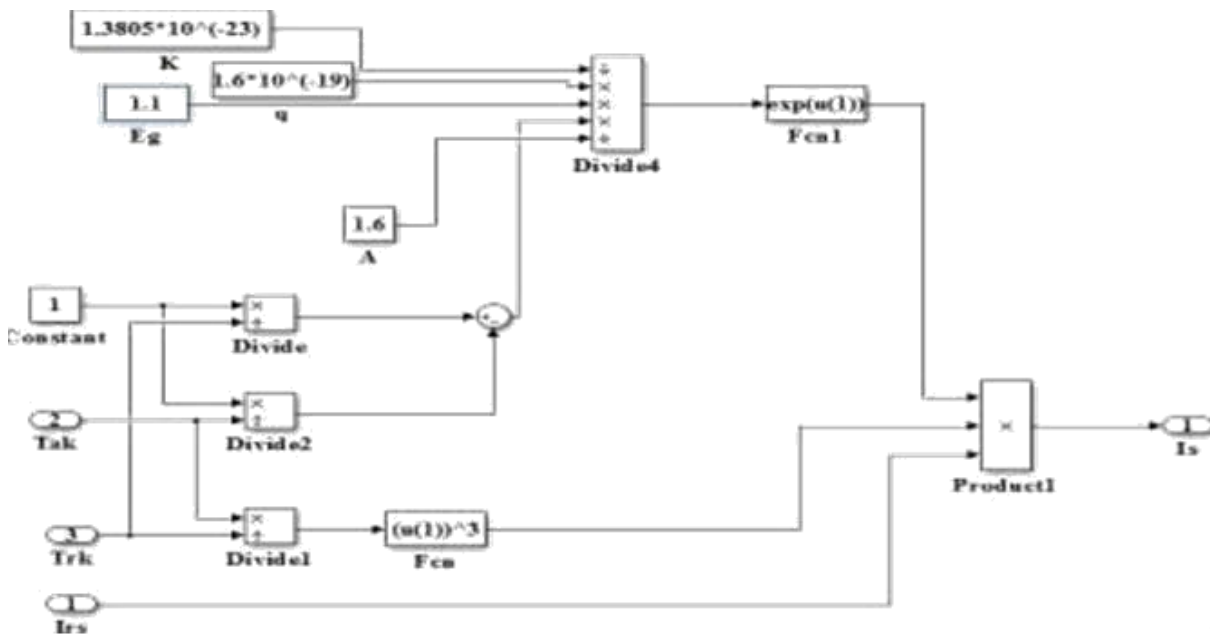


Figure 1.7 solar module saturation current

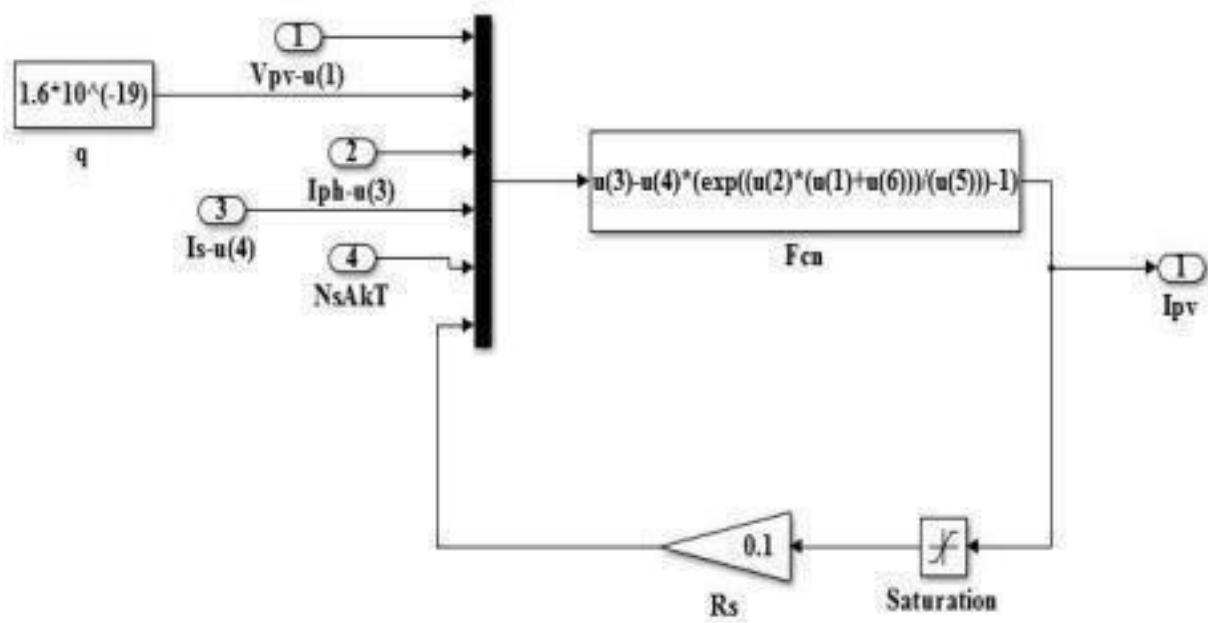


Figure 1. 8 at 25 degree the output current

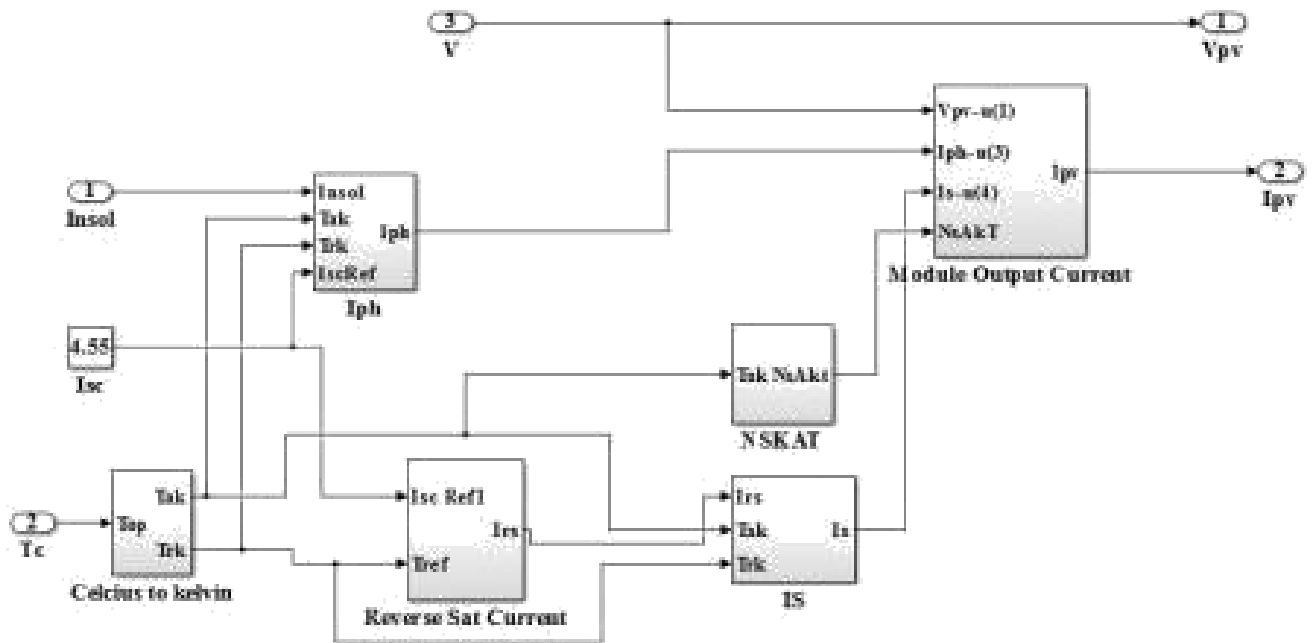


Figure 1.9 solar module complete simulation diagram

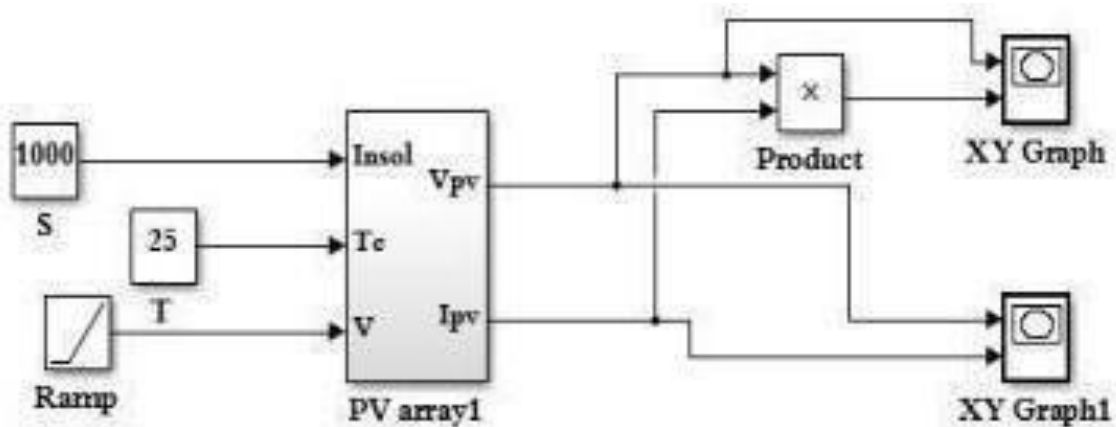


Figure 1.10 Matlab model of PV module

1.7 PV Characteristic Curves

Solar characteristic curve is based on three parameters which defined the efficiency of solar panel , one is voltage , current and power.

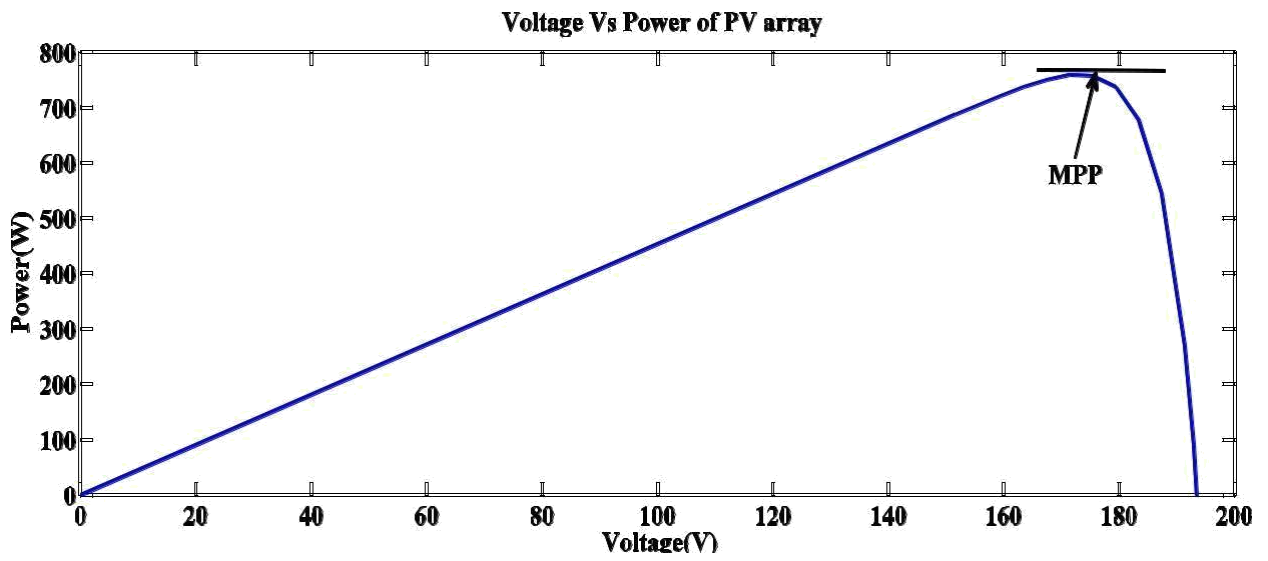


Figure 1.11 voltage Vs power graph

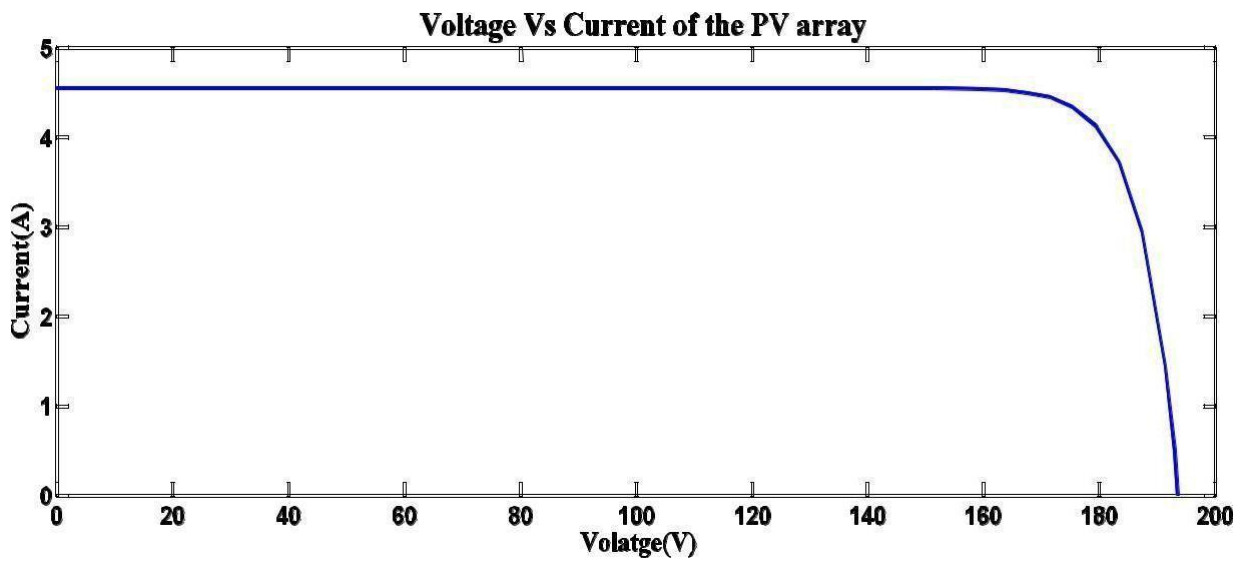


Figure 1.12 short circuit current and open circuit voltage graph

CHAPTER 2

Literature Review

2.1 Literature Review

The main focus of this research is on multi energy system in which we study about renewable resource of energy generation system. From last few decades world is facing energy crises badly and in Pakistan there is a lot of energy crises in which industry and academia and research organizations all suffer. Solar based energy solution is the low-cost source of energy generation system in this paper author focus on renewable sources and its effective utilization [1]. The smart grid control system mechanism has been discussed in this paper for smart cities a new concept that has been implemented, the control of smart grid is very important and also it is useful for peoples because electricity cost increases day by day [2]. The free energy resources can be recovered and can be reused for products, multi-source energy system can combine to get a small grid system in which the grid is connected and also the grid can be used stand alone [3]. A multicriteria approach is used to for multi-source energy system. In this approach author propose multiple criteria for

multi-source energy system [4]. Data analytics tell the pattern of previous load profile and open data and open software both are useful for researchers to analyze the load profile of smart grid and can tell the load forecast [5]. There are some drivers required for multi energy system like voltage stabilization circuit for solar based systems, buck boost converter for wind-based system and some driver circuits are required for the conversion of heat energy into electrical energy [6]. One major factor which control of energy system or grid control system, there are many techniques available but some are very effective and some of them are not efficient [7]. Micro grid operation and its control technique is very important for complete system, the operation analysis and periodic monitoring of grid is very important and grid connected system can be used more effective way

[9]. Energy storage is the main issue we cannot store energy, if we want to, we need to bear much cost to store the energy [9]. Scheduling is very important factor for multi energy system [10].

2.1 Voltage stabilization circuit using DC-DC converter

The voltage stability is the main issue of renewable energy sources, for stabilization we need to use a DC-to-DC converter which can act as buck mode or boost mode, these circuit stabilize the desired output voltage, voltage fluctuation damages the appliance running on renewable sources if

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its voltage is not stabilized. So A feedback based voltage stabilization is the main requirement of this project for the smooth operation.

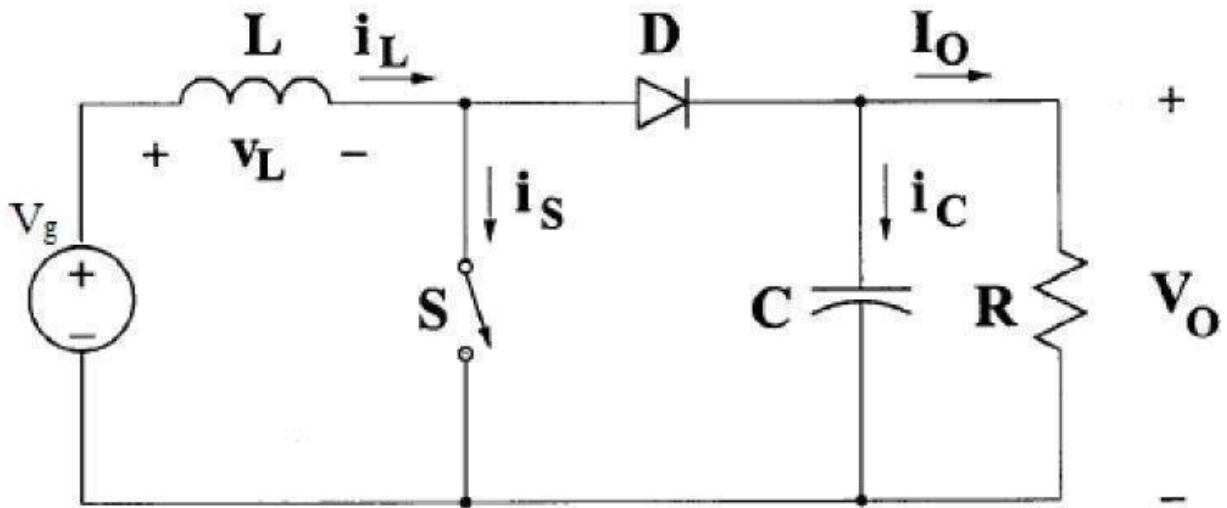


Figure 2.1 Circuit diagram of boost converter topology

2.2 Mode 1 Operation of Boost Converter

There are modes of operation of boost converter, the first mode is at $t=0$ and the switch of inverter is closed.

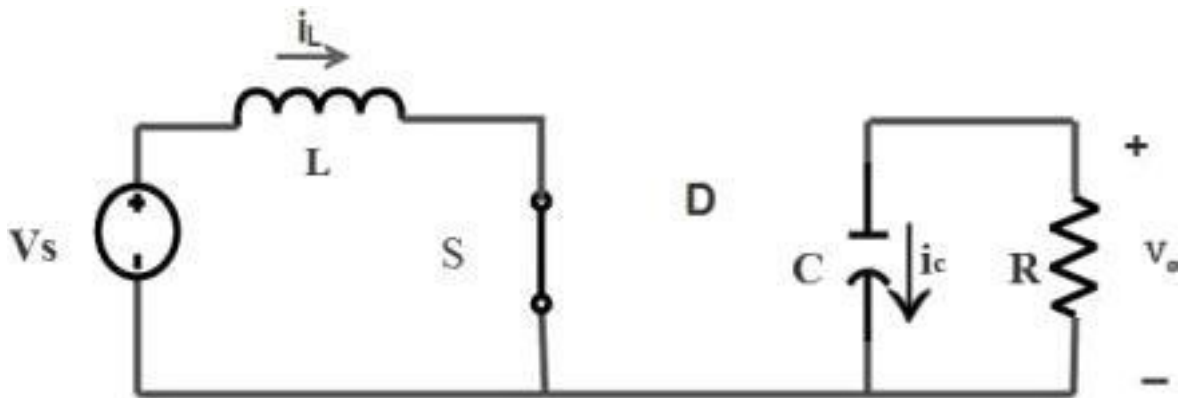


Figure 2.2 Mode 1 operation of Boost converter

2.3 Mode 2 Operation of Boost Converter

The second mode of boost converter is open the source and the inductor act as source and discharge the capacitor.

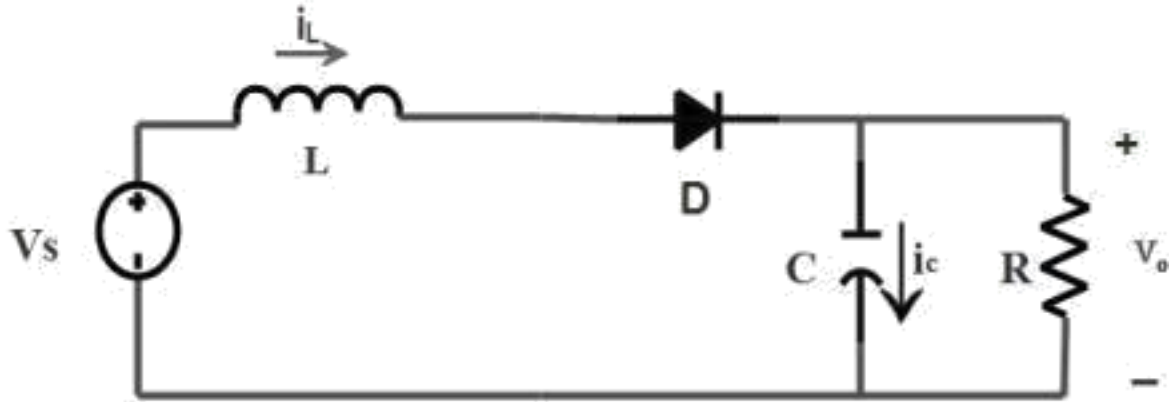


Figure 2.3 Mode 2 operation of boost converter.

2.4 Inductor Selection

Inductor selection is major part of project in which the larger value of inductor, the lowest ripple factor, so selection of inductor is major part boost converter. Inductor play vital role in voltage stabilization.

$$L = \frac{v_{In} \times (V_{out} - V_{IN})}{\Delta L \times f_s \times V_{out}} \quad (2.1)$$

$$\Delta L = (0.2 \text{ to } 0.4) \times I \times t \quad (2.2)$$

2.5 Output Capacitor Selection:

To regulate the output ripple the value of output capacitor is calculated as

$$C_{out(min)} = \frac{I_{out(max)} \times D}{f_s \times \Delta V_{out}} \quad (2.3)$$

$C_{out(min)}$ = Minimum output capacitance for boost converter

2.6 Wind Turbine

Wind is also a renewable source of energy and in Pakistan we can generate the power from wind using wind energy conversion system.

There are many parts of wind-based power generation some them are shown in figure above, like rotor, gear box and generator etc.

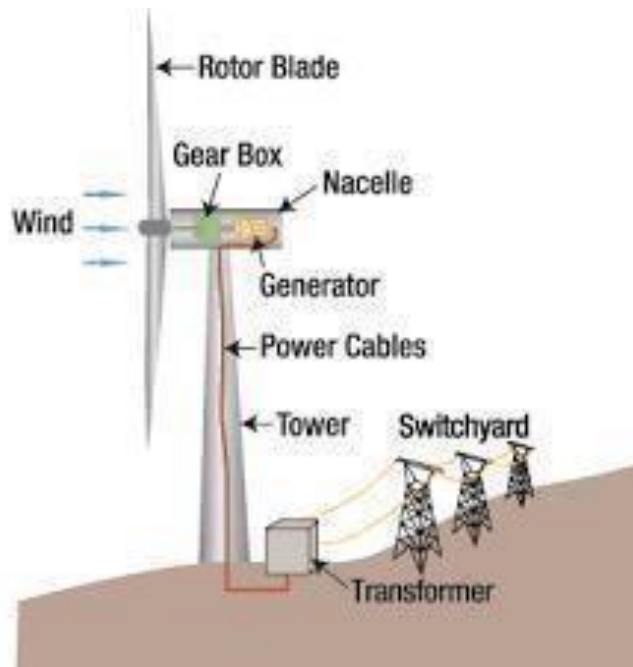


Figure 2.4 Wind Model

CHAPTER 3

Requirement and Specification

The system which we have designed is based on two types of inverter, one is single phase inverter and the other three phase inverter. Because normal household use there is requirement of single-phase loads also.

3.1 Single phase Inverter

Single phase inverter consist of four switches in which one switch can turn on at a time

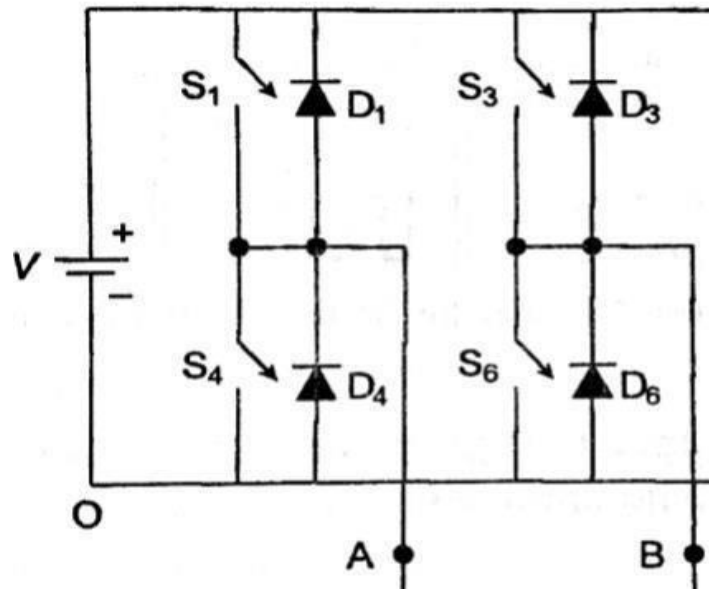


Figure 3.1 Basic circuit of Inverter

The above diagram shows the basic functionality of single phase inverter which is based on four switches

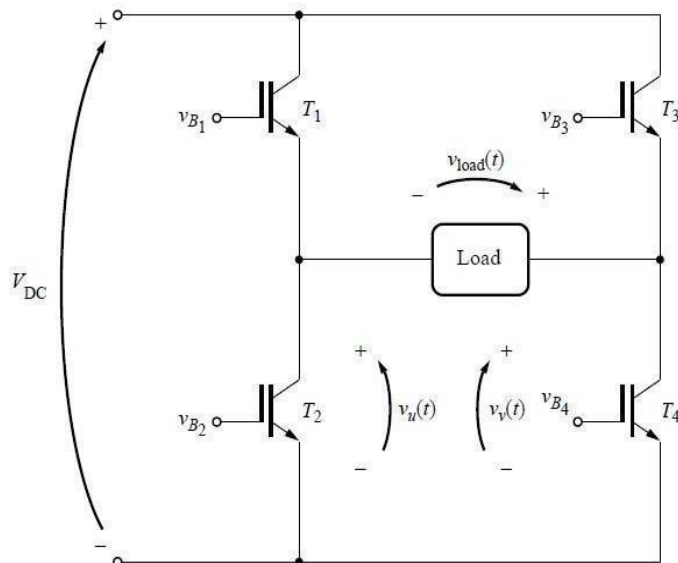


Figure 3.2 Basic functionality of Single phase inverter

This circuit explains the functionality of single phase inverter in which for positive half cycle T1 and T4 turn on and for negative half cycle T2 and T3 turn ON.

3.2 Gate Driver circuit

As we realize that Metal-oxide semi-conductor field effect transistor is driven by switching signal for proper activity.

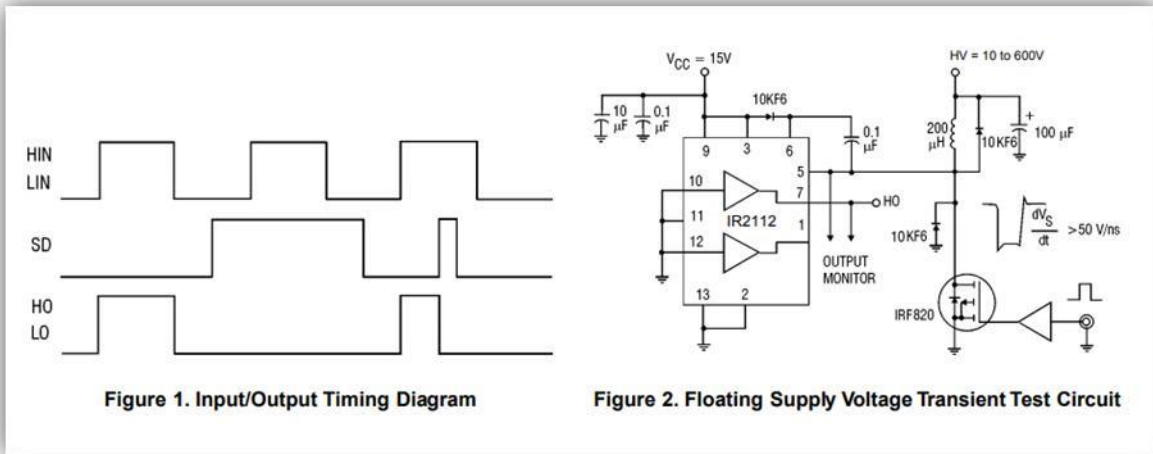


Figure 1. Input/Output Timing Diagram

Figure 2. Floating Supply Voltage Transient Test Circuit

Figure 3.3 Gate Driver circuit

The switching time of each signal is shown below

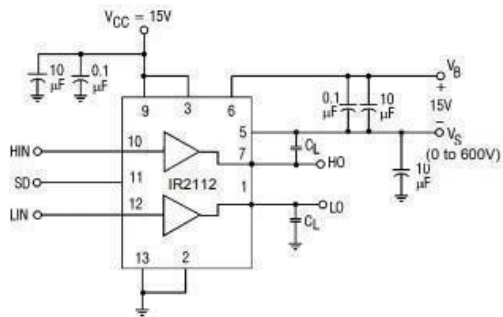


Figure 3. Switching Time Test Circuit

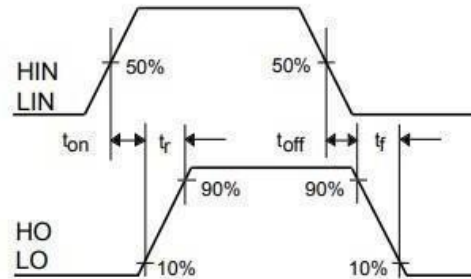


Figure 4. Switching Time Waveform Definition

Figure 3.4 Signals of gate driver

3.3 Maximum Power Point Tracking

At the point when a heap is straightforwardly associated with PV cluster, the functioning point is infrequently at the sunlight panel's max power; in this manner it isn't producing the greatest force. The direct-coupled frameworks abuse just 31% of the PV limit. The load and a PV array mismatching needs further over-estimating of the PV array and consequently raises the entire system cost. To reduce this difficult,(a max PPT) can be employed operating the PV system at the MPP. MPPT charge controllers used for obtain maximum power from PV module under certain

circumstances like temperature and irradiance. The maximum power point (MPP) of a PV array lies at the knee of the voltage and current curve. Maximum power can be obtained from a PV array depends on three important factors: irradiance, temperature and load because the efficiency of solar cells depends on irradiance, operating temperature, and spectral characteristics of sunshine, and so on. The poor efficiency of PV systems, some techniques is suggested, amongst which is new perception of called “maximum power point tracking” .All the techniques have similar objective to maximizing the PV array out power by chasing the maximum power on operational condition. The load impedance is described as bellow.

$$r_{load} = \underline{V_o} / I_o \quad (3.1)$$

$$R_{opt} = V_{mpp} / I_{mpp} \quad (3.2)$$

When the newly generated power is higher than the previously generated power then another power will be generated and if the new power is less then previous power will be the max pow point..

3.4 Algorithms for Maximum Power Point Tracking

There are many algorithms that are capable to tracking MPPs. Most of the algorithms are basic and easy to implement. Those are based on current and voltage feedback, for example, the incremental conductance and perturbation and observation method. These methods are varied in complexity, speed of convergence, sensor requirement, range of operation and their applications. Having an interesting aspect of suggested methods, P&O and hill climbing methods were the main consideration because ease of implementation and simplicity in algorithm MPPT strategies are fundamental in solar purposes in light of the fact that the MPP of a sun based board changes with the temp and illumination, so the utilization of MPPT techniques is important to obtain the most extreme force from a sun based exhibit. Throughout the last many years a few calculations are proposed to decide the Max pow point. These strategies shift in various components, for instance, required consolidating speed, cost, diverse nature, sensors, extent of feasibility, right after when insolation or temperature change, and equipment needed for the execution or prominence, among others. An intensive review of nineteen different (MaxPowPT) calculations can be found in. The P&O and the InCond calculations are the most direct and fundamental among all of these frameworks. These methods enjoy the benefit of a basic execution yet they moreover have burdens.

Various frameworks considering different guidelines are neural framework fluffy rationale control, current breadth, partial open circuit voltage or short out current, and so on A huge bit of these frameworks yield a close by generally outrageous and a few, like the incomplete open circuit voltage or short out current, give an approximated MPP, not the cautious one. The V-P curve has one and only most extreme in run of the mill conditions, so it is not a risky. Be that as it may, if

the PV exhibit is mostly under the trees, there are a several maxima in these curves. With a specific end goal to mitigate this issue, a few algorithms have been utilized.

3.5 Perturb & Observe Algorithm

P & O algorithm is otherwise called the "hill climbing" strategy, is extremely well known and every now and again utilized as a part of practice in view of its simplicity of execution and the straightforwardness in calculation. PV exhibit and gives us the power curve. We imagine that Solar panel is operating on a voltage which is far away from the Max ppt so keeping this thing in mind we did the following calculations

3.5.1 Benefits: Perturb and observe algorithm is very popular and most frequently used in practice because of

1. Ease of implementation.
2. Low cost
3. Its simplicity in algorithm.

3.5.2 Drawbacks: There are few restrictions that decrease its MPPT efficiency. They are,

1. Exact operating point can't be measured.
2. Oscillation near the maximum power point.

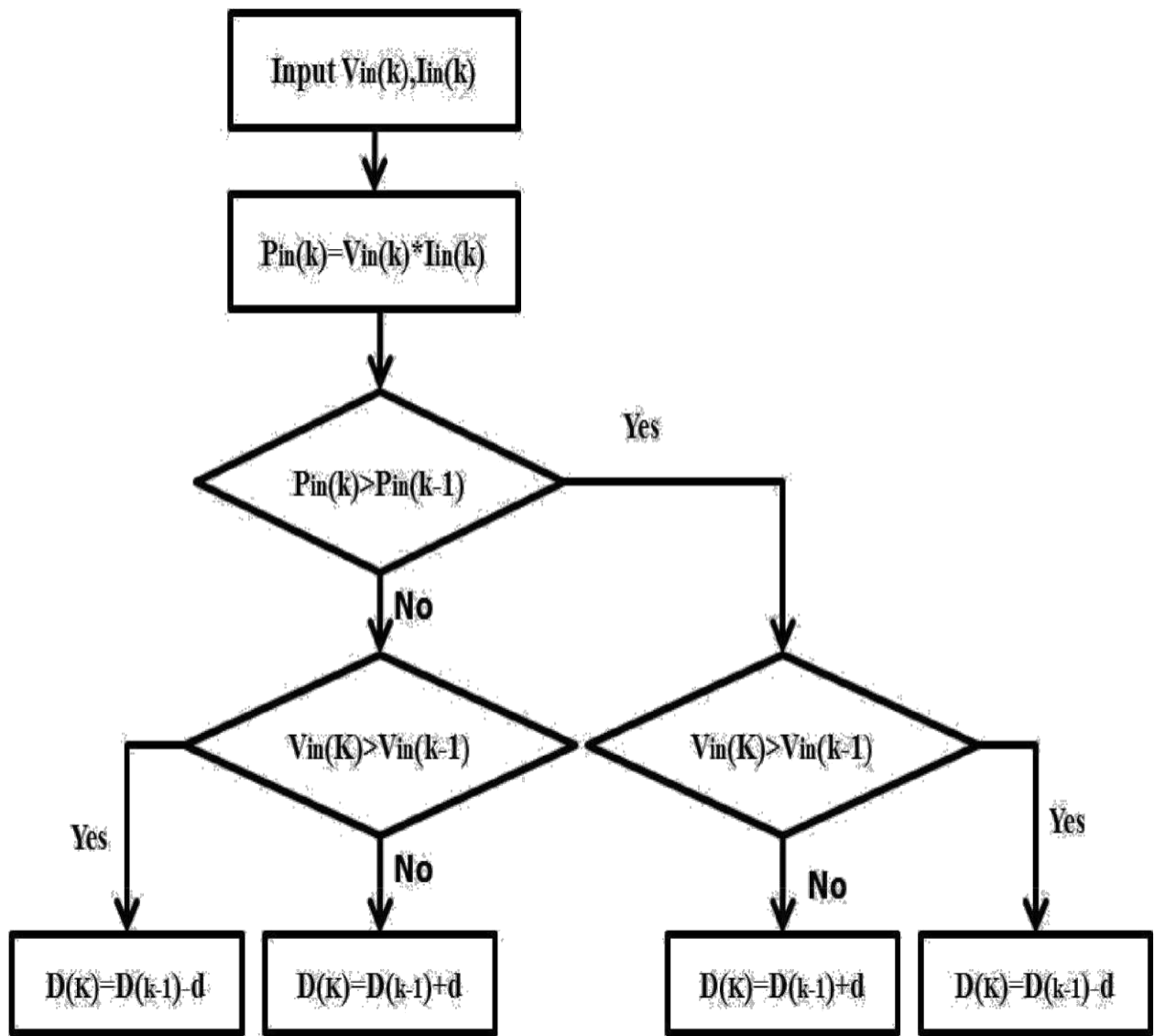


Figure 3.5 flow diagram of Perturb and Observe method

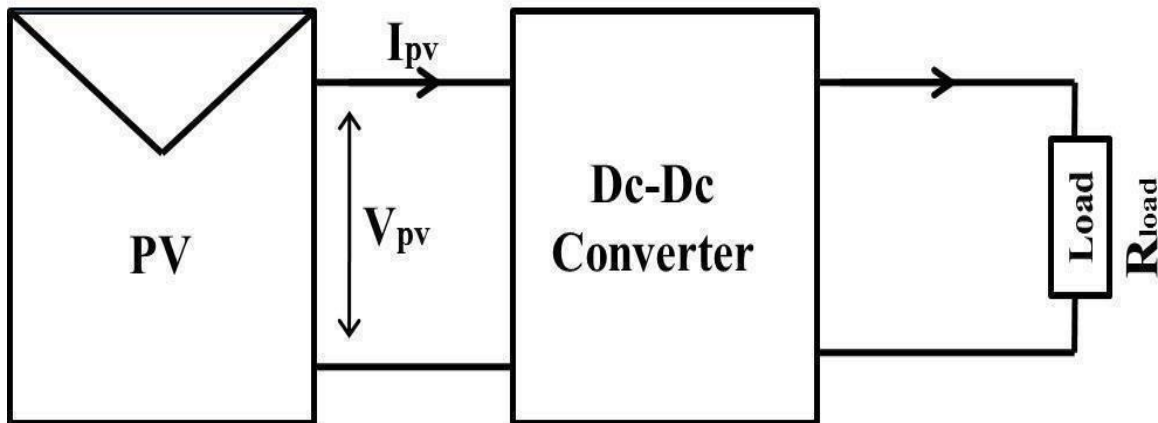


Figure 3.6 Connecting the DC-DC converter with PV array.

According to the maximum theorem if we transfer the maximum power from source to the load the Z of source should be match with Z_L . In this scenario the optimal impedance R_{opt} is matched with the load impedance R_{load} by changing the duty cycle.

$$R_{opt} = (1 - D)2R_{load} \quad (3.3)$$

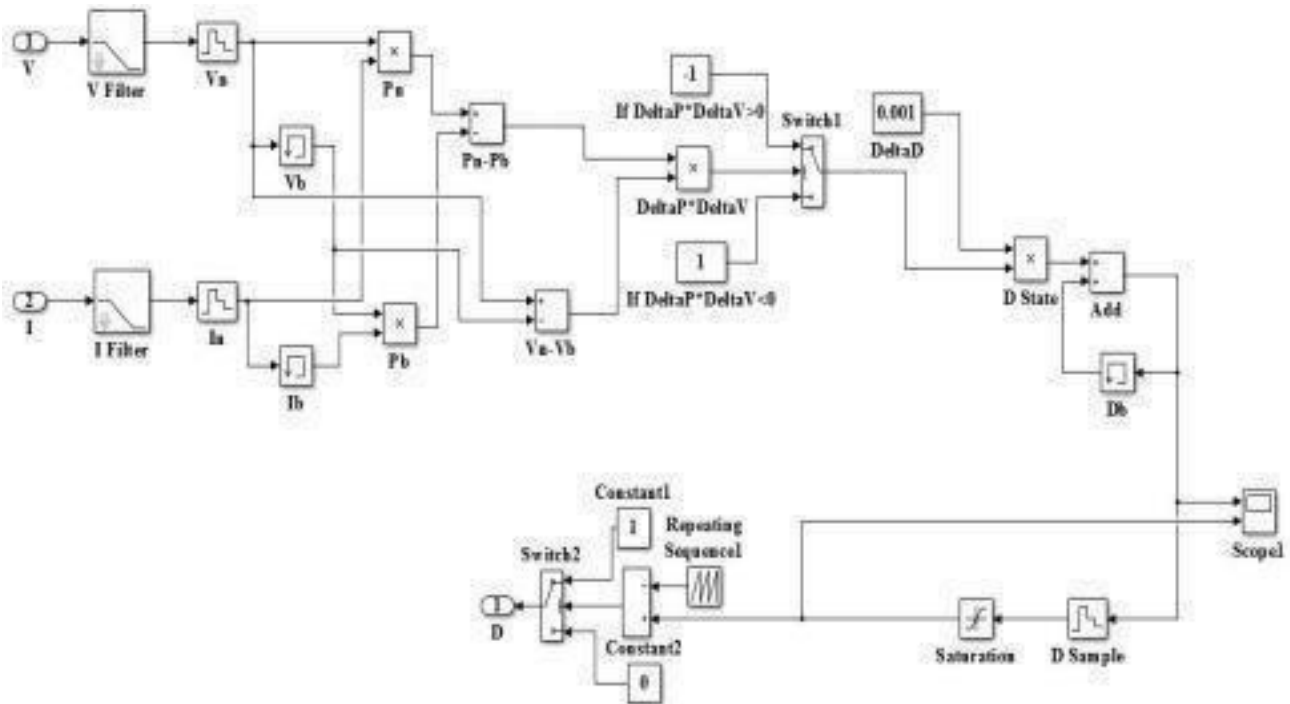


Figure 3.7 Simulink diagram of Perturb and Observe.

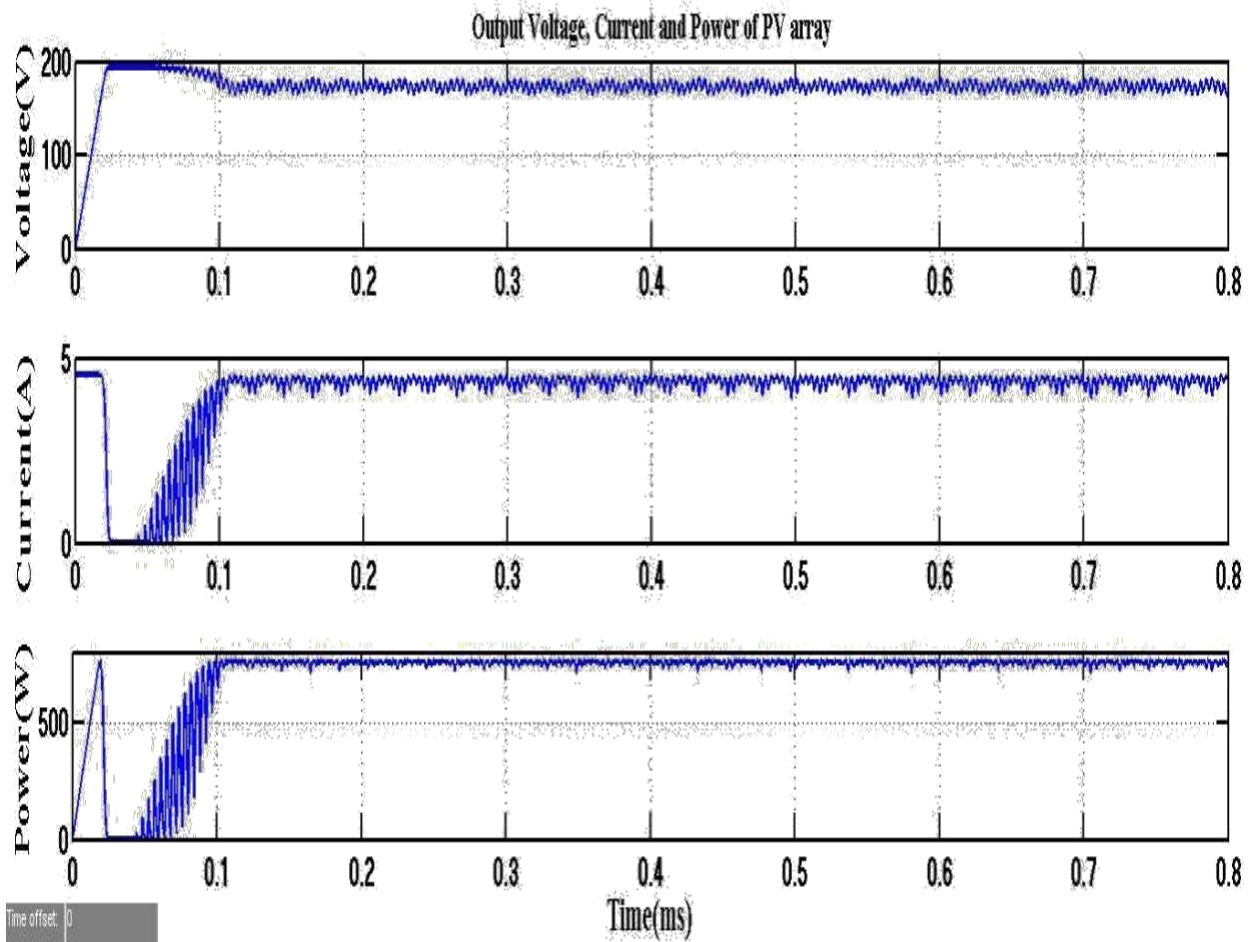


Figure 3.8 Output Voltage, Current and Power of the PV array

CHAPTER 4

System Design

4.1 Introduction

There are many techniques available but the effective one is SPWM, this technique PWM are easily generated and have a very low THD. For three phase inverter we need six PWM signals for 6 IGBTs. For the generation of SPWM we take two signals and use comparator for those signals to generate the PWM signal. There are 6 pulses available for 6 IGBTs and we can only provide one high pulse at one IGBT. Two IGBTs are connected in lag and don't need to provide high signal on both IGBT at a time.

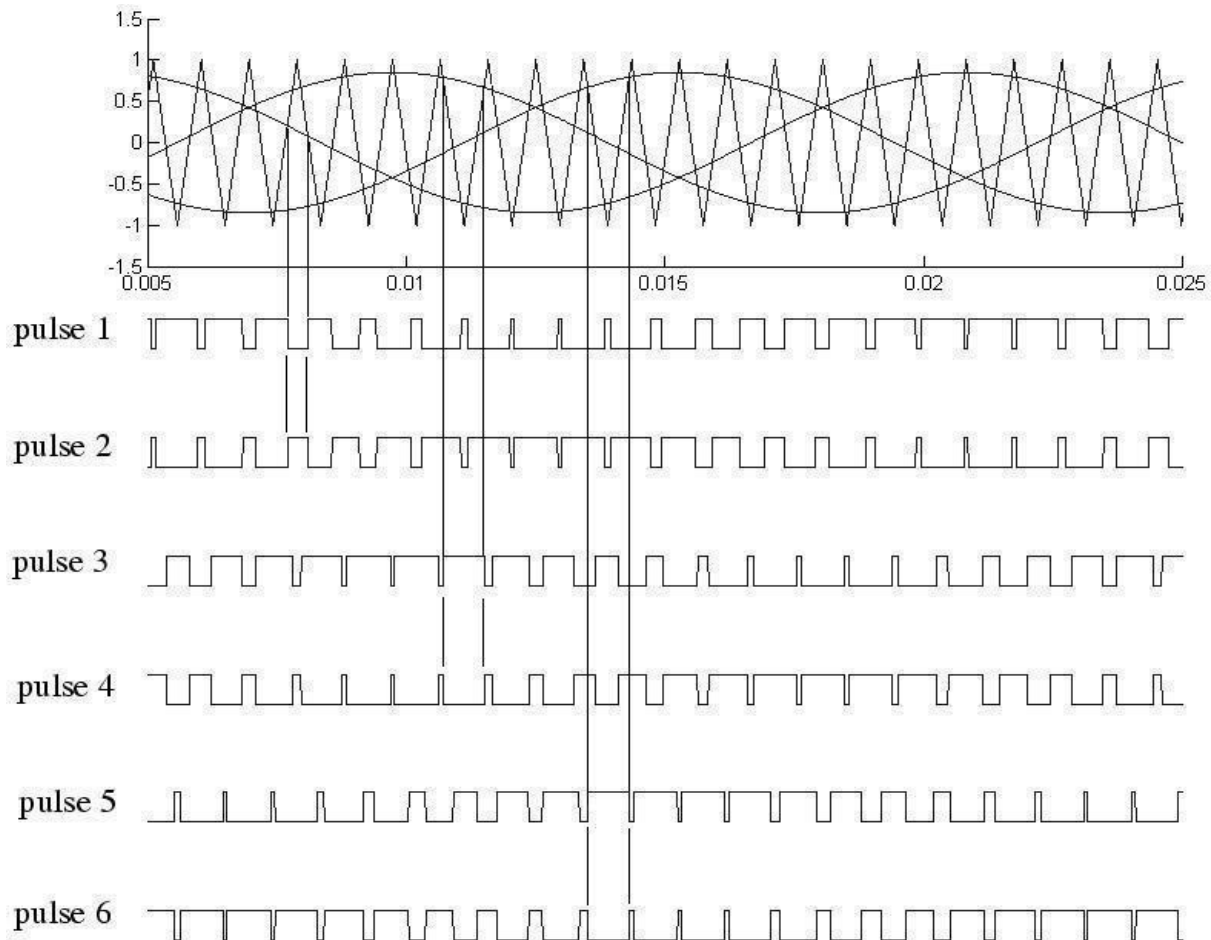


Figure 4.1 inverter gate pulses

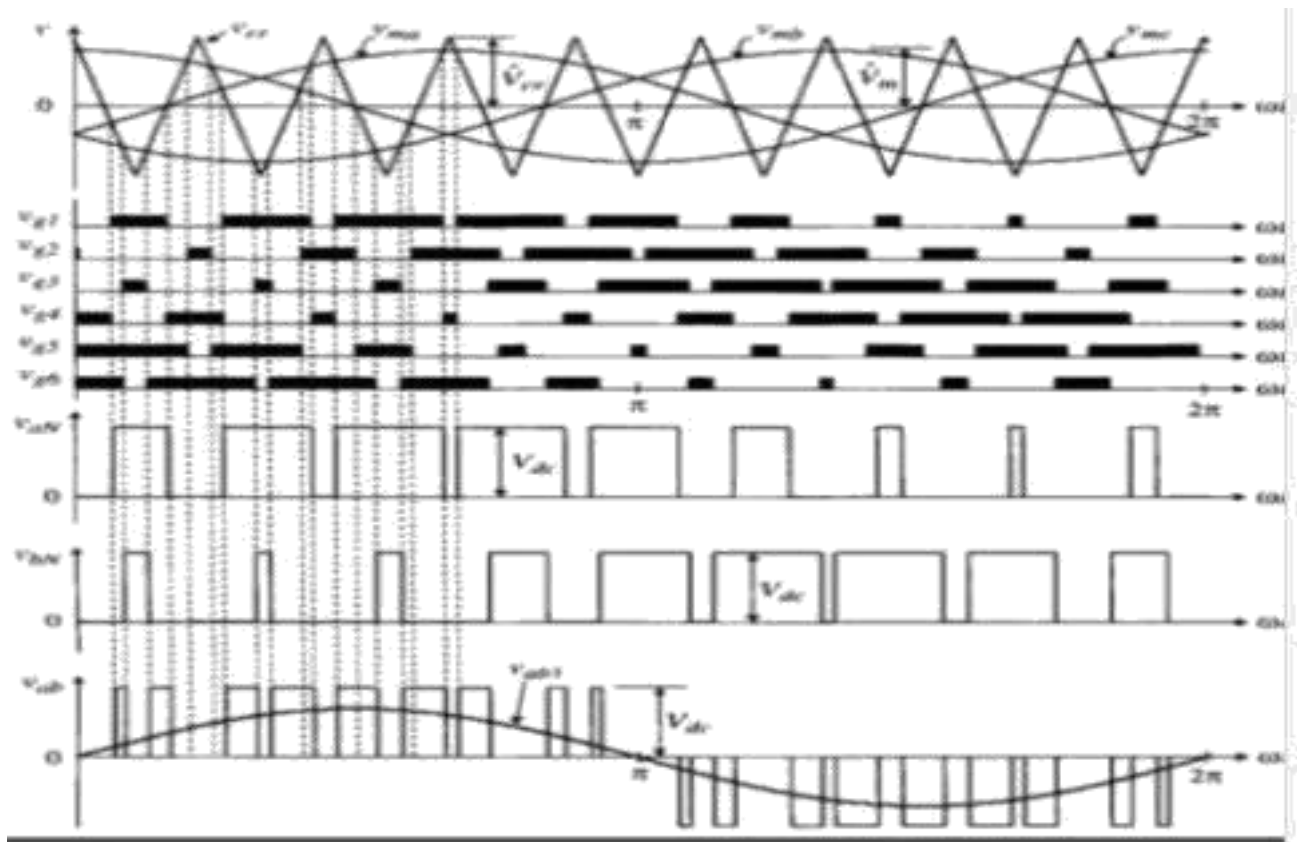


Figure 4.2 line voltage with gate pulses

In SPWM there is one modulation index and this modulation index is denoted by m . so the modulation index is calculated by using the following equation.

$$m = (4.1) * V_{cc} * f$$

$$n = (4.2) * f_m$$

the ratio n can be calculated by using the two frequencies like f_c (carrier frequency) and f_m is modulation frequency. We take the ratio and calculate the n factor. N factor must be ODD.

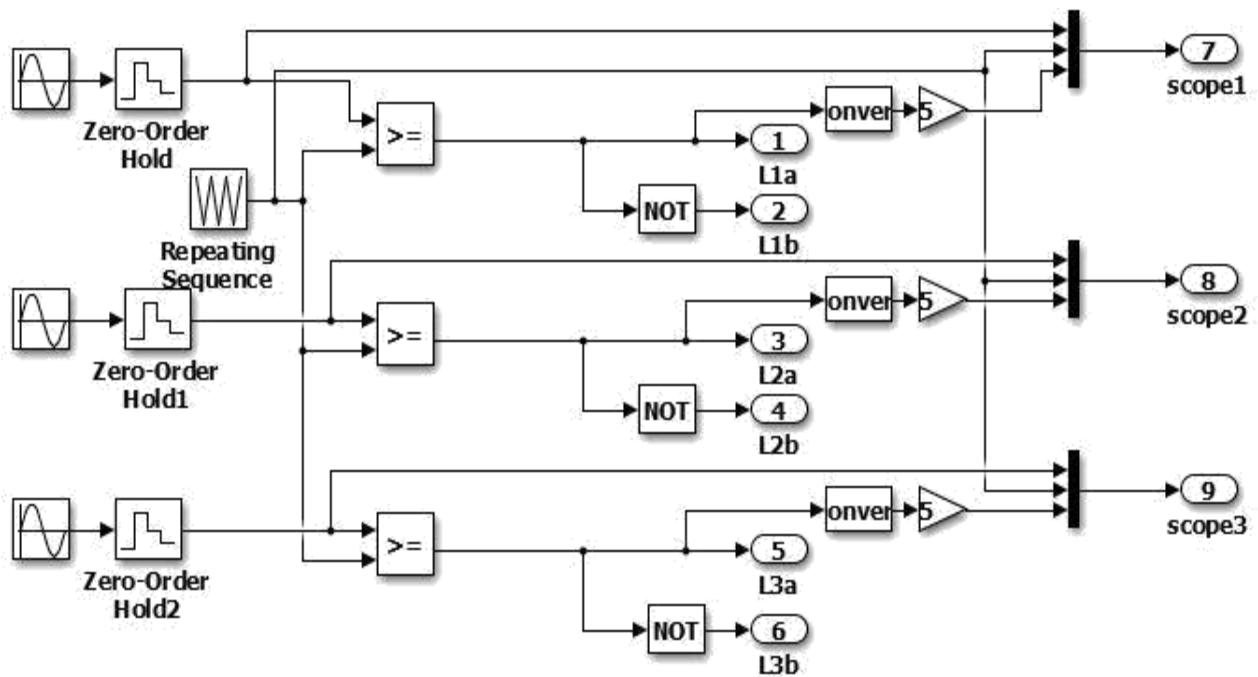


Figure 4.3 SPWM diagram of simulink

There are 6 switching sequences for inverter in which when the upper IGBTs are on , lower would turn off..

SPWM is one of the best pulse width modulation technique.

4.2 Advantages of SPWM

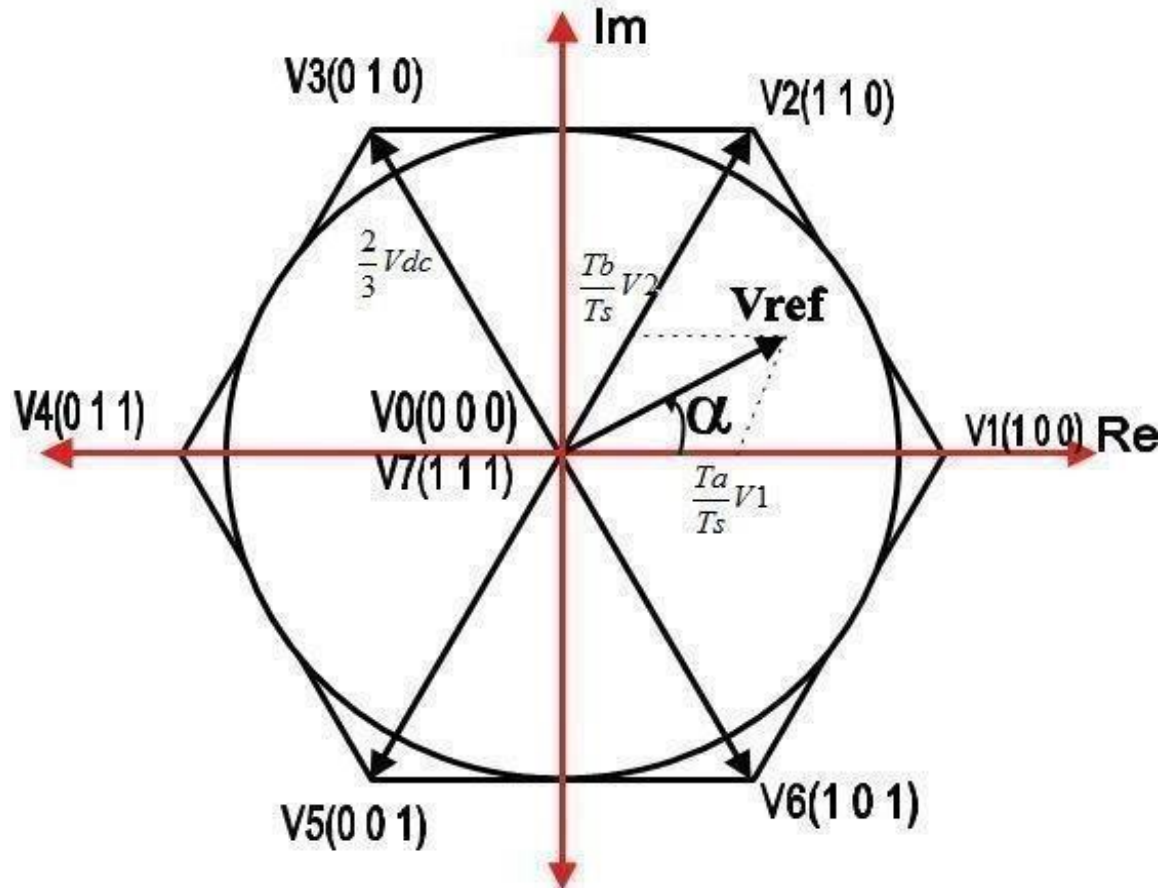
- Power consumption is very low
- Upto 91% energy efficient.
- Very high power handling capability
- There is no effect of temperature.
- Digital implementation is very easy

CHAPTER 5

Methodology

5.1 Introduction

The most famous technique of renewable energy conversion system is SVPWM based which has a very low THD.



5.2 Space Vector PWM Mathematical Equations

The most advanced technique for controlling the 1Ph and 3Ph inverters is SVPWM. The best PWM signal generation technique is SVPWM. We can generate the magnitude of voltage frequency from our own desire. This technique has a very low THD.

The output voltage is the main factor for the generation of switching pattern. Park and koon transformation is used for this.

Switching States

For three phase inverter , it has six switching states and for single phase inverter there are four states are available.

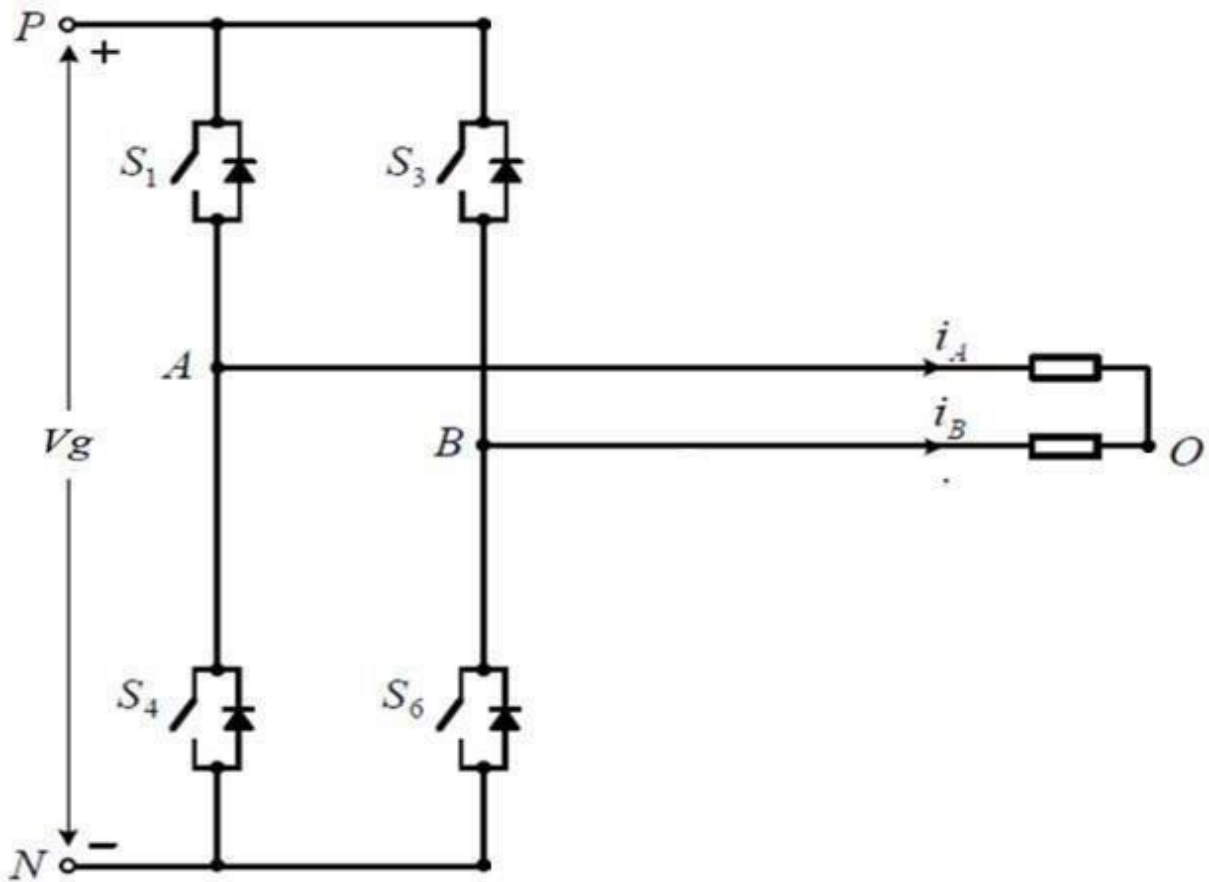


Figure 5.2 inverter basic circuit

The two transistors are connected in each leg and all three legs have six transistors in which each transistor requires a gate driving signal and each transistor requires gate pulses. The output voltage and frequency are dependent on the gate signal. In DC voltage, there are only two levels of voltage required.

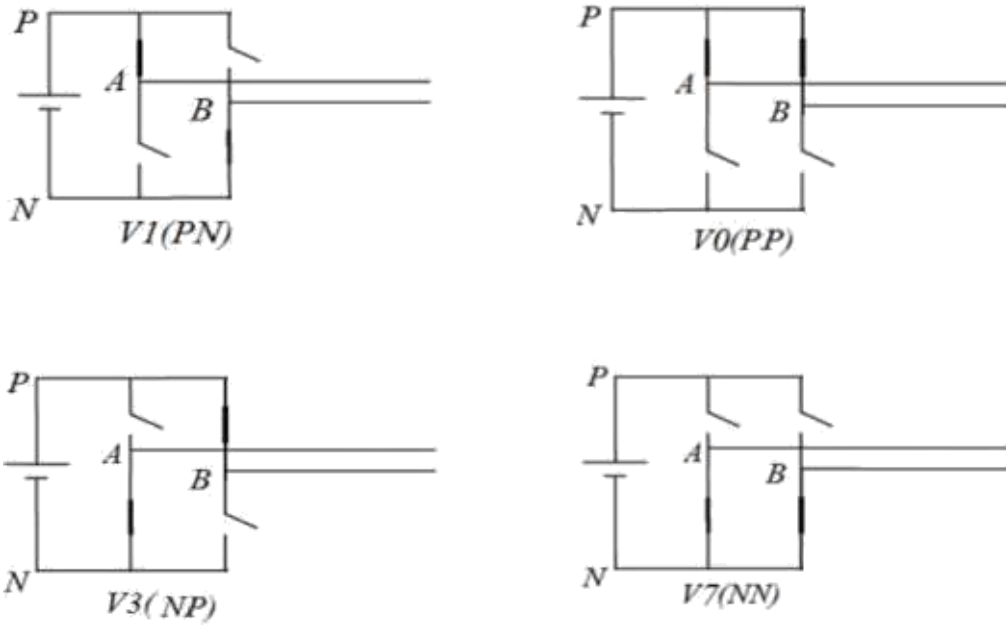


Figure 5.3 switches detail

5.3 Voltage Space Vectors

This modulation technique is represented in two dimensional plane. The three vectors , V_{ab} , V_{bc} and V_{ca} .

$$\begin{aligned}
 V_{AB} &= V_g \\
 V_{BC} &= 0 \text{ and} \\
 V_{CA} &= -V_g
 \end{aligned}
 \tag{5.1}$$

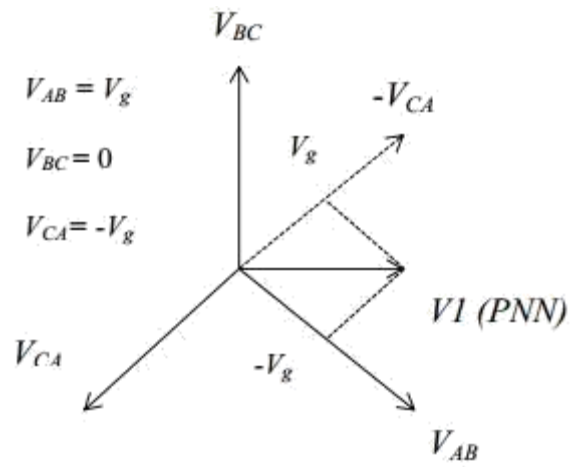


Figure 5.4 Space vector
The non zero vector (V1 -V4) is shown figure.

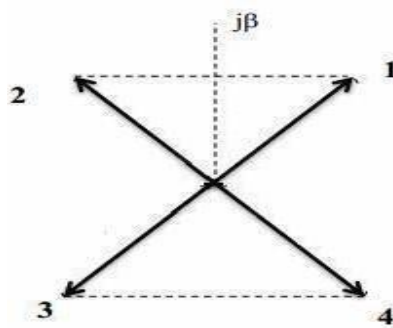


Figure 5.5 plane non zero vector

The output voltage of single phase is shown below. The equations represent the output voltage.

$$V_{AB} = 0$$

$$V_{BC} = 0 \text{ and} \\ V_{CA} = 0$$

There are six vectors and six zero vectors of three inverter are represented for three phase inverters. We just analyze each vector rather than analyzing the complete three phase vector.

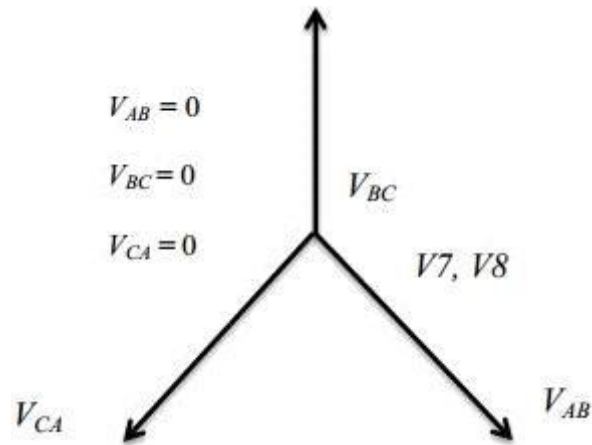


Figure 5.6 Vector's representation in plane

5.3 Calculation of Switching Times

Space Vector	Switching State	On-state Switch	Vector Definition
\bar{V}_0	<i>PP</i>	S_1, S_3	$\bar{V}_0 = 0$
\bar{V}_4	<i>NN</i>	S_4, S_2	$\bar{V}_4 = 0$
\bar{V}_1	<i>PN</i>	S_1, S_2	$\bar{V}_1 = \frac{2}{3} * V_g * e^{j0}$
\bar{V}_2	<i>PP</i>	S_1, S_3, S_2	$\bar{V}_2 = \frac{2}{3} * V_g * e^{j\frac{\pi}{3}}$
\bar{V}_3	<i>NP</i>	S_4, S_3, S_2	$\bar{V}_0 = 0$
\bar{V}_4	<i>NP</i>	S_4, S_3	$\bar{V}_4 = 0$

The rotating vector is used to calculate the gate signal and the signal is represented as follows.

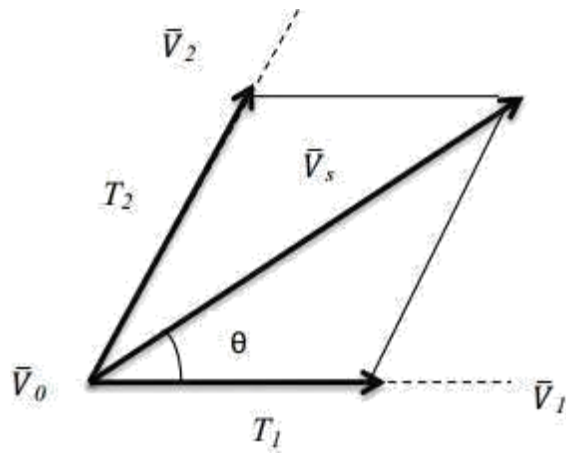


Figure 5.7 Generating vector V_s from V_1 , V_2 and V_7

5.4 Switching duration of each transistor

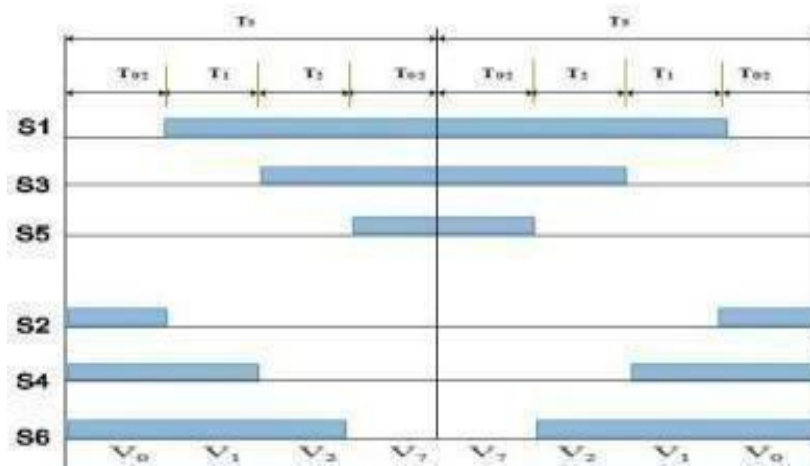


Figure 5.8 Space Vector PWM switching pattern at sector-1

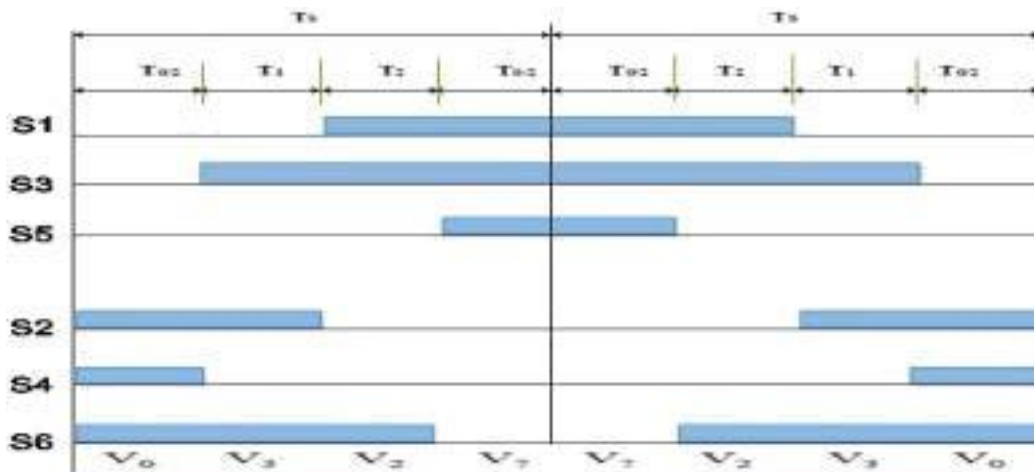


Figure 5.9 Space Vector PWM switching pattern at sector-2

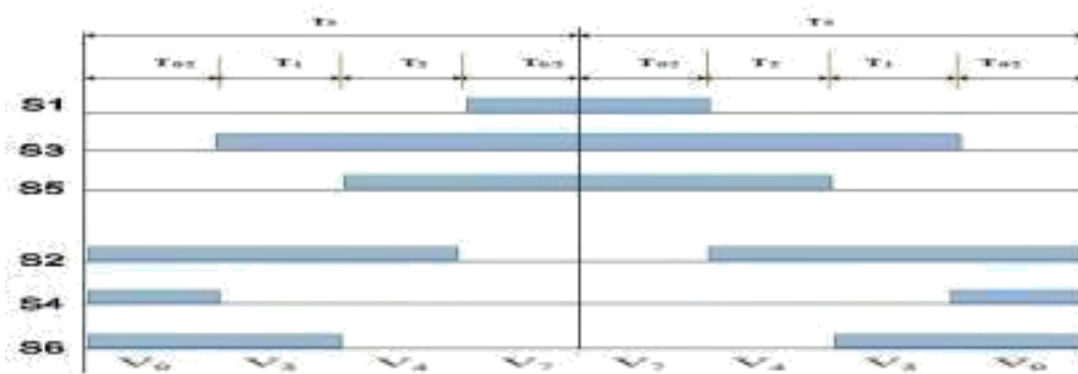


Figure 5.10 Space Vector PWM switching arrangement at sector-3

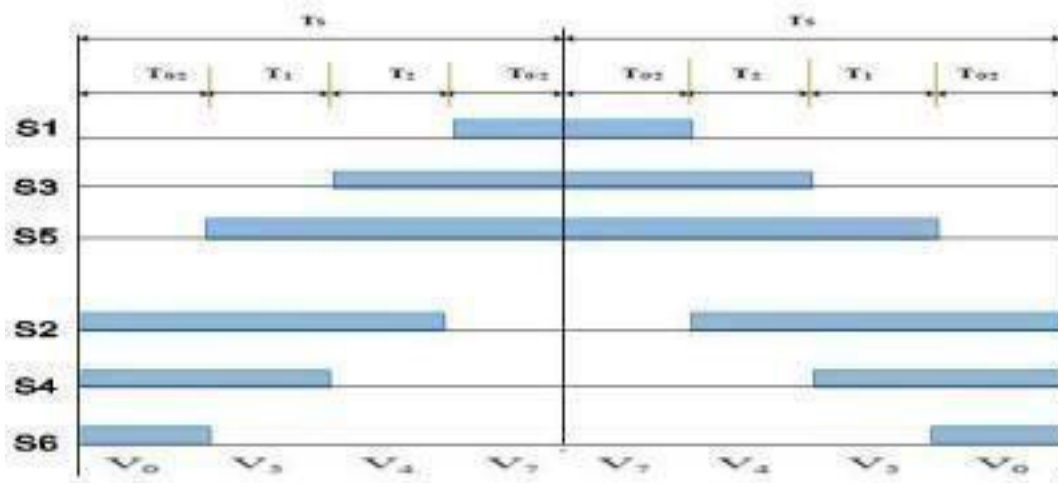


Figure 5.11 Space Vector PWM switching arrangement at sector-4

30

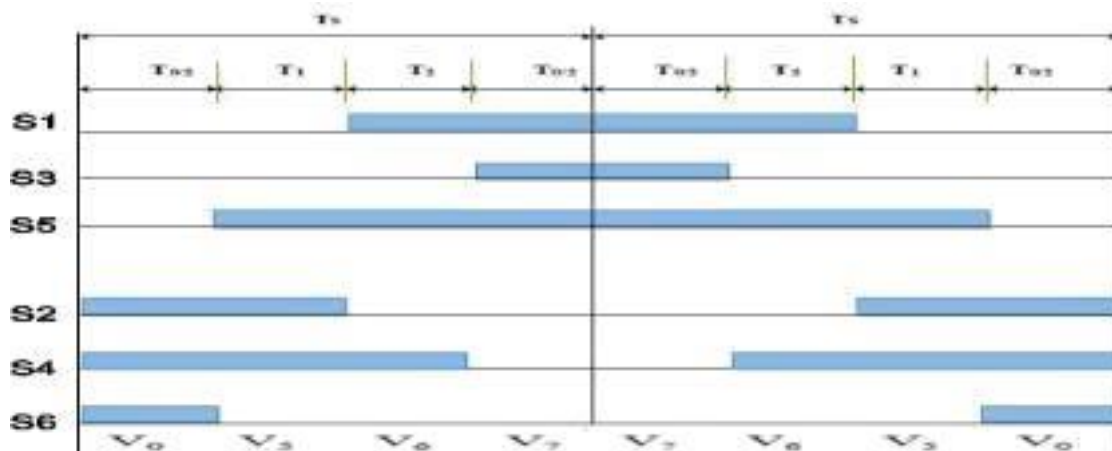


Figure 5.12 Space vector PWM Switching arrangement at Sector-5

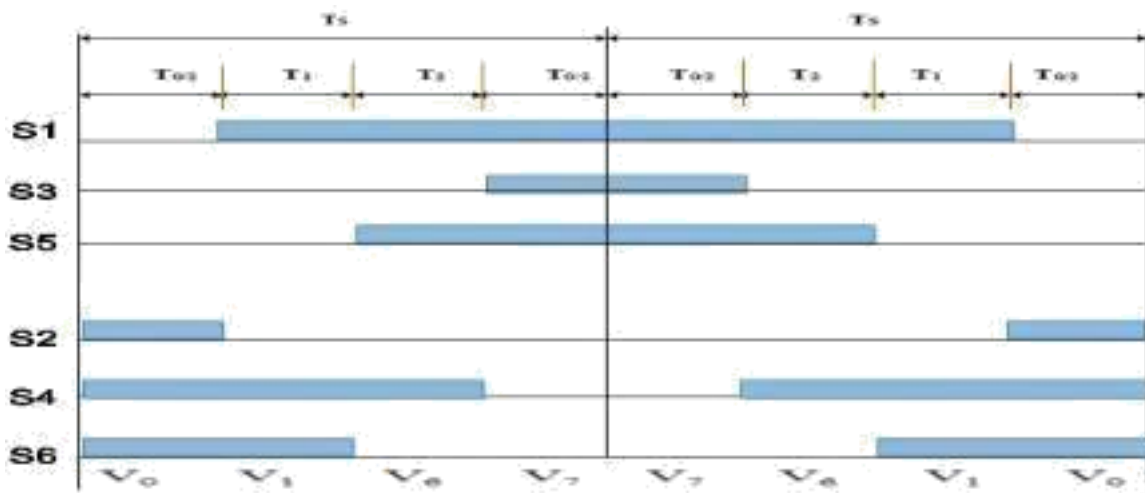


Figure 5.13 Space Vector PWM switching arrangement at sector-6

Switching sequence for each IGBT is constructed and implemented in figure below.

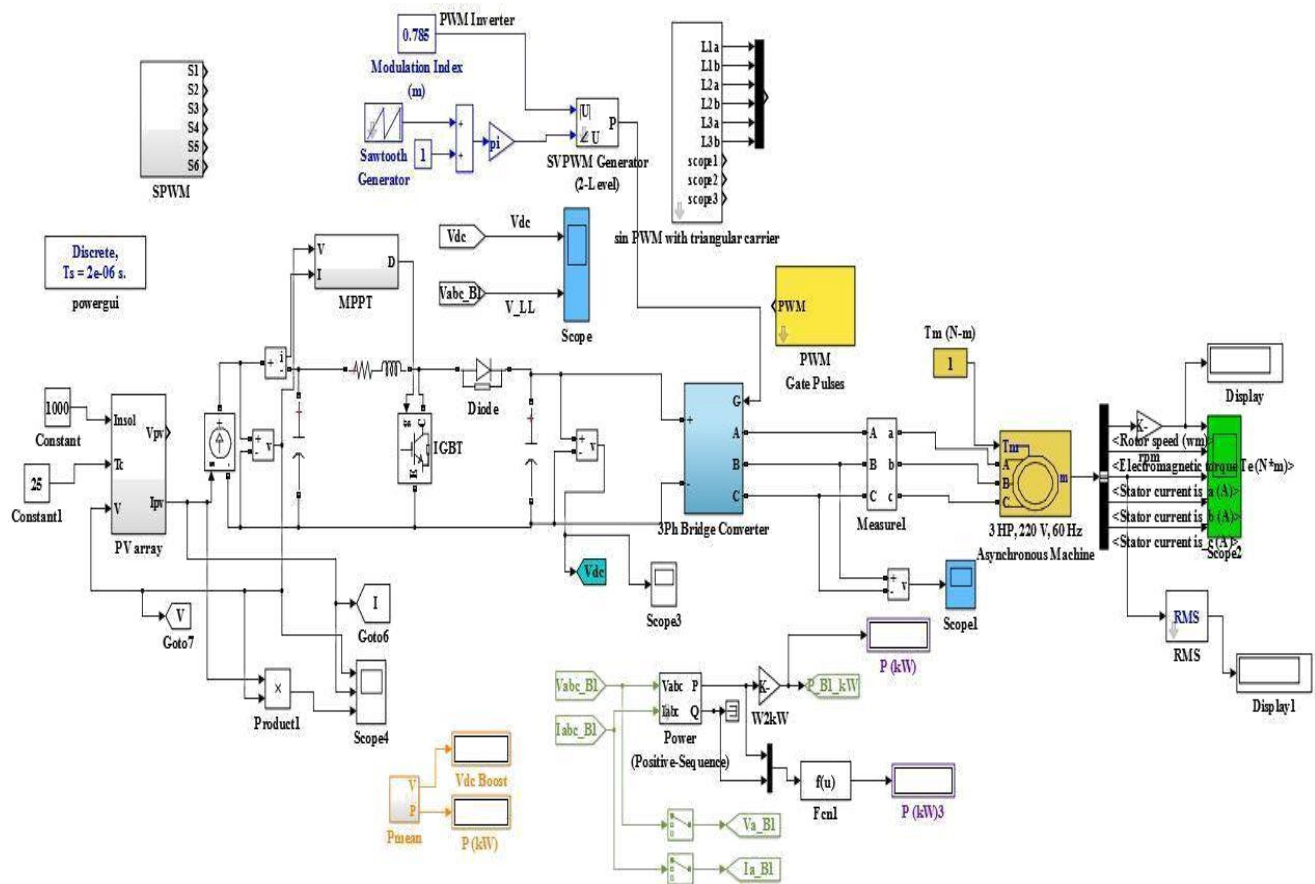


Figure 5.14 the whole system diagram with PV module

The above system shows the circuit for three inverters so we have also designed the energy management system for complete system.

5.5 Energy Management System

We have designed the energy management system for a single-phase system which measure the voltage, current of system and measure the power.

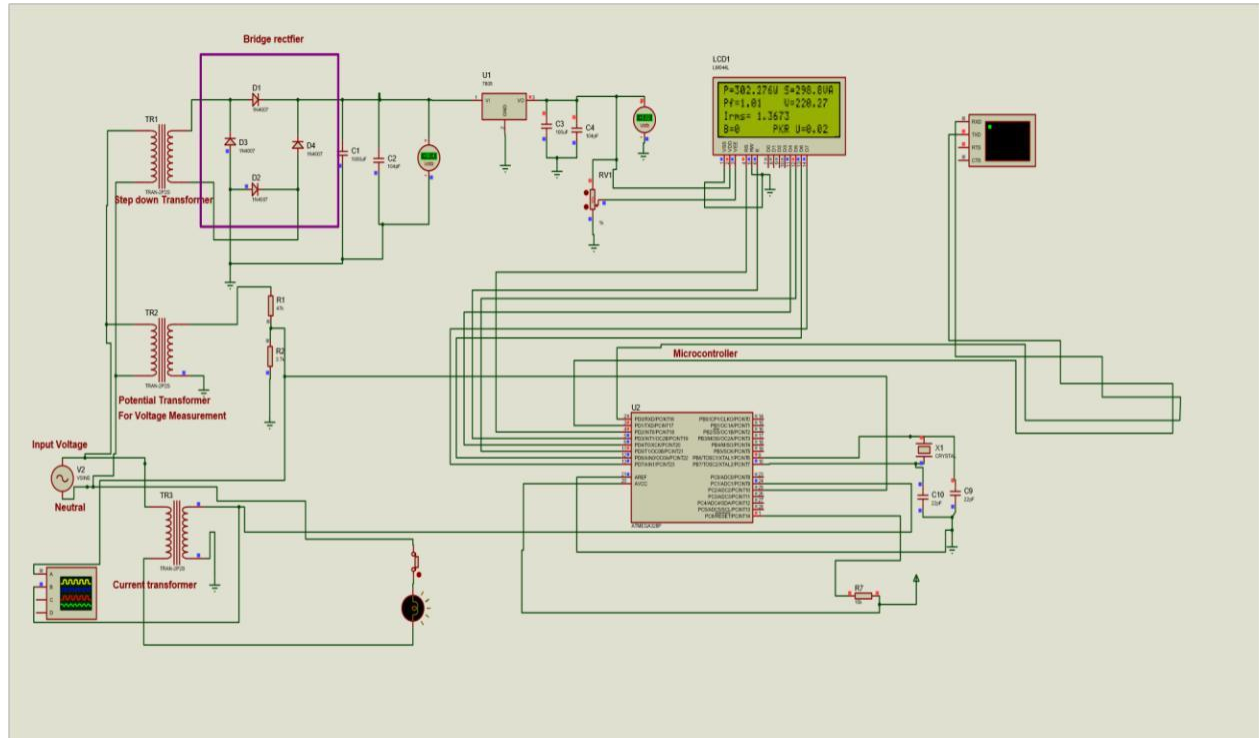


Figure 5.15 Energy management system

The above simulation which we have designed in proteus because proteus provide us real time simulation in which we can implement directly on hardware.

CHAPTER 6

RESULTS AND CONCLUSION

We have tested our system on MATLAB and proteus as well. The system is based on single phase and three phase inverters.

6.1 Results of single phase inverter

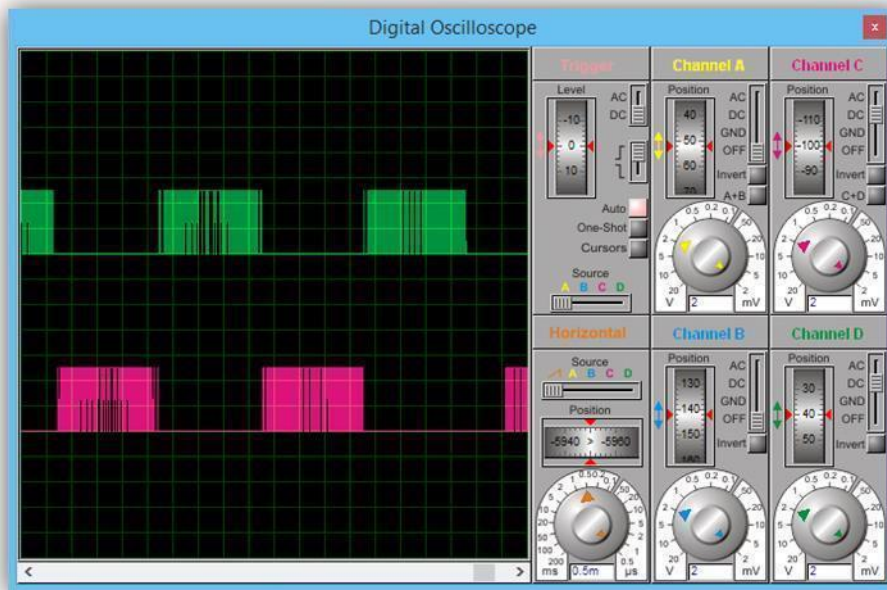


Figure 6.1 SPWM signal of microcontroller

We have generated the signal for gate of MOSFET using arduino microcontroller. The SPWM signal is of 10KHz because we need to convert the system from square wave to sine wave.

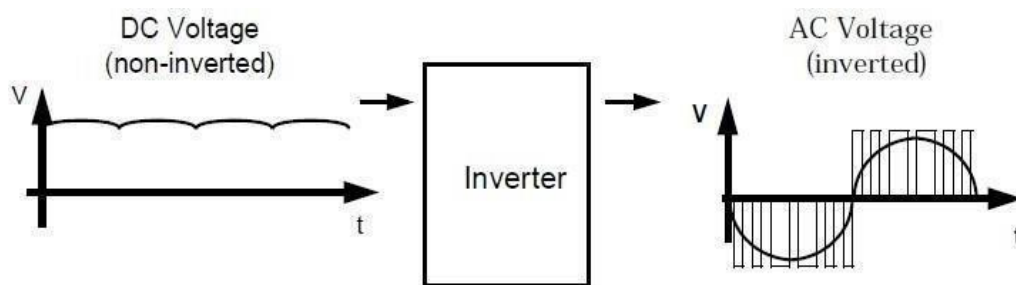


Figure 6.2 Inverter principle

The above diagram shows the inverter principle.

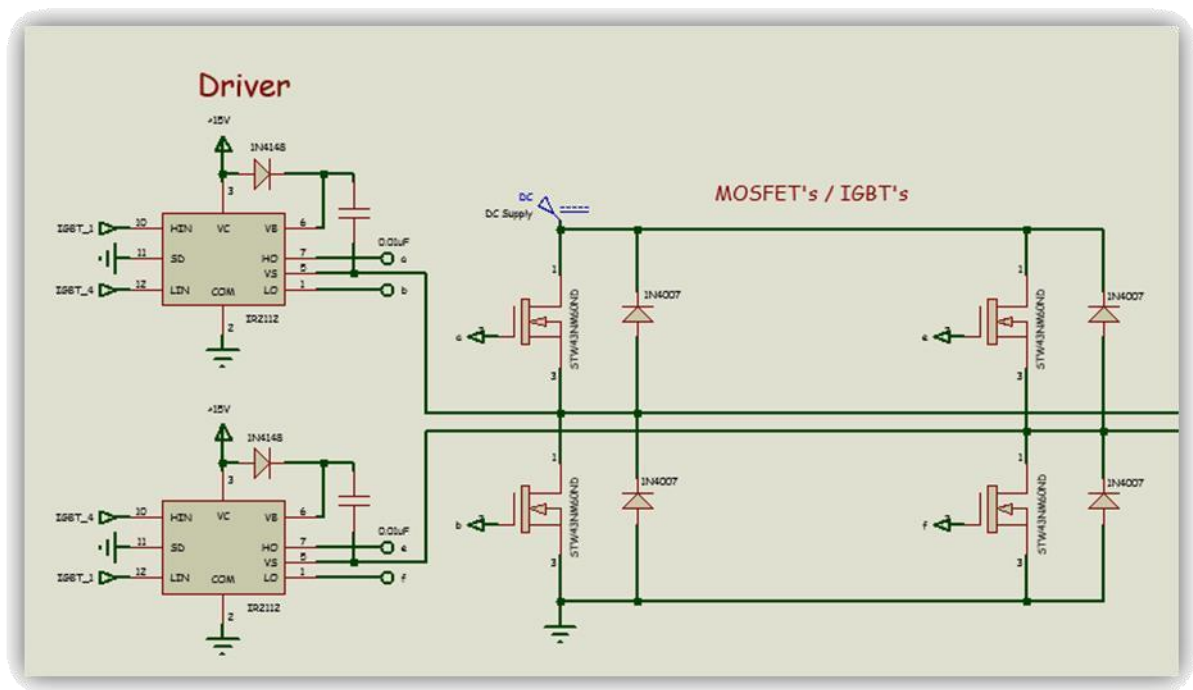


Figure 6.3 Single phase inverter circuit

The above diagram shows the simulation of single phase inverter in which the gate driver used for driving the gate of MOSFET.

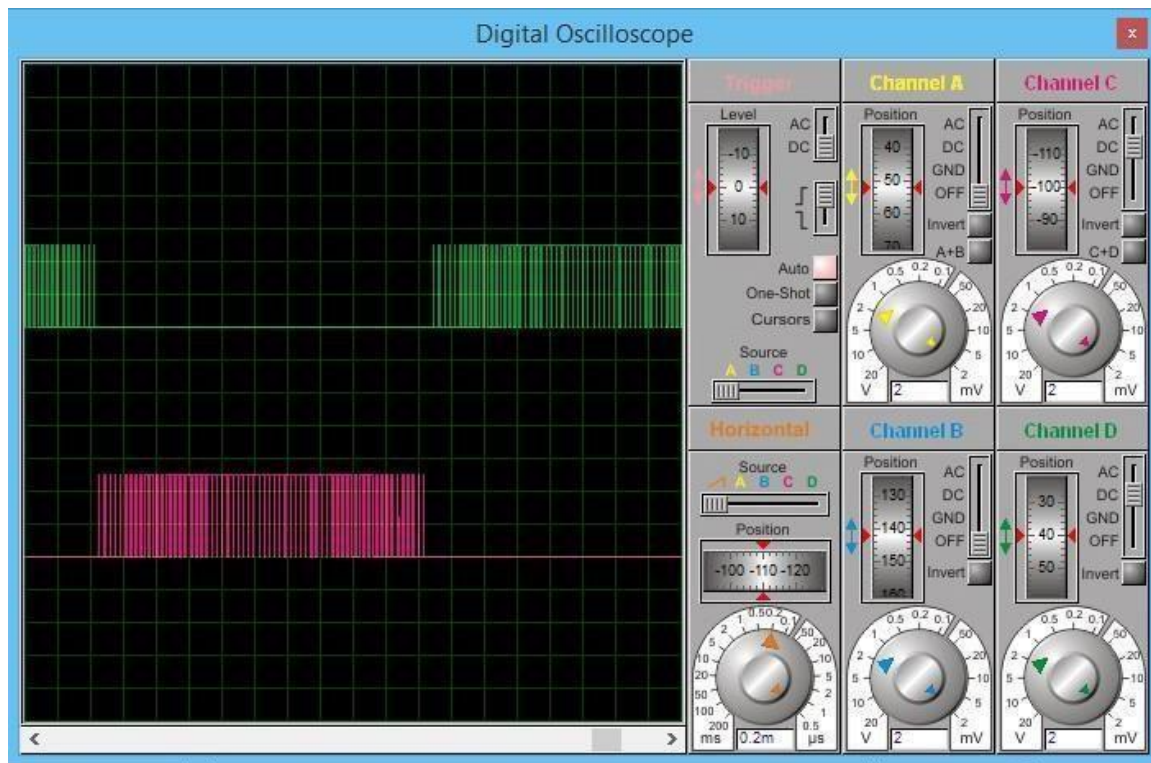


Figure 6.4 SPWM signal of gate driver

This diagram shows the output signal of gate driver circuit which amplitude is 12V amplitude.

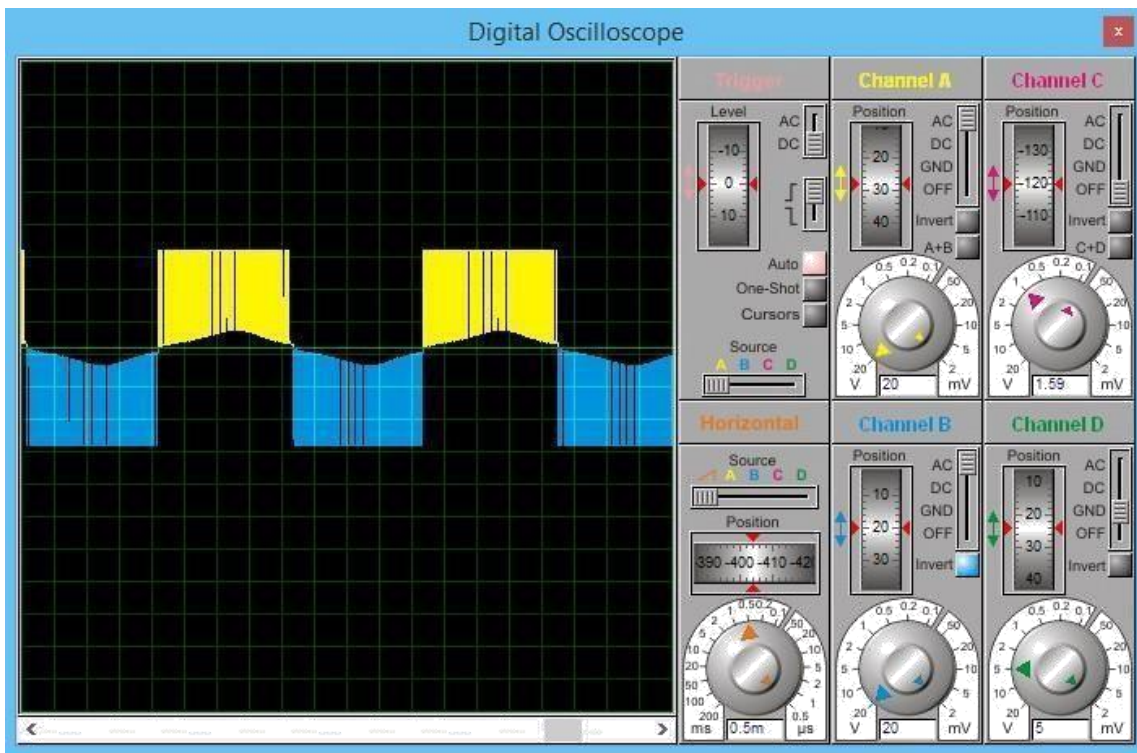


Figure 6.5 Output signal of inverter without filter

This diagram shows the SPWM signal on single phase inverter. In which the wave is about square wave.

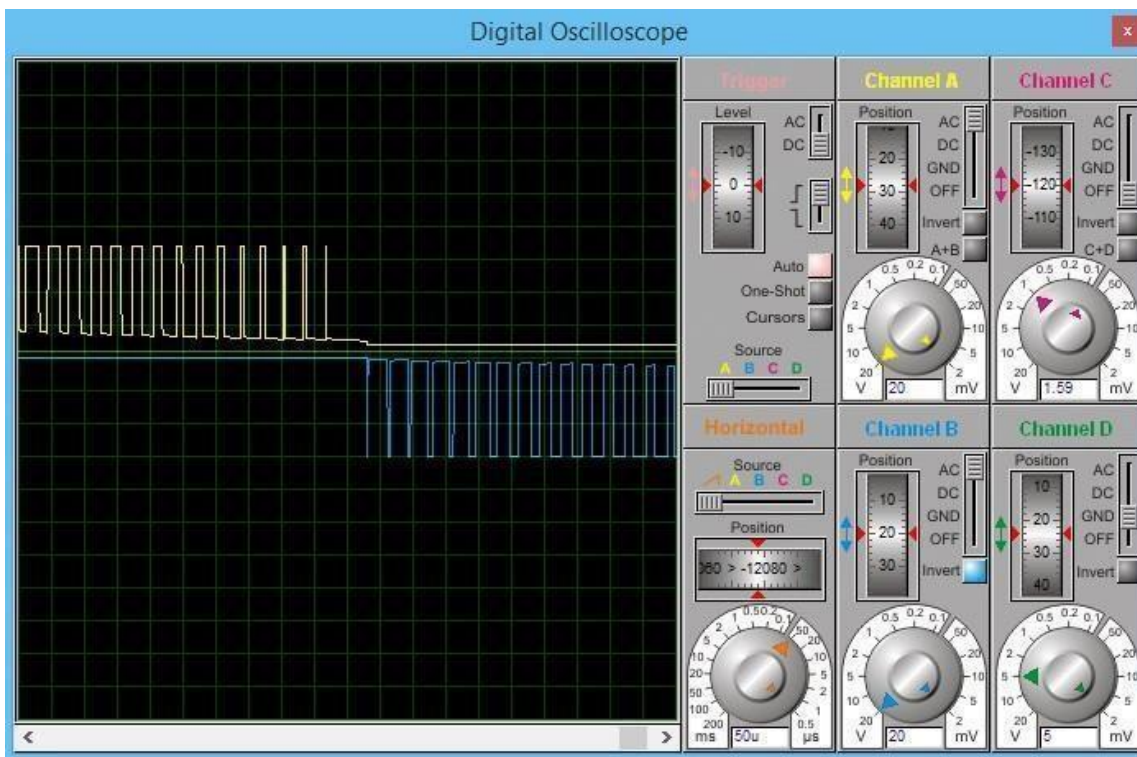


Figure 6.6 Output signal of inverter

This diagram shows the unfiltered output of inverter in which a modified sine wave signal is shown above.

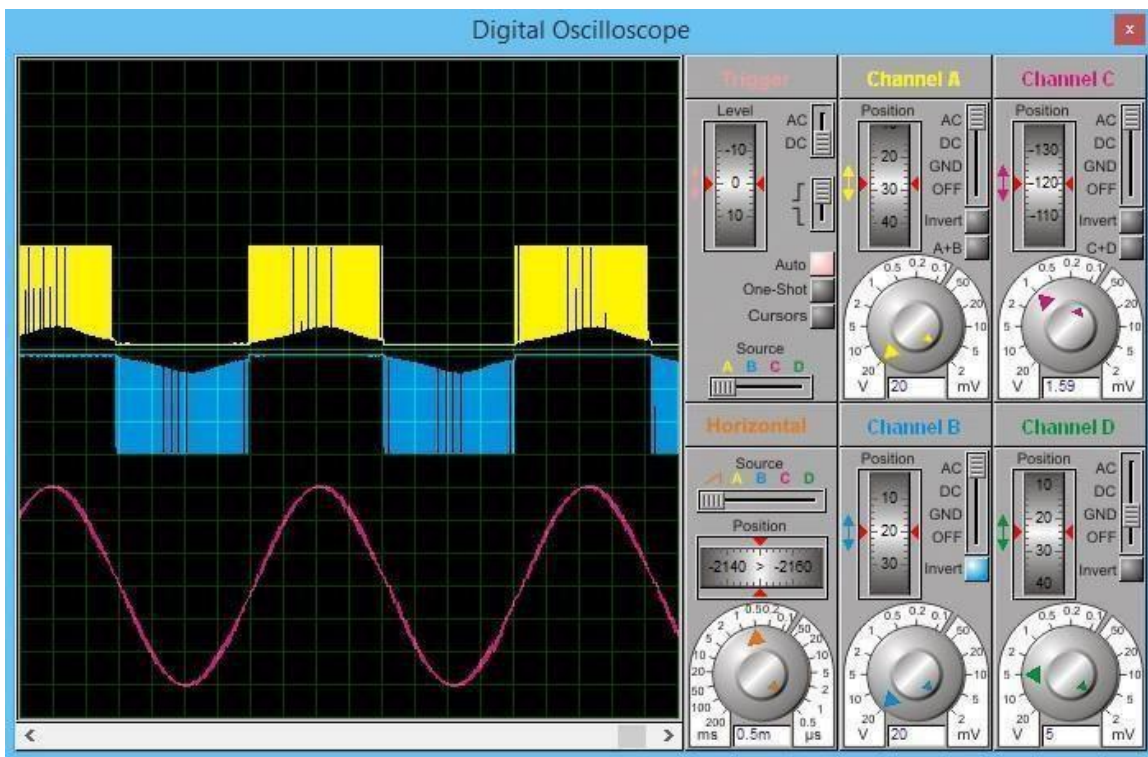


Figure 6.7 Two output signal of inverter

One wave form shows that the SPWM signal and the other wave shows output of sine wave.

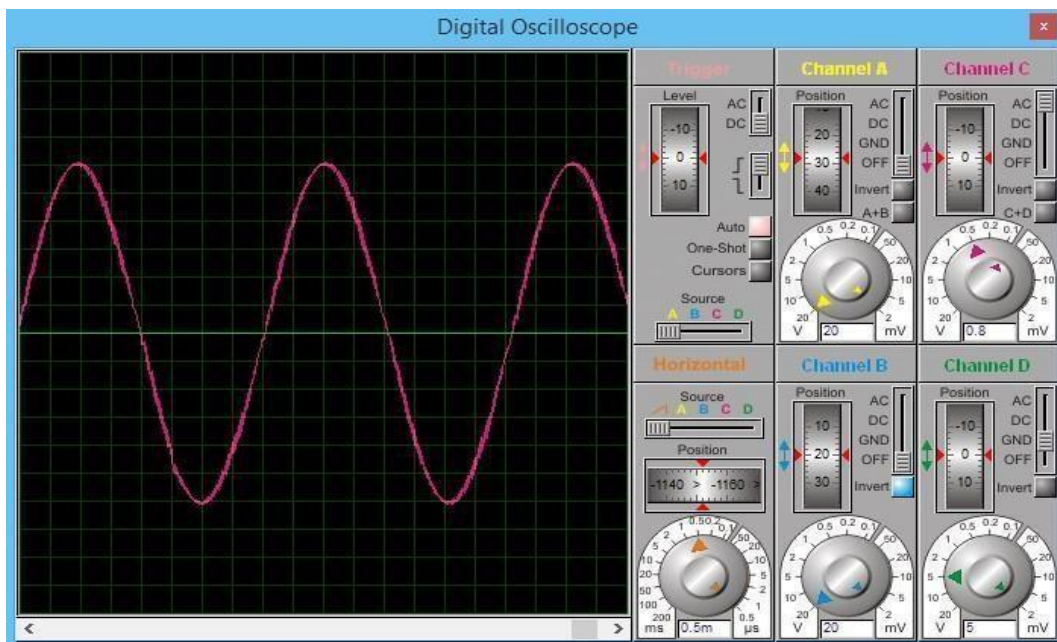


Figure 6.8 Pure sine wave signal of inverter

The above diagram shows that the pure sine wave inverter of single phase.

6.2 Results of three phase Inverter

The output of three phase inverter is shown below

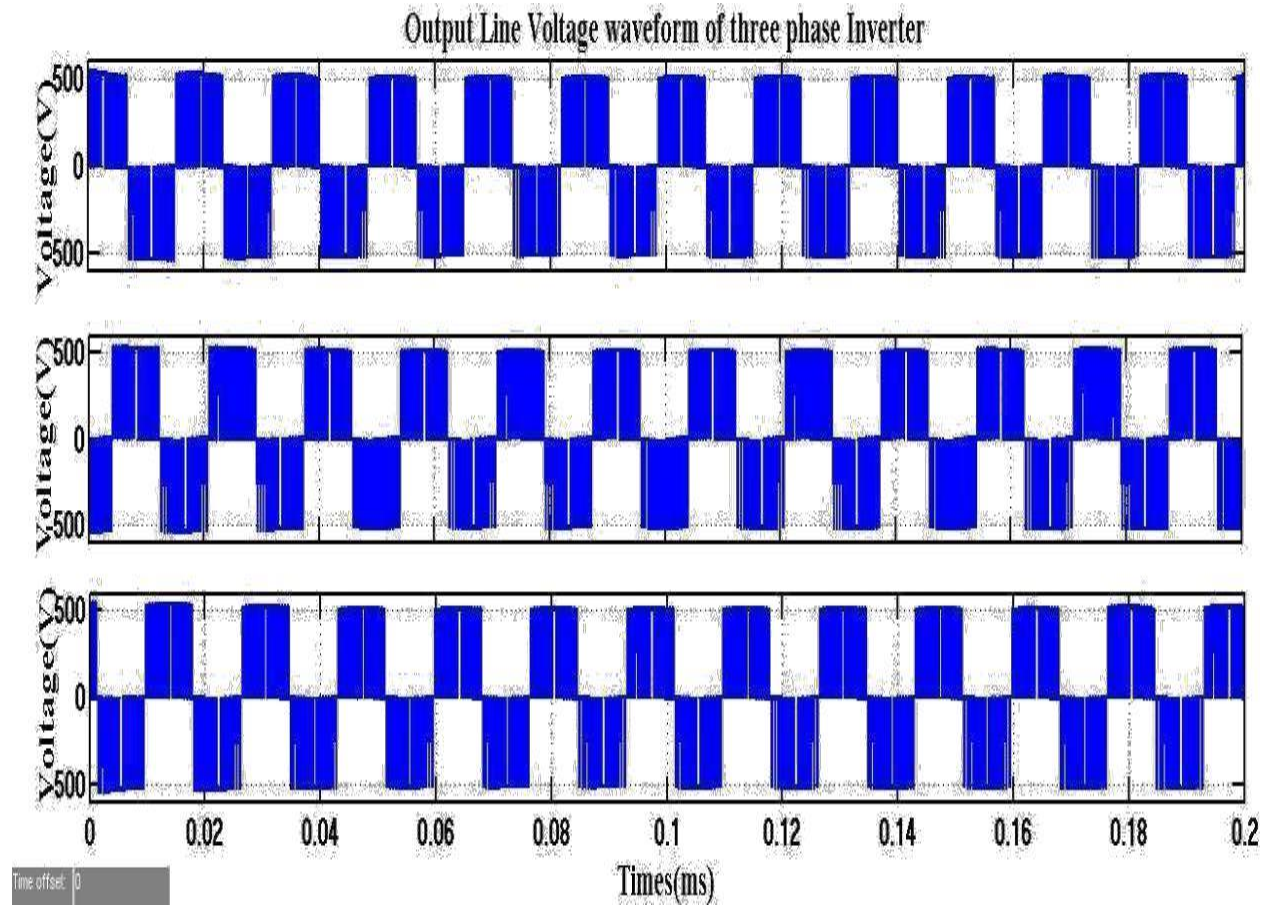


Figure 6.9 Three phase inverter output

The line to line voltage is shown in figure above and the three phase voltage is shown above the output is shown without filter and the three is phase shift of 120 degree. This output contain harmonic distortion the output is not pure sine wave.

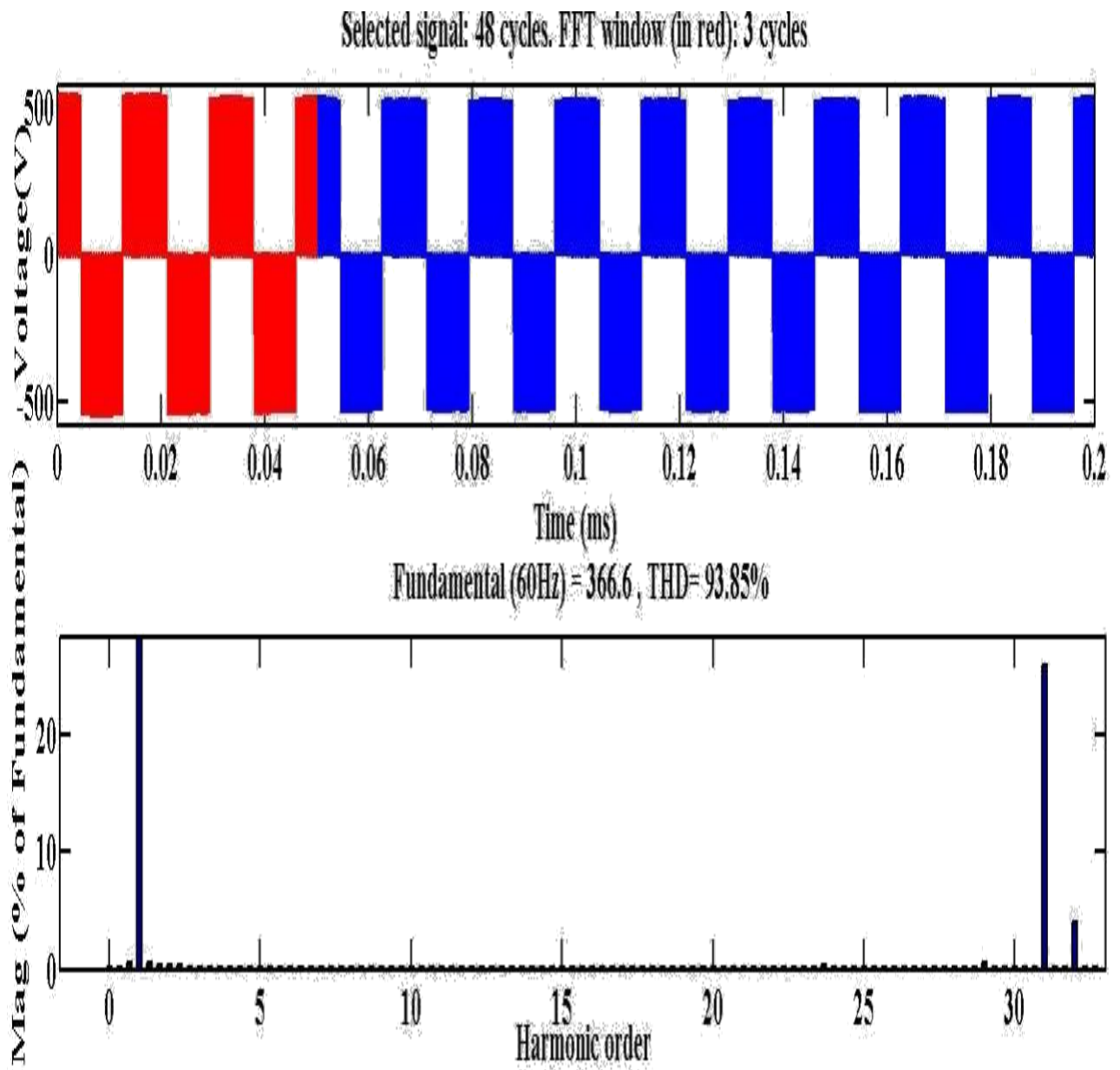


Figure 6.10 FFT analysis of the three line voltage of three phase inverter.

The fft analysis is shown in figure above with different frequencies like we have tested on 50Hz and 60Hz. The output THD of voltage is 92%. And its fundamental components has value of 366. The THD filter is designed with a very low cost.

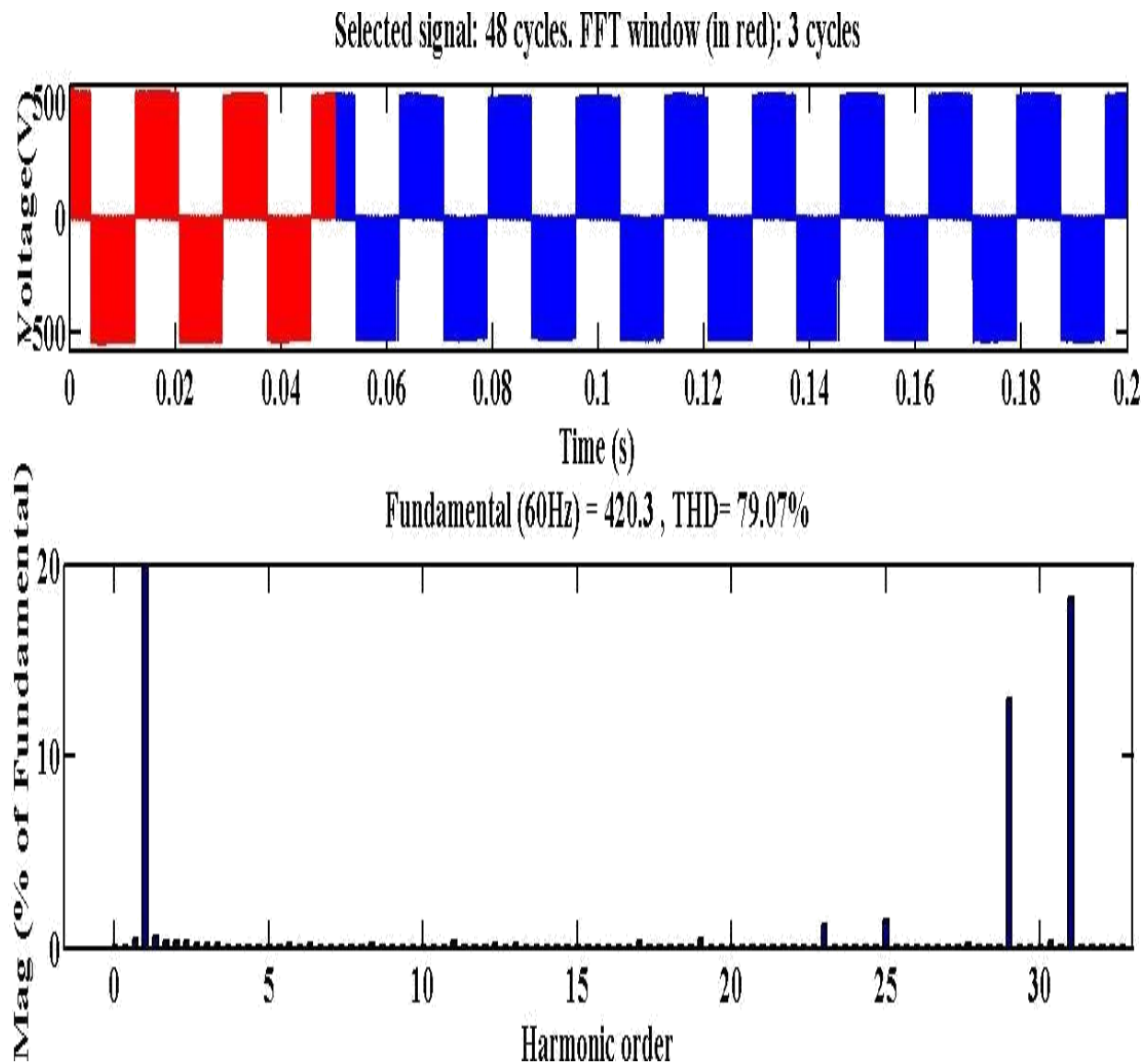


Figure 6.11 FFT analysis of line voltage by SVPWM

The FFT analysis for SVPWM is shown above in which there is very low THD. The analysis is done using different frequencies and see that there is a very good output voltage. The output THD is very low which improve the efficiency of inverter.

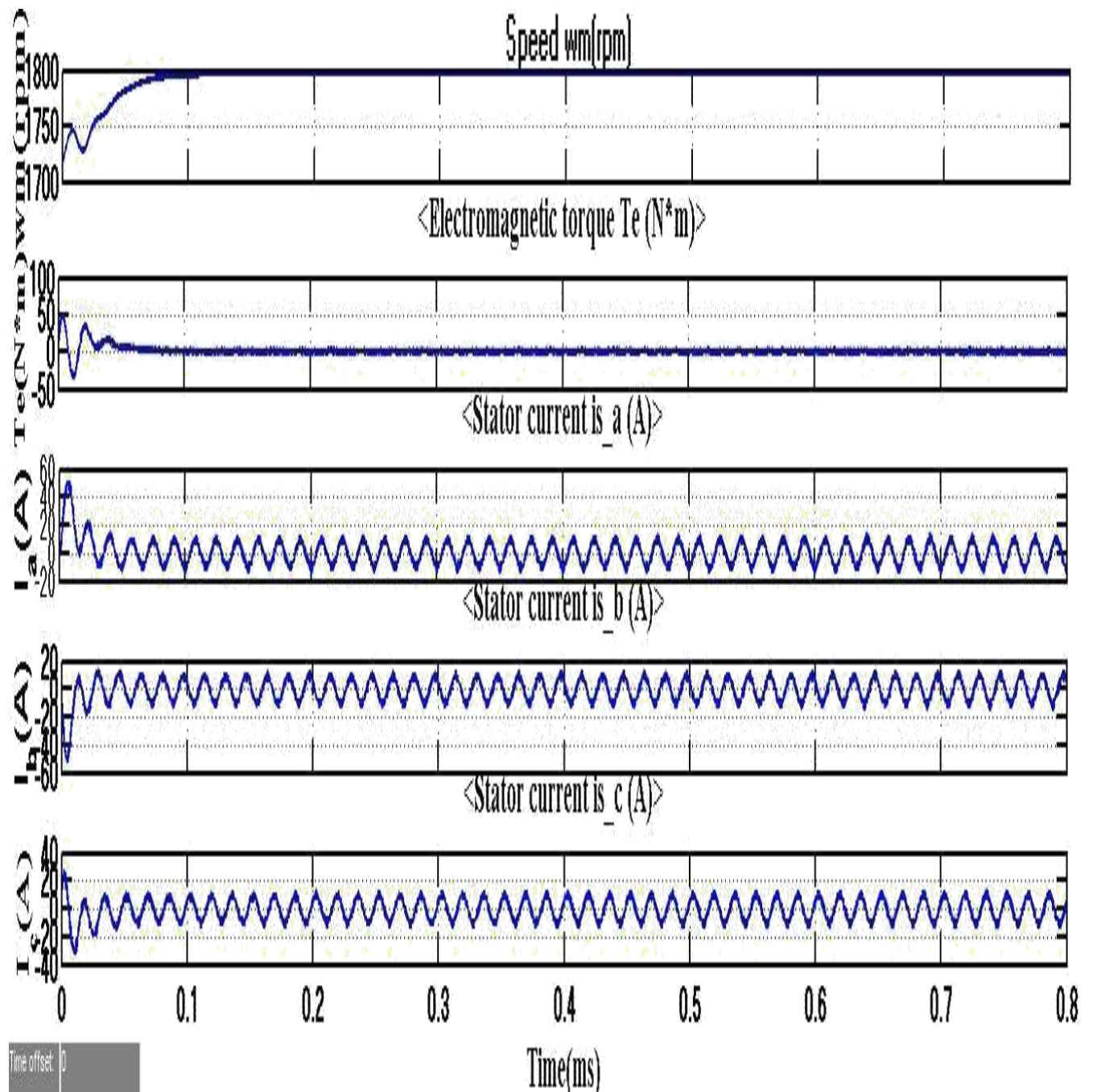


Figure 6.12 Relation of torque, speed and three phase stator current.

The above figure shows the little oscillation in output current, because the output has little oscillation as for inductive load is concern.

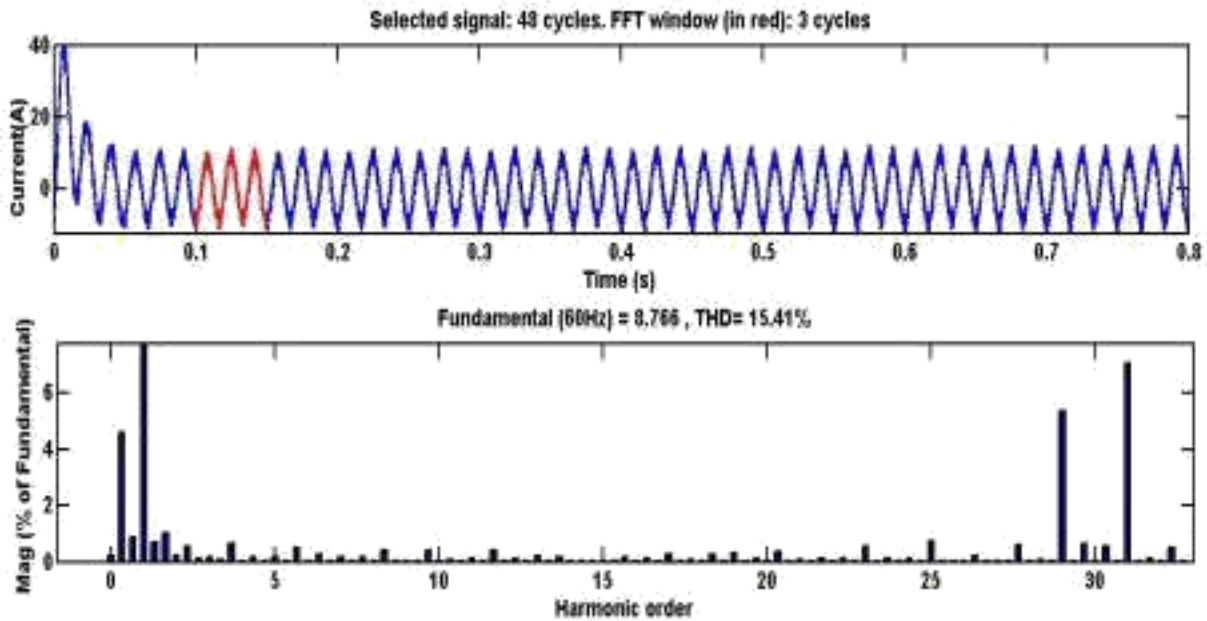


Figure 6.13 THD at switching frequency of 1.98 KHz.

We have designed a very cost effective LC filter which is used to reduce the THD and also improve the efficiency of inverter.

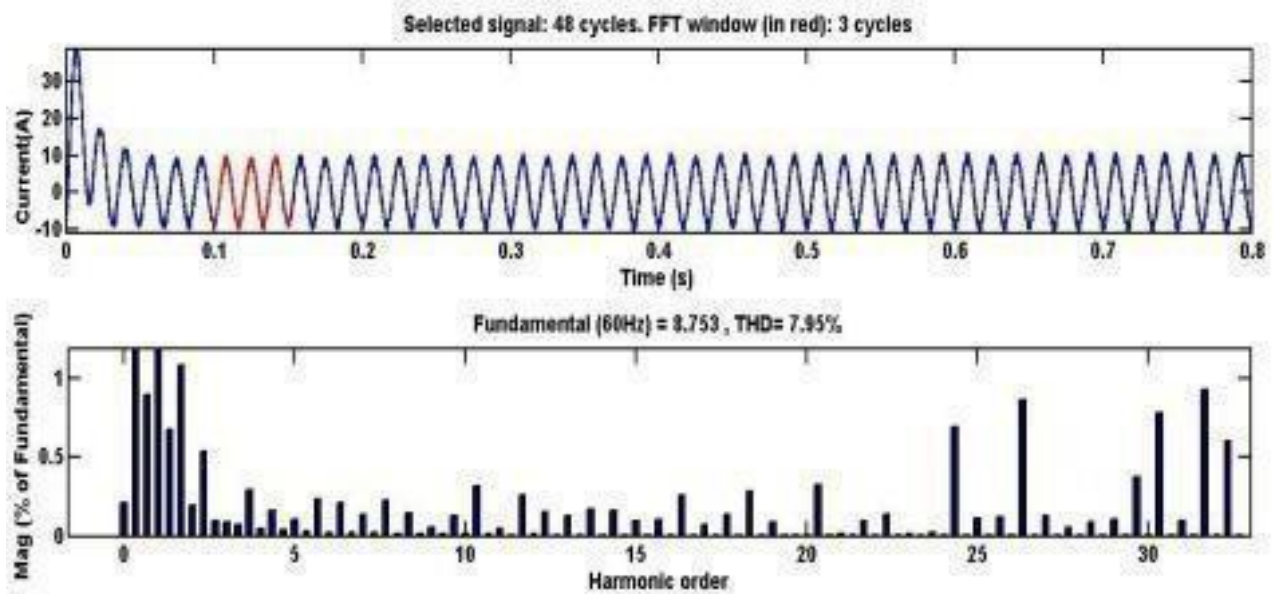


Figure 6.14 at frequency 3.9 KHz.

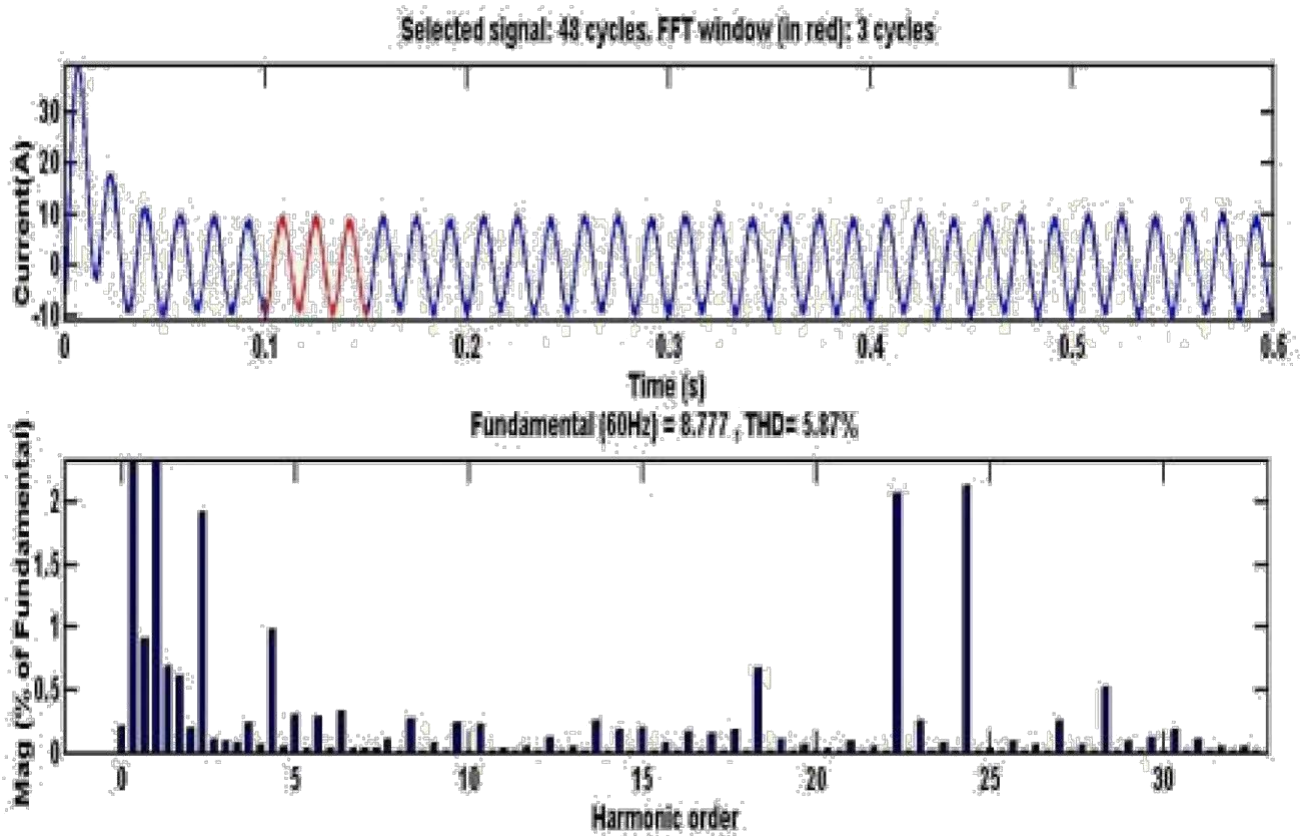


Figure 6.15 At frequency 5.7 KHz

The above figure shows the THD on inductive load and the filter improve the output.

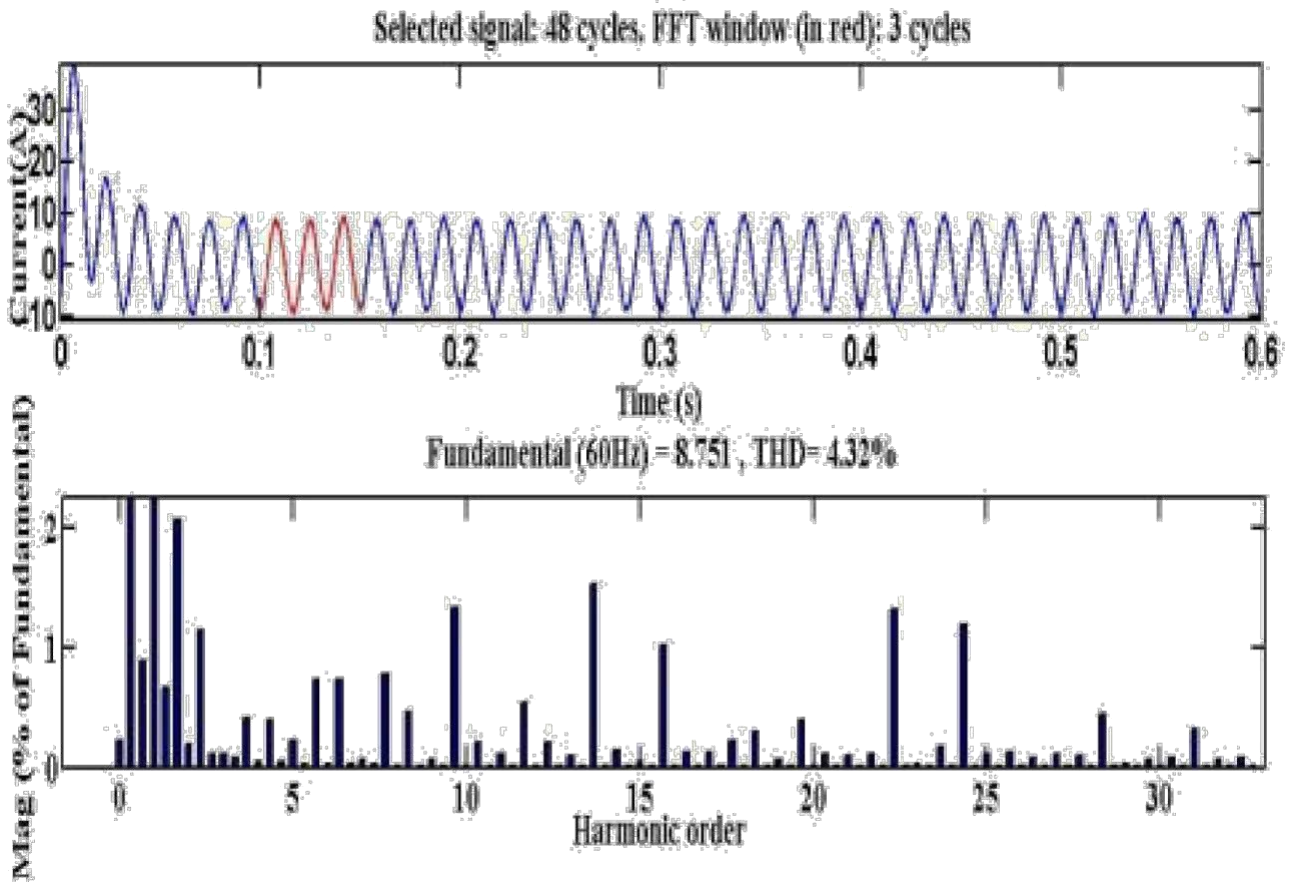


Figure 6.16 At frequency 9.3 KHz.

The THD calculated at the inductive load is almost 4.5% which is very low and the efficiency inverter is very good which reduce the losses of inverter.

MI	THD (%)	Fund. Component	h29	h31
0.5361	132.292	252.11	6.871	13.381
0.6352	114.821	297.84	7.843	15.525
0.7251	101.501	338.55	8.852	17.262
0.7851	93.542	365.96	9.471	18.371

Table 6-1: THD of Line voltage Vab by SPWM

The above table are shown the value of THD and compare the value of THD with SPWM and SVPWM.

MI	THD (%)	Fund. Component	h29	h31
0.934	60.43	495.3	14.47	20.37
0.953	57.95	505.2	14.56	20.65
1	52.42	527.4	15.01	21.17

Table 6-2: THD of Vab in over modulation region

The above table show the value of THD of SVPWM and also tell the value of THD with index.

PWM Technique	P _{in} (W)	P _{out} (W)	Efficiency η
SPWM	770	590	76.6
SVPWM	770	680	88.3

Table 6-3: Efficiency comparison by using both techniques

Induced Torque(Nm)	1	2	4	5	6
Total Harmonic Distortion	31.5	31.3	31.0	30.7	30.2

Table 6-4: Relation of THD with induced torque

Table 6-4 shows the efficiency comparison of both techniques. Experiment results reveal that SVPWM has lower loss as compared to SPWM.

CONCLUSION

We have completed the simulation of dc hybrid micro grid for reefer ship in MATLAB and proteus. Basically we did the simulations in which we used renewables (solar panel, wind turbine), inverters, Lc filters, DQ transformation and PWM generator to generate switching sequence. We have also designed the stabilization circuit for the stabilization of the DC bus voltage. After that we have designed energy management system for reefer ships. Energy management system measures the real pow, apparent pow, pf, Irms values. Significance of our energy management system is that it measures the value at run time which is very much important in maritime purpose.

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