DESIGNING AND MODELLING OF PV CELL ARRAY FOR A GRID CONNECTED SOLAR POWER GENERATIONUSING MATLAB

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A thesis submitted in partial fulfilment of the requirements for the Degree of

Master of Technology

(Energy Systems)

By

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Under the guidance of

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CERTIFICATE

This is to certify that the work contained in this thesis titled "DESIGNING AND MODELLING OF PV CELL ARRAY FOR A GRID CONNECTED SOLAR POWER GENERATION USING MATLAB" has been carried out by Miss.Priyangana Borah under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Compared to the traditional energy resources, photovoltaic (PV) system that uses the solar energy to produce electricity considered as one of renewable energies has a great potential and developing increasingly fast compared to its counterparts of renewable energies. Such systems can be either stand-alone or connected to utility grid. However, the disadvantage is that PV generation depended onweather conditions. Thus there is also a need for developing control techniques for three phase gridconnected PV systems including a method for DC link voltage control that stabilizes the voltage at theinverter input to insure a continuous flow of energy exchange between the grid and the PV system. An LCfilter also is necessary to filter the output current and voltage from the harmonics and protect the grid fromtheir destructive effect. This paper presents detailed modeling of the grid-connected photovoltaicgeneration system components, in Simulink / MATLAB software. Simulation results presented here validate the component models and the chosen control schemes.

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CHAPTER 1

INTRODUCTION

This chapter represents a background of solar energy followed by a short description of the current status of PV technology and grid connected pv systems.

1.1 Background of solar energy

The growth of world energy demand and the enviromental concerns lead to an increase of the renewable energy productionover the last decades.Energy sources such as solar wind or hydro become more and more popular because they produce no emission and are inexhaustible. Pv energy is the fastest growingrenewable source with an history dating since it has been first used as power supply foe space satellites.The increase efforts in the semiconductor material technology appeared in the appearance of commercial PV cells and consequently made the PV as an important alternative energy source.

One of the major advantages of pv technology is the lack of moving parts which offers the possibility to obtain a long operating time(> 20 years) and low maintainance cost. The main drawbacks are the high manufacturing cost and low efficiency(15-20%). As one of the most promising renewable and clean energy resources, PV power development has been boosted by the favourable governmental support.

According to European Photovoltaic Industry association(EPIA), at the end of 2012 the total installed PV capacity in the world has reached over 67.4 GW , with an increase of 68.5%compared to 2011. Europe stills leads the market with over 50GW of cumulative power installed with a 70 % increase in 2012. Italy became the first time the top PV market in 2011 with 9 GW newly connected capacity ,with an impressive 290% increase from 2010. This increase was a consequnce of advantageous tariffs if the systems were installed by the end of 2010 and connected untill mid 2011.Germany was the second big player on the PV market in 2011 with 7.5 GW of new connected systems with a 44% increase from 2010 where more than 80% of the installed systems were located in the LV network.

In figure 1.1 (A),the total PV power intalled in Europe at the end of 2010 is presented. The figure shows an unbalance market , where germany is leading with 24.7 GW of total installed capacity . Italy has increased its PV capacity at a total of 12.5 gw and holds the second place on the market. On the other side , Spain is third in 2011 after a low development of PV power.The rest of EU countries are still far behind but progress are expected in the future.

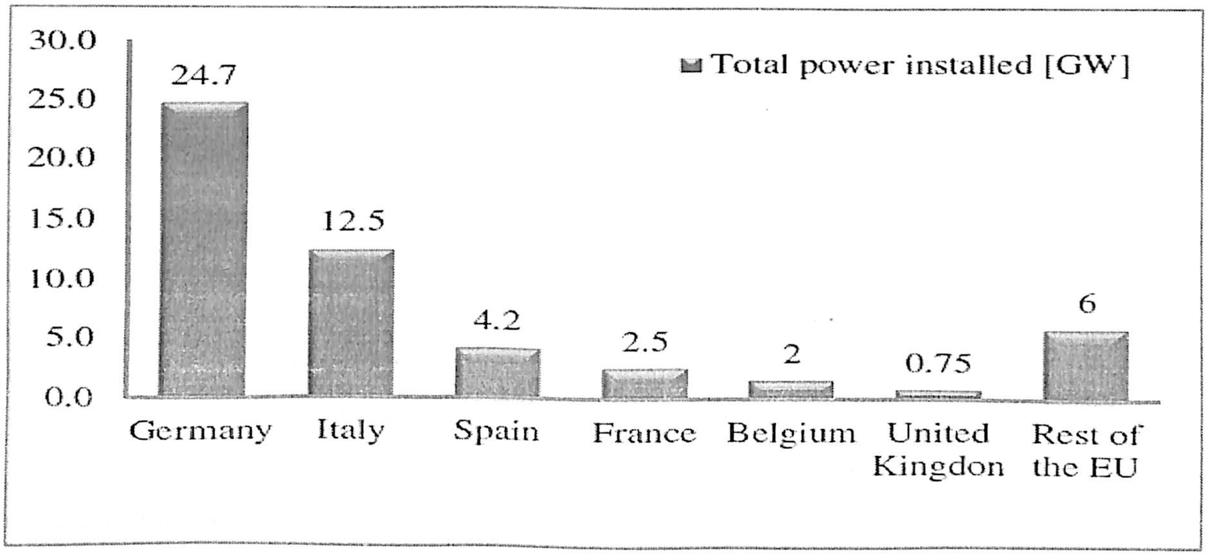

Figure 1 European total PV power intalled at the end of 2012.

The high penetration of the PV technology was induced by the continuous increase of energy price generated in traditional coal and gas power plants.PV power systems have been required to reduce cost in order to compete on the energy market , but at the bsame time to provide a great reliability. Usually the reliability of a PV system is associated with the inverter topology and the main components (switching device , capacitors) .The lifetime of a system regarding the PV panels has been approximated to be around 25 years , while in the inverter sector , future improvement are expected.

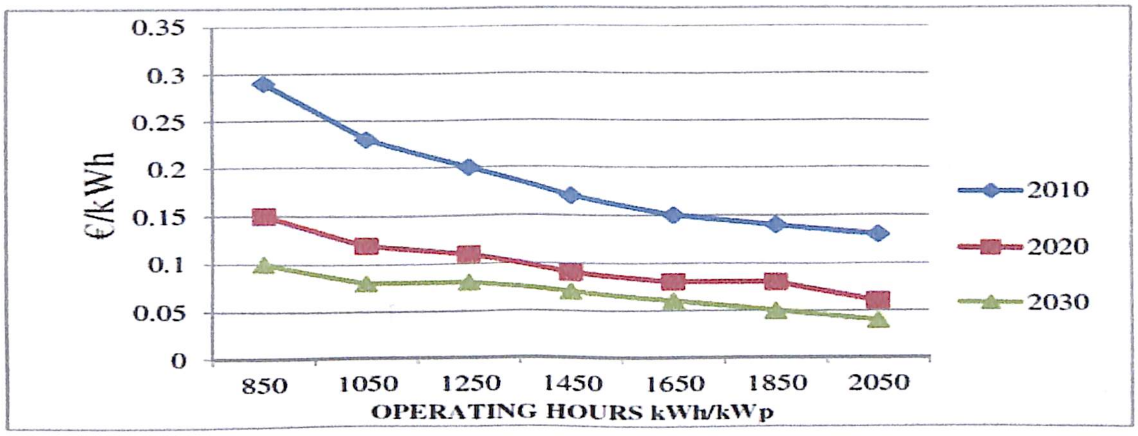

Figure 2 Levelised cost of electricity for large PV ground-mounted systems

The energy generation costs in 2010 varied from €0.15/kWh in the north of Europe to €0.12/kWh in south of Europe and Asia. By 2020, the expected generated cost for large PV systems will vary between €0.07/kWh to €0.17/kWh. Also the prices for resedential PV systems are expected to drop significantly in the next 20 years.

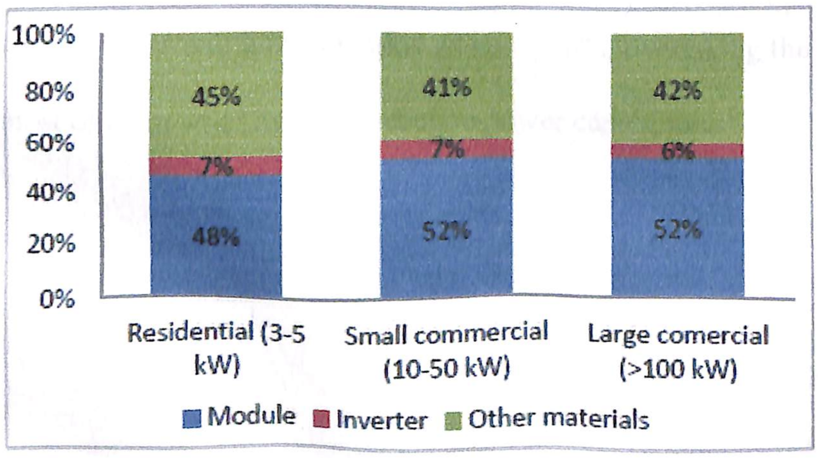

Figure 3 System percent share of each component for different power rating.

In Figure 1.1(C) ,the typical percentage contribution to total cost for a variety of specific cost components (eg: modules, inverters, installation labour, etc) are shown. Typically , PV module costs are about 50% of total installed ones, while inverters represented approximately 6-7%. Other costs such as installation labour materials, and regulatory compliances represents an important part from the total prices.

The fast expansion of PV system into the lower parts of the grid raised several concerns for grid reinforcement. In consequence , grid operators had to impose strict operational rules in order to keep LV grid under control and to harmonize the behaviour of all distributed generators connected to it in terms of reliability , efficiency and costs.

The first cost effective measure, which brought a major improvement to grid stability, was for the grid operators to suggest PV systems manufactureres to equip their products with grid support functions. It is expected that untill the end of 2015, the shipments of smart inverters in terms of MV will have a market share of 60%, overtaking the standard inverter(fig1. 1(D)). Still most of them will have only reactive power capabilities.

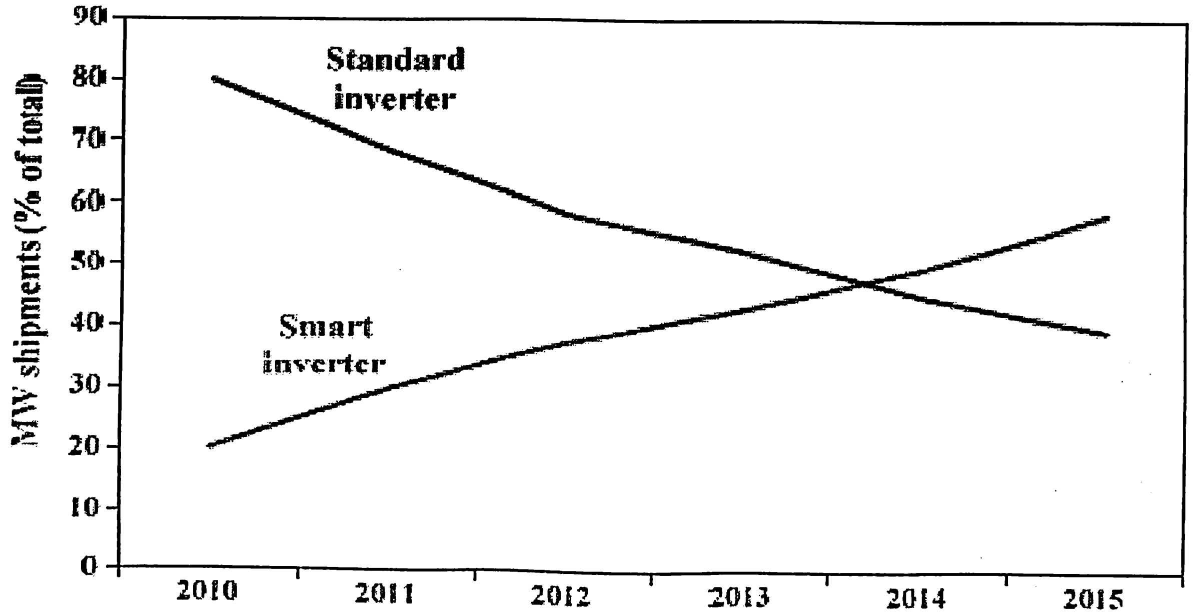

Figure 4 Total world market share for standard and smart PV invert.

1.2 LITERATURE REVIEW

Grid connected PV systems

Grid connected PV systems represents around 92% of the total PV installed power.

Thyristor based central inverters connected to the utility grid emergerd on the market in the mid 1980s. Later in 1990s ,SMA produced the first transistor based inverters. Figure 5 briefly presents the evolution of grid connected PV systems together with off grid systems upto year 2011.

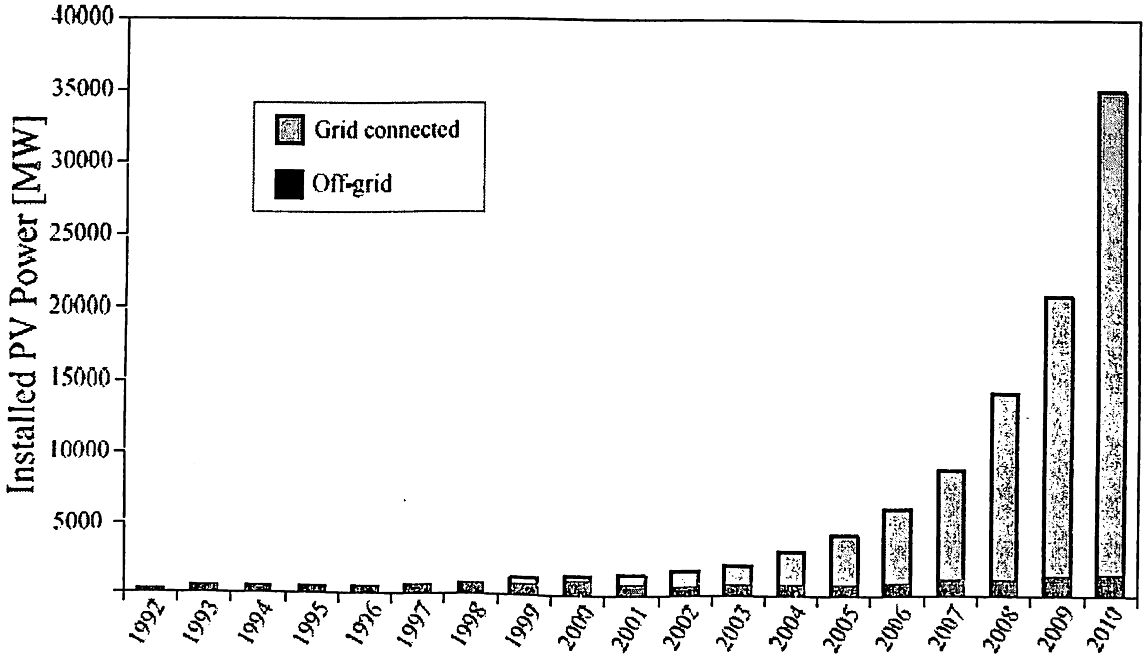

Figure 5 Cummulative installed grid connected and off-grid PV power in the reporting countries between 1992-2009

It can be observed that the off-grid development has slightly changed since 1999, whereas the installed power of grid connected systems increased slightly since 2006.

According to International Energy Agency (IEA), the PV systems can be divided into 2 main categories:

1.off-grid or the stand alone and

2. grid connected ,depending on the connection of the utility grid.

Further , a shrort description of the configuration is presented.

The stand alone systems are used in places where there are no connection to the utility grid. They provide electricity to small rural areas and are usualy used for low power loads(refrigeration, lightning) .Their power ratings are around 1KW and they offer a good alternative to meet the energy demands of off-grid communities.

Grid connected distribution systems gained popularity in the last years, as they can be used power generators for grid connected customers or directly for the grid. Different sizes are possible since they can be mounted on public or commercial buildings.

Grid connected centralized systems are specific for power plants. They produce and transform the power directly to utility grid. The configuration is usualy ground mounted and the power rating is usualy of KW rating.

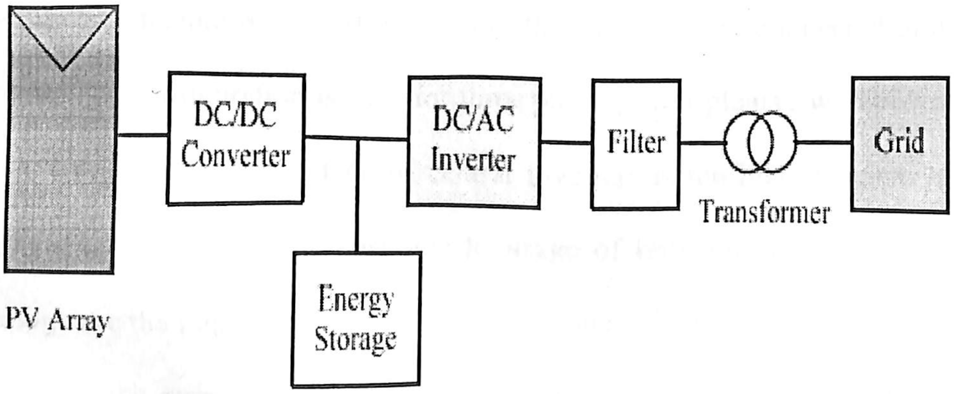

Figure 6 Component of grid connected PV systems

The typical configuration of a PV system can be observed in figure 1.2(B). Depending on the number of modules ,the pv array converts the solar irradiation into specific DC current and voltages. A DC/DC boost is used when the voltage required by the inverter is too low. Energy storage devices can be included in order to store the energy produced in case of grid support connection.The power converter is realized by a 3 phase inverter which delivers the energy to the grid. High frequency harmonics that appears due to power semiconductors are reduced by the filter. The power transformer is used only for the galvanic isolation between the pv system and the utility grid.

Topologies of grid connected PV systems:

In PV plants applications, various technological concepts are used for connecting the PV array to the utility grid. Further, the existing configurations will be explained

Central Inverters:

For this architecture presented in fig 7(a) ,the pv arrays are connected in parallel to one central inverter.The configuration is used for three phase power plants , with power ranges between 10-10000 kw.The main advantage of central inverters is the high efficiency(low losses in power conversion stage) and low cost due to usage of only one inverter . The drawbacks of this topology are the long DC cables required to connect the PV module to the inverter and the losses caused by the string diodes, mismatches between PV module and the centralized maximum power point tracking.(MPPT).

String Inverters

The configuration presented in fig 7(b) entered in the PV market in 1995 with the purpose of drawing the drawbacks of central inverters. In this type compared to the cental inverters the Pv strings are connected to different inverters.If the voltage level before the inverter is too low , a DC to DC converter can be usedto boost it.For this topology one string is connected to each inverter, therefore the need of string diode is eliminatedleading to total loss reduction of the system.the configuration allows individual MPPT for each string; hence the reliability of the system is improved due to the fact that the system is no longer dependent on only one inverter compared to the central inverter tropology.

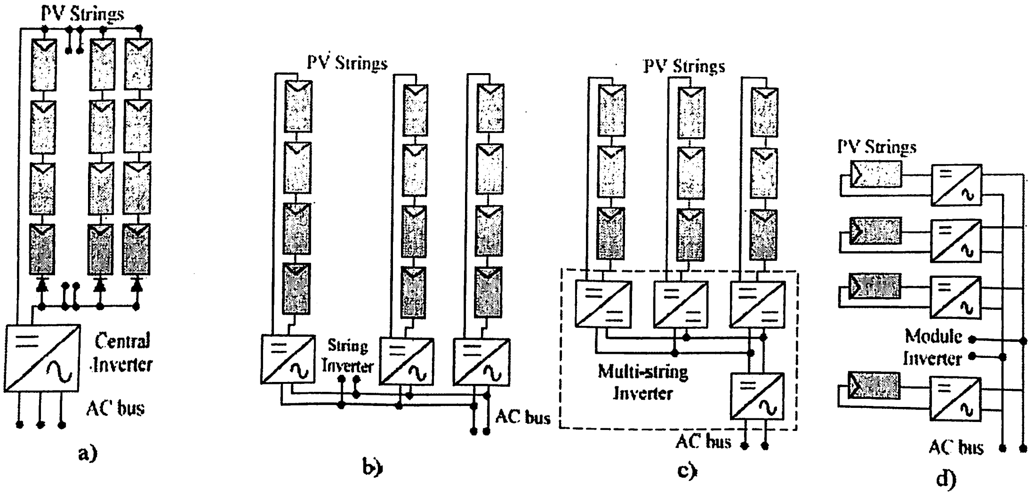

Figure 1-7 PV grid connected systems configurations a).Central Inverters; b). String Inverters; c).Multi-String Inverters; d). Module inverters [13]

Figure 7 Different types of inverter Modules present

Multi-string Inverters:

The multistage inverter configuration presented in fig7(c) became available on the PV market in 2002 being a mixture of the string and module inverters. The power ranges of this configuration are maximum 5 KW and the strings use an individual DC to DC converters before the connection to a common inverter. The topology allows the connection of inverters with different power rating and PV modulew with different current voltage characteristics. MPPT is impl;emented for each string , thus an improved power efficiency can be obtained.

Module inverters:

Module inverters are shown in fig 7(d) consists of a single solar pannel connected to the grid through an inverter. A better efficiency is obtained compared to string inverters as MPPT is implemented for each pannel.Still voltage amplification might be neededwith the drawbacks of reducing the overall efficiency of the topology (losses in DC to DC converter). The price per watt achieved is still high compared to the previous configuration.

Motivation

Over the last decades various reasons have determined a continuos increase of the PV power systems.Some of them are the price drop of the PV modules manufacturing, better social acceptance of apv parks or government support for generating energy. At the same time , the grid connected systems development requires better understanding , evaluation and perfamance of the PV invertersin case of normal and abnormal condition in the grid , as well as the quality of the energy generated by the PV systems.The increased number of grid connected PV inverters gave rise to the problems concerning the stability and safety of the utility grid, as well as power quality issues.

PROBLEM

The main problems are:

1.voltage rise problem

2.50.2 Hz problem

3.Increased harmonics

4.Increase Voltage unbalance

5.Anti-islanding

OBJECTIVE

The main objectives are:

1.Modelling the design of solar pannel

2.Designing of solar charging unit of MPPT(Maximum power point tracking)

3.Inverter design

4.Output waveform from each of the individual as well as total circuit.

CHAPTER 2

MODULE DEVELOPMENT OF PV CELLS

2.1 INTRODUCTION

Although the rapid development of photo voltaic material technology have reduced the production cost of solar PV modules , generating electricity from a solar cell is still considered as an expensive method compared with conventional fossil fuel generated electrical power.

Solar energy obtained from solar PV cell is not constant all the time . Solar energy is affected by external conditions like solar irradiance and cell temperature. Solar irradiance and cell temperature are pointed out to be affecting PV cell output to a much greater extend than the other conditions. Moreover the amount of extracted power from a PV system is a function of the PV array voltage and current set point . Due to the reasons stated above , it is crucial to maximize the output electric power available from the PV cell .Several power MPPT system have been proposed. In order to abstract maximum output power from a PV cell with the help of MPPT control, the understanding and modelling of PV cell is necessary. Providing an accurate robust modelof PV cell simplifiesthe simulation evaluation and development of PV systems. The model is able to simulate both the VI characteristic curve and the PV characteristic curve. The model is used to study different parameter variations effect on the PV array including operating temperature and solar irradiance level. This model can also be utilized to simulate MPPT for solar power system. The result of the PV characteristic curve is compared to the curve provided by BPSX 150 PV module datasheet. Matlab/simulink software is used to implement the models and obtain simulation results.

Section 2 briefly describes the equivalent circuit of solar PV cell. Section 3 reviews theexisting model and simulates the mathematical modelin matlab, showing I-V and p-V curves of the model. Section 4 provides a new simulation model for solar PV cell . The circuit consists of an ideal current source (representing he current generated due to photon interaction) abd an ideal diode.

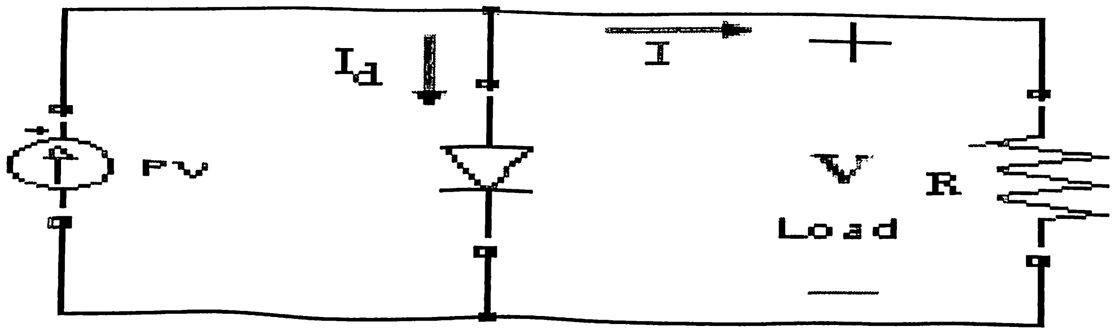

Figure 8 Simple equivqlent circuit of solar cell

Where,

$$I = I_{ph} - I_d$$

Iph= Short circuit current due to sunlight (photons),

Id= Current shunted through the diode

R= load resistance

I= Current through load

V= Voltage across the load.

In practical devices, PV cells have parameters like parasitic series resistance (Rs) and parasitic shunt resistance (Rp).

Rs represents the resistsnce of the conductor material and Rp accounts for the loss caused by a slight leakage current which penetrates through the parallel resistance path to the device.

Figure 2 shows a more practical model of PV cell

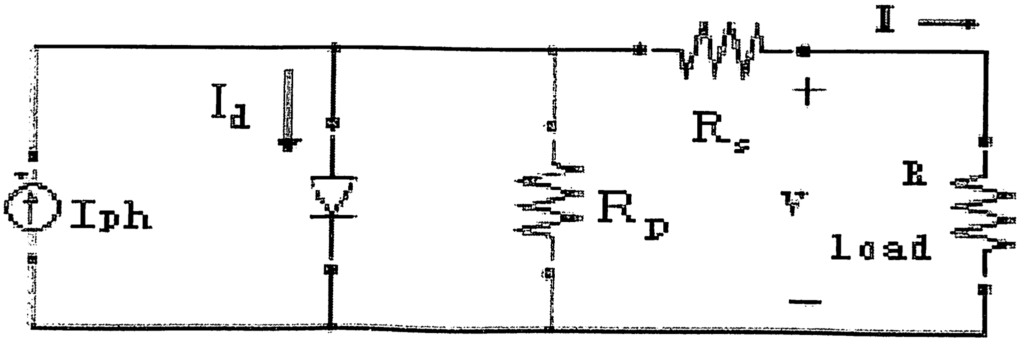

Figure 9 practical model of PV cell

2.2 Review of an existing mathematical model:

Based on the equivalent circuit provided in figure 2.1(B) , the PV cell output voltage can be defined as a function of the output current of the pv cell as follows

$$V=\frac{n*k*T_{ref}}{q}*\ln\left(\frac{I_{ph}+I_0-I}{I_0}\right)-I*R_s \qquad (3.1)$$

Where,

K=Boltzmann constant(1.381e-23J/k),

q = Electron charge (1.602e-19 c),

I = cell output current (A),

Iph= Photocurrent which is a function of irradiance level and junction temperature (and is 4.75 a in the example used in this paper),

Io= reverse saturation current of the diode (0.0002 A in the example used in this paper),

Rs= series resistance of the cell (Ω),

Tref = reference cell operating temperature(293k),

V= cell output voltage

Tref has the same unit as in (Kelvin) equation (3.1) which gives the output voltage of a single solar cell. The voltage can be multiplies with the number of solar cells in series in order to obtain the output voltage of a PV array.

The output current (I) is affected by ambient temperature and solar irradiance level, among other factor such as the cell load. The effect of the change in T and S (irradiance level) should be included in the mathematical model of the solar cell. If ambient temperature or sun's irradiation changes, the solar cell will operate under a new temperature. The cell will have a new output voltage and photon current. These effects should be clarified in the model of solar cell. Based on the present model the effects are represented by two coefficients Ktv and Kti.

$Ktv = 1+\beta t*(Tref - T)$ .... (3.2)

$Kti = 1+\gamma t*(T-Tref)/Sref$ ....(3.3)

Where,

$\beta t = 0.004$,

$\gamma t = 0.065$,

$Tref = 293K$.

A change in solar irradiance can also cause a variance in the solar cell operating temperature and photon current . So the change in solar irradiance level can be represented by two coefficients Csv and Csi.

$Csi = 1 + (1/Sref)*(S - Sref)$ ....(3.4)

$Csv = 1 + \beta t*\alpha*(S - Sref)$ ....(3.5)

Where,

Csv= cell output voltage correction factor ,

Csi= correction factor for photon current.

The constantα is the slope of the change in the cell operating temperaturedue to the change of the solar irradiance level and it is 0.2 in the reviewed model.

Considering all the correction factor , new output voltage and photon current of the cell can be obtained:

Vnew =Ktv*Csv*V ....(3.6)

Iph_new =Kti*Csi*Iph ....(3.7)

The resulting IV curve of the cell module can be drawn as shown in figure 2.2(A) .

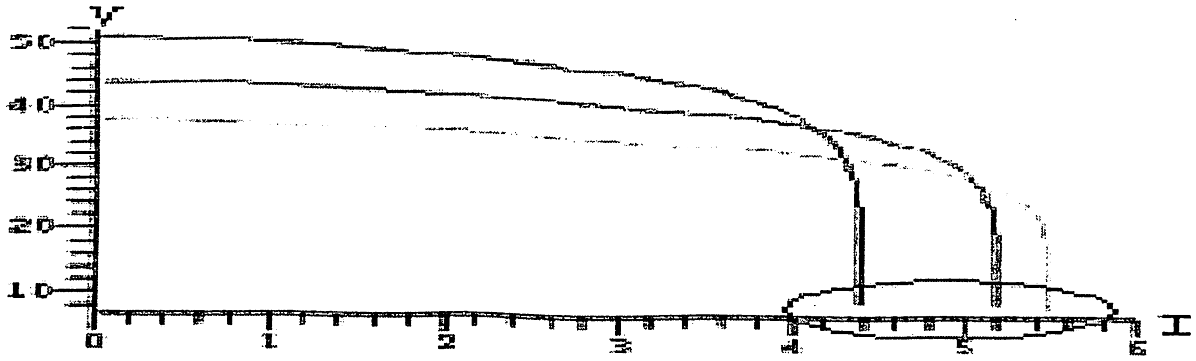

Figure 10 calculated VI curves

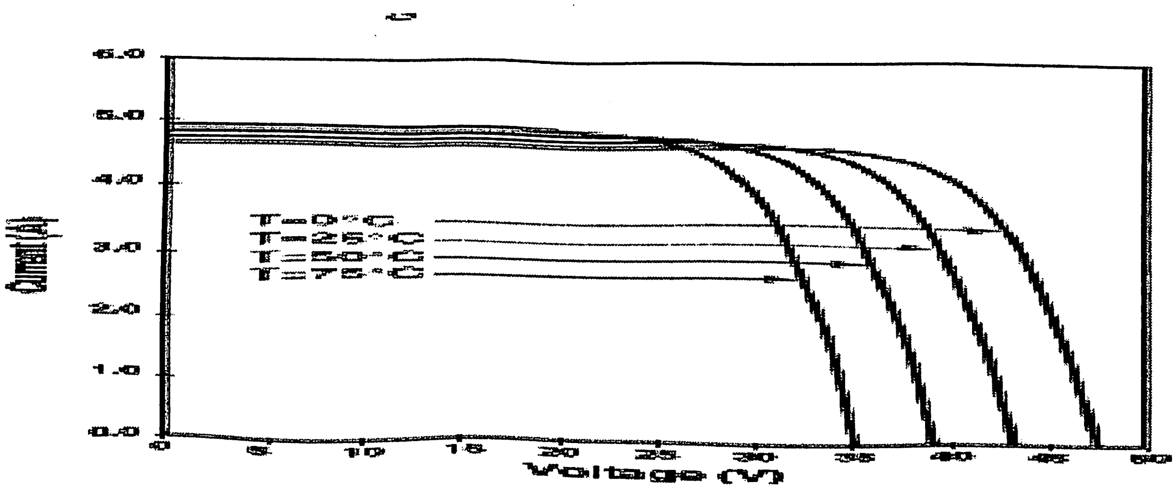

Figure 11 IV curves provided by the datasheet

Figure 10 shows the I_Vcurve provided in the datasheet of a commercial solar PV array. By comparing Fig 10 to fig 11 ,it is clear that the mathematical model doesnot provide the complete I_V characteristic of the PV cell. The I_V curve characteristic below 10v is missing.

Figure 11 reveals a main drawback of this PV cell module.This model cannot provide power to the load when the external load is operating at light voltage level,for instance 5volt.

The drawback is due to two reasons:

First,the I_V curve equation (3.1) of the model uses output current of the pv cell (I) as a feedback variable. However, when the value of I is equal to short circuit current value, V may vary from 0 to 10. The moment I hits 4.75A (the short circuit current under the standard environmental test condition), the output voltage will stop changing . Therefore , using output current I as a feedback variable to get output voltage V is undesirable.

Secondly , the issue is that this model uses several coefficients which are not provided by the real PV cell datasheets.This will also cause inaccuracy in simulation

A more accurate mathematical and a simulation model under matlab/simulink is proposed in the next session.

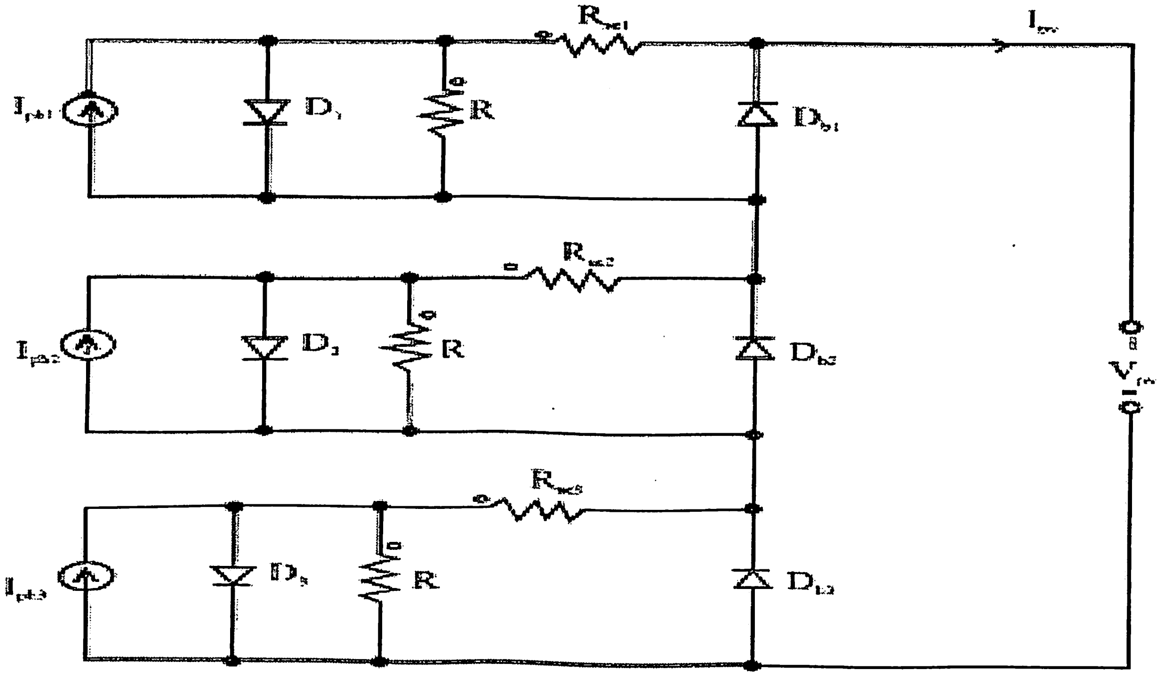

Figure 12 Series connected PV array with ByPass diode

2.3 Proposed SolarPV simulation Model

The general blockof the proposed solar PV simulator is created and shown in figure5. The PV model includes a buck converter, a mathematical calculating block and a buck controller. The PV model can be inserted into a simulated solar energy system. Normally a boost converter is connected to the PV model output. The boost converter will control the voltage applied to the load. Once the PV model starts tp supply power to the load(through the boost converter) , the output current is sensed and feed back to the OVC(output voltage calculation) block inside the PV model to obtain the theoritical output voltage of the PV module.The value of this theoritical output voltage acts as a reference voltage for the buck converter.Through buck controller the desired output voltage is generated by the buck converter and supplied to the load.

The OVC block is used to calculate the theoritical output voltage value of this model as defined by equation (4.1). This PV cell mathematical modeling method is known as "INTERPOLATION".

$$V=C_2*V_{oc}*\ln[\frac{1}{C_1}*(1-\frac{I-I_0}{I_{ph}})+1] \tag{4.1}$$

$$C_2=\left(\frac{V_{mp}}{V_{oc}}-1\right)/\ln\left(1-\frac{I_{mp}}{I_{sc}}\right) \tag{4.2}$$

$$C_1=(1-\frac{I_{mp}}{I_{sc}})*e^{(-\frac{V_{mp}}{C_2*V_{oc}})} \tag{4.3}$$

$$V=V_{pv}+\beta*(T-T_{ref})+R_s*I_0 \tag{4.4}$$

$$I_0=\alpha*S*(T-T_{ref})+I_{sc}*(S-1) \tag{4.5}$$

Where,

$\alpha = 0.0012\times$ Isc , which is the temperature coefficient of short circuit current and

$\beta = 0.005\times$ Voc , which is the temperature coefficient of open circuit voltage.

Vpv in equation (4.5) is the value of output voltage from PV model under standard testing environment.

The only set of data needed for this model is the array open circuit voltage (Voc), the array short circuit current (Isc) and the array MPP voltage (Vmp) and current (Imp) at a given point. This modeling method avoids using coefficients that are not provided by PV module datasheet and therefore the issue of unknown co efficient in the reviewed model is eliminated.

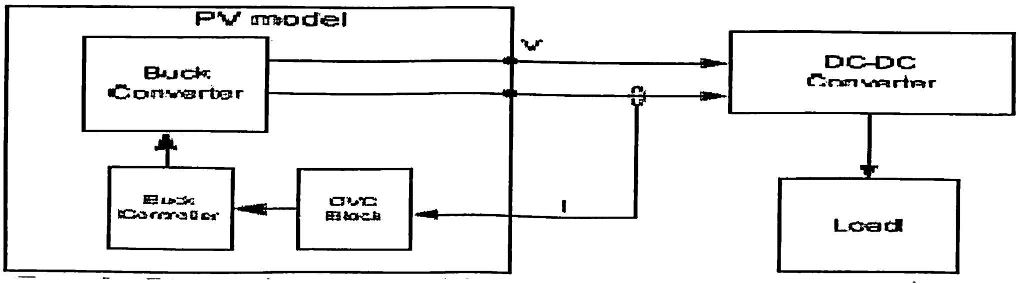

Fig2.3 (A) : Block diagram of the proposed simulator and its application

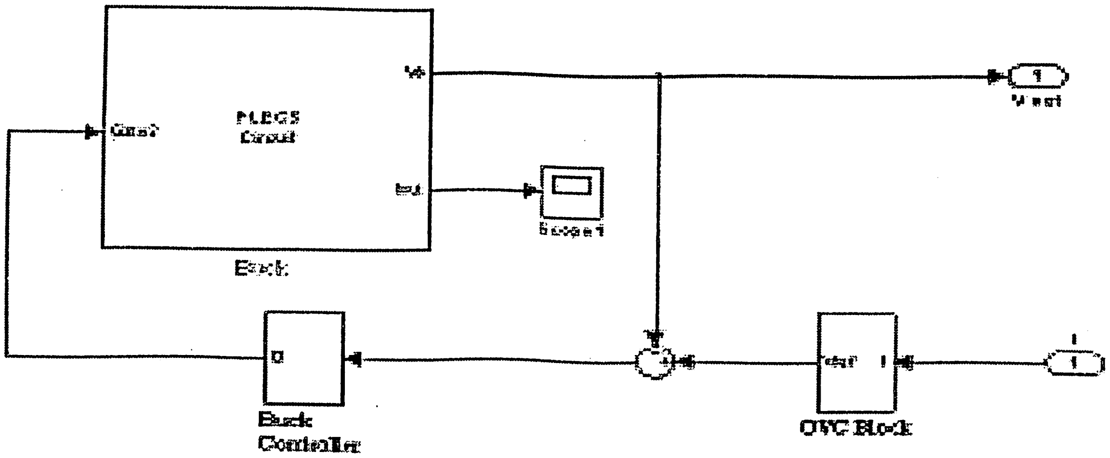

Figure 13 proposed PV model design useng matlab

The wholePV model is designed and tested using the software Matlab/simulink.The converters are implemented using a software called PLECS that is run under matlab/simulink.The output voltage of the buck converter is equal to the theoritical output voltage of the PV model.

Table 1 provides the data used as example input parameters to the simulator. By varying the input current , the ambient temperature and the solar irradiance level in the OVC block, the IV and the PV characteristic curves can be obtained as shown in figure 7 through figure 9.Figure 7 and 8 shows I_V and P_V curves of the proposed simulator under standart sun irradiation level with varying temperatures. The figure shows the I_V curves under different solar irradiation levels with the same standard ambient temperatures.

TABLE 1: Input parameters obtained from BOSX150 datasheet.

V_{oc}	$I_{sc}R_p$	V_{mp}	I_{mp}	R_s	T_{ref}	S_{ref}
43.5V	4.75A	34.5V	4.35A	0.1Ohm	298K	1KW m^2 /

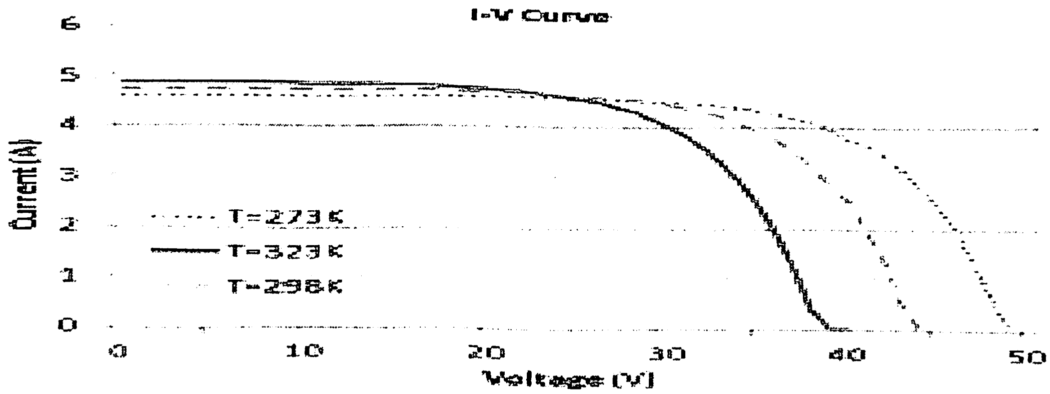

Fig. 7: I-V curve of the PV model under different temperatures

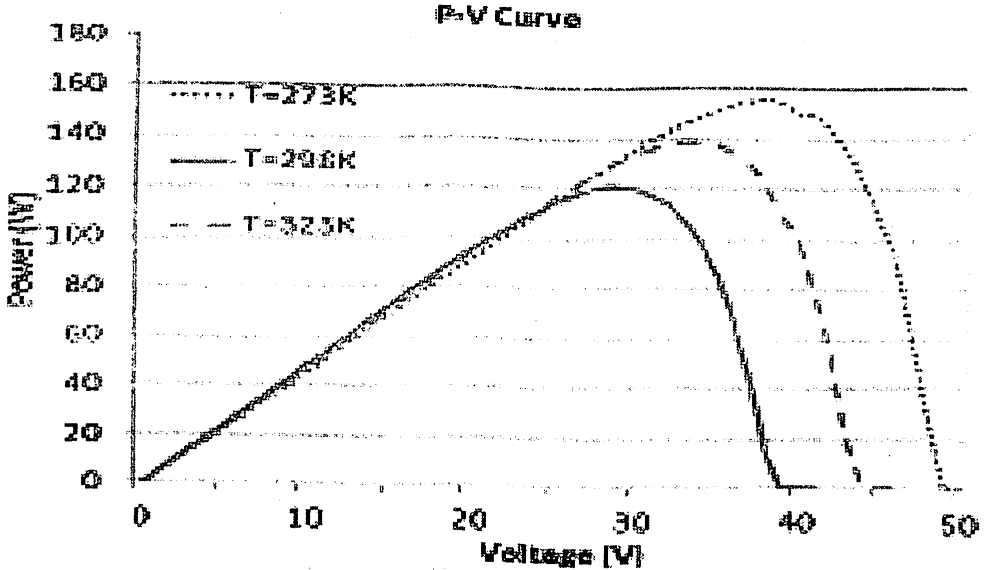

Fig. 8: P-V curve of the PV model under different temperatures

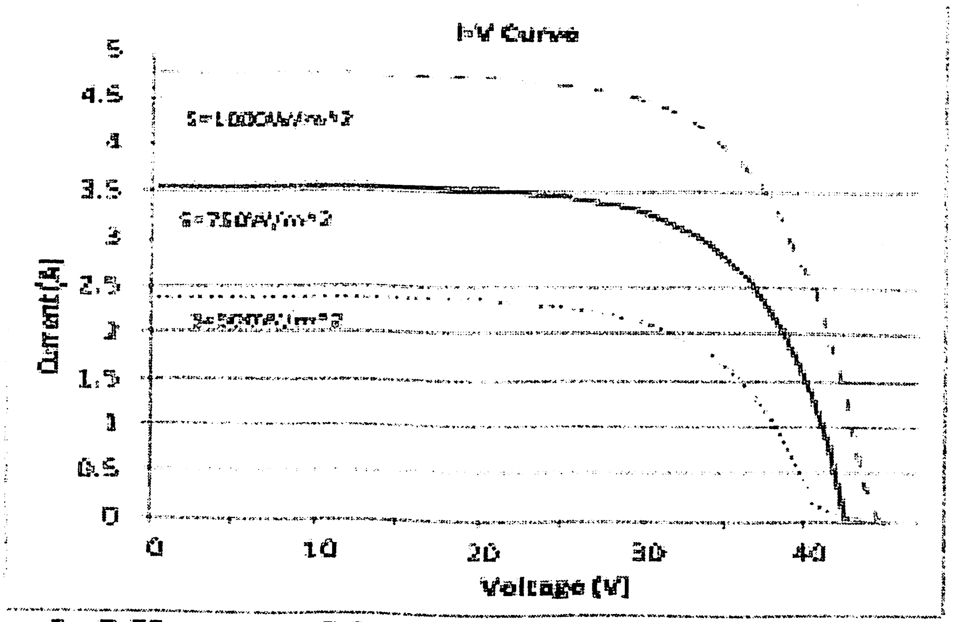

Fig. 9: I-V curve of the PV model under different solar irradiation levels

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Figure 14 The different waveforms henerated by PV cells

This new model is able to accurately simulate real PV module I_V and P_V characteristics. It can also be used to design and simulate solar PV systems with different power control methods .Further work will present results for using the presented model in the simulation and design of a complete solar PV renewable energy system.

2.4 PV Array Model

Since a typical PV cell produces <2W at 0.5 V approximately,the cells must be connected in series-parallel configurationon a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage.The equivalent circuit for the solar module arranged in Np parallel and series is shown in figure 10. The equivqlent model for the solar module and maximum power point algorithm is implemented to MATLAB. The equivalent model is described on the following equation:

$$I = N_p I_{ph} - N_p I_s \left[\exp\left(qV/N_s k T_c A \right) - 1 \right]$$

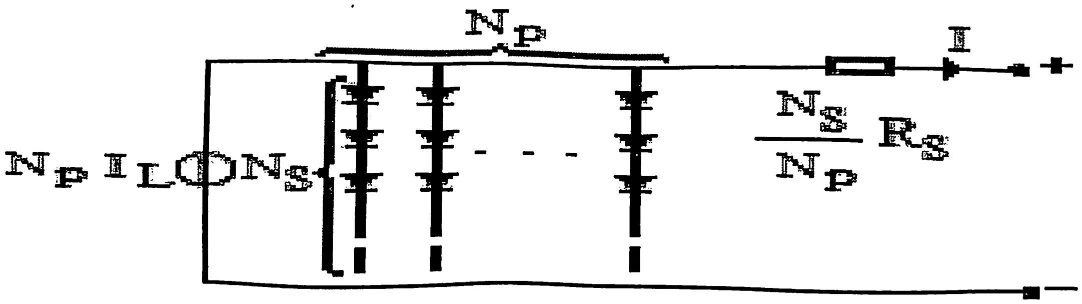


Figure 15 Mathematical model of PV array

CHAPTER 3

Matlab and Simulation Result

3.1 Simulation of PV array

In figure below 3.3 (B) ,PV array cinsists of six PV modules connected in series altogether generating 133V DC voltagge.Basically PV module can be implemented as voltage input type PV module or current input type PV module. In this paper Current input type PV module implemented in simulink. The simulink model for single PV module is shown in figure 5.PV module parameters Aare shown in tabular column 2.

TABLE 2: Tabular column for current input PV module

Input to PV module	.PV current Ipv (A) .Insolation (W/m2)
Output	.PV voltage Vpv (V) .PV output power Ppv(W)

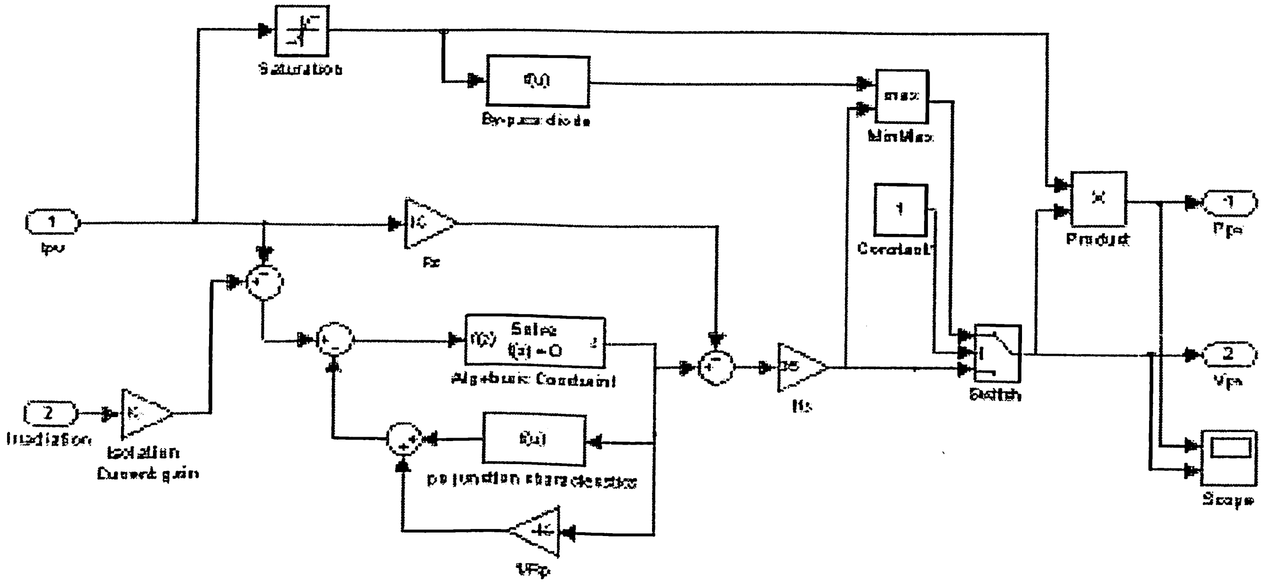


Figure 16 Single PV module simulink model

Open circuit voltage Voc (volts)	22.2
Short circuit current Isc (amps)	5.45
Rated current Ir at maximum power point tracking (mppt)(amps)	17.2
Rated voltage Vr,at mppt(volts)	4.92
Pn –junction reverse saturation current (Io) (amps)	2.615e-01
Irradiation to short circuit current gain (G)	0.00545
Cell parallel resistance (Rp)(ohm)	2.742
Cell series resistance (Rs)(ohm)	0.01309
Default no. of cells in series(Ns)	36

TABLE 3: Tabular column for PV module Parameters

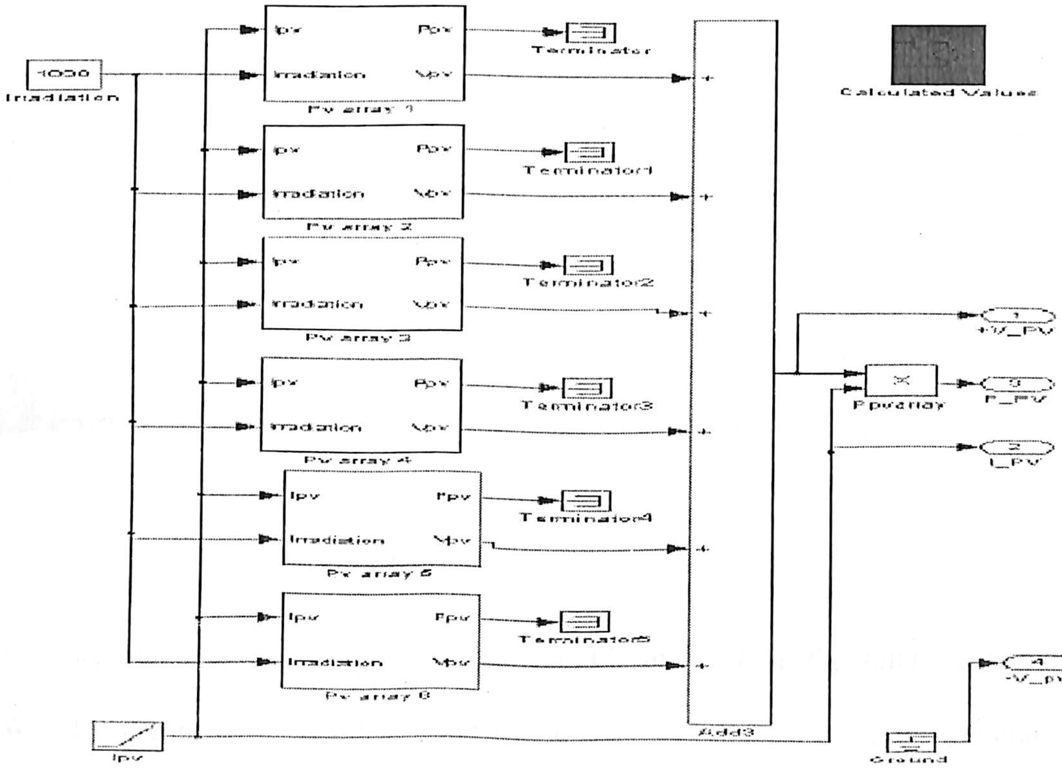


Figure 17 PV array simulink model

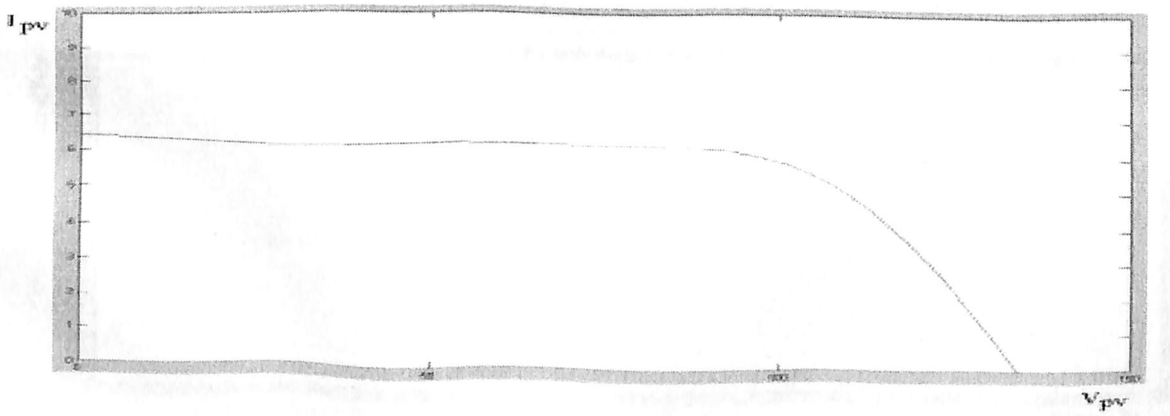


FIG 3.1: IV characteristic of PV array

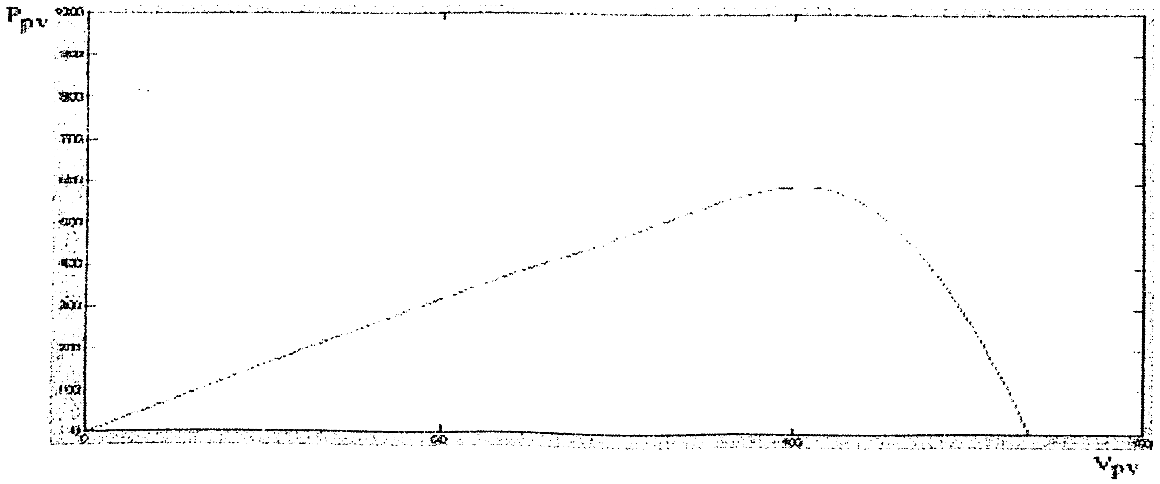


FIG 3.2: PV characteristic of PV array

The IV characteristics and PV characteristic of PV array when the solar irradiation level is 1000W/m2 are shown in figure 3.1 and figure 3.2 respectively. PV array generated voltage changes when solar irradiation level changes.Figure 3.3 shows Pv array generated voltage change when solar irradiation level changes from 500w/m2 to 1000w/m2.

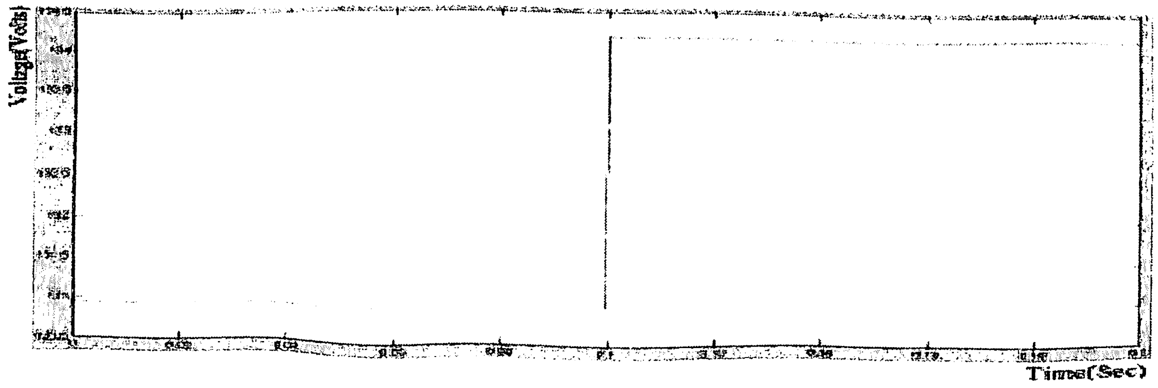


FIG 3.3 : Change in array voltage due to sudden increase in Irratiation

CHAPTER 4

BATTERY MODULE

4.1 INTRODUCTION

Battery in a PV cell module is basically required to store the generated voltage from the PV array.This battery model can be divided into the following types:

1) Experimental model
2) Electrochemical model
3) Equivalent circuit model

Out of the above mentioned model the equivalent circuit model is most suitable for dynamic simulation. The figure below shows a generic dynamic simulation ,which assumes that the battery is composed of a controlled- voltage source and a series resistance.This model is based on Shephred battery model. This model which is a generic battery model considers the state of charge(SOC) as the only state variable.

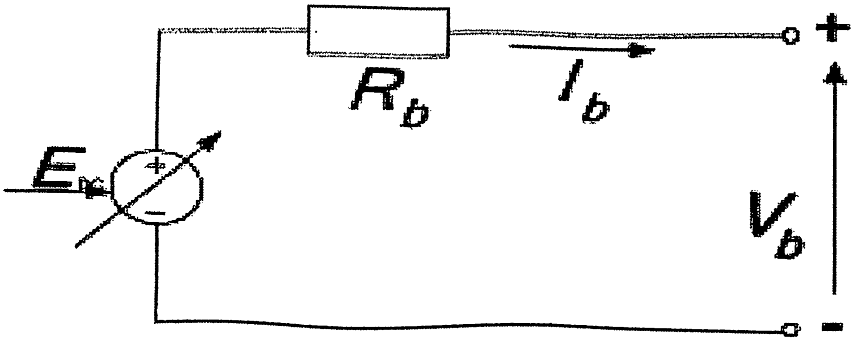


FIG 4.1 (A): A generic battery Model

This can be expressed as a controlled voltage source by the given Equation:

$$E = E_O - K\frac{Q}{Q - \int i_b dt} + A\exp(-B.\int i_b dt)$$

Where,

E= No load voltage(in Volts),

Eo=battery constant voltage (in volts),

K=polarization voltage (in volts),

Q=Battery capacity (in Ah),

A= Exponential zone amplitude (in volts),

B= Exponential zone time constant inverse (in Ah-1)

4.2 GRID CONNECTED PV/BATTERY GENERATING SYSTEM

The Figure below shown is the configuration of the grid-connected PV /Battery generation system. Via a DC/DC converter ,aPVarray and battery are connected to the common dc bus respectively, and then interconnected to the ac grid via a common DC/AC inverter. To help balance the power between PV generation and loads demand battery energy storage can charge and discharge continuosly. Whenever the generation exceeds the demand, PV array will charge the battery to store the extra power at produced at that time,meanwhile, when the generation is less than the demand, the battery will discharge the stored power to supply loads. Independent control objective for each of PV system, battery energy storage system and the inverter is present, and by controlling each part, the entire system is operating safely.

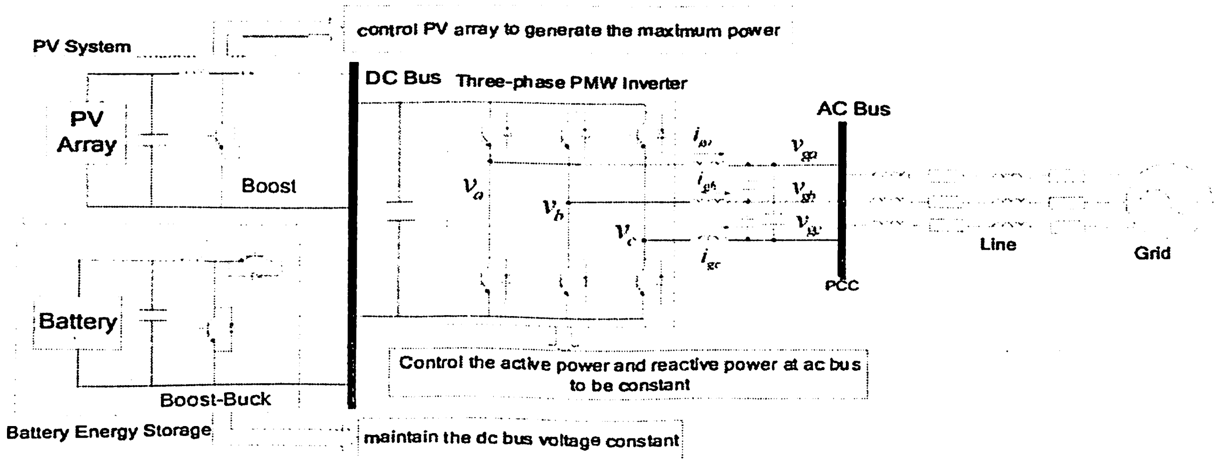


Figure 18 Configuration of grid connected hybrid pv/battery generating system.

4.3 Power control at PV side and Maximum Power Point Tracking(MPPT)

Under a given operating condition, ie, temperature and irradiance the PV array must operate electrically at a certain voltage which corresponds to the maximum power point. To do this, the most important thing is to apply a maximum power point tracking (MPPT) technique . Various MPPT techniques have been proposed and implemented, such as look-up table methods, perturbation and observation (P & O) methods and computational methods.

4.4 The boost circuit and its control

A boost chooper circuit is always used as the DC/DC converter for two-stage PV generation system.

The use of boost circuit will enable low voltage PY array to be used as the output voltage of PV cell is low. As a result, the total cost will be reduced. In order to reduce high frequency harmonics a capacitor is generally

connected between PV array and the boost circuit. Figure below is the configuration of the boost circuit and its control system.

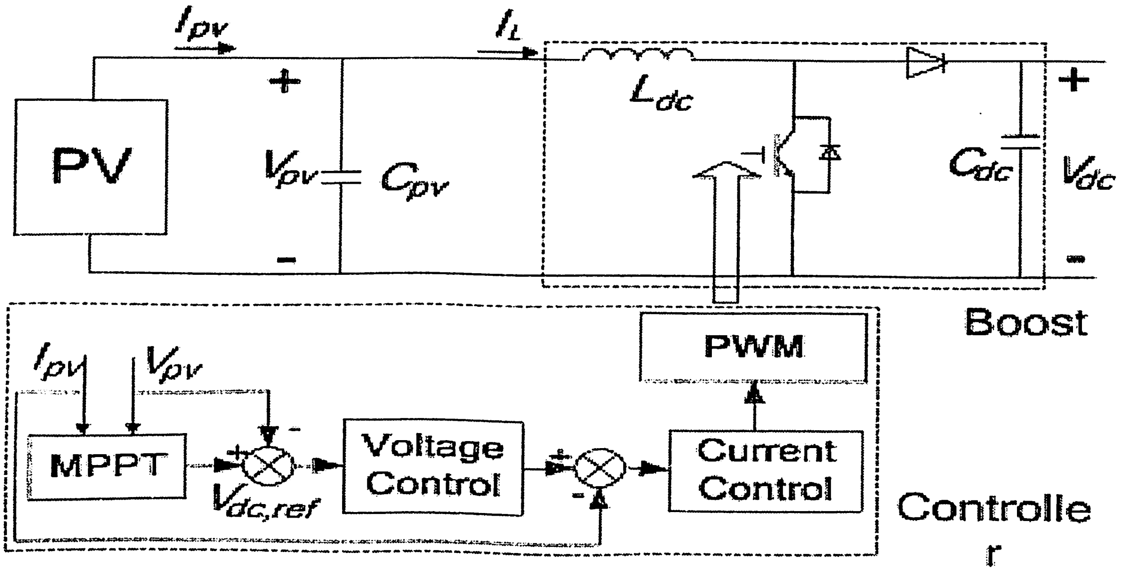


FIG 4.4(A): Boost circuit and its control

4.5 Battery energy storage system

The main component of Battery energy storage system (BESS) are:

1.a battery bank,

2.a bi-directional DC/DC converter and

3.a control system.

The system should be able to operating in twodirections: firstly, the battery can be charged to store the extra energy and secondly it can discharge the energyto loads whenever required.

In the circuit it can be seen that, BESS is typically connected to the dc bus through a bi-directional DC/DC

converter, as shown in figure below. Normally the utility grid is considered as a backup source and the battery

bank serves as a short-duration power source inorderto meet the load demands which cannot be fully metby the PV system, particularly during fluctuations of the solar or transient periods.

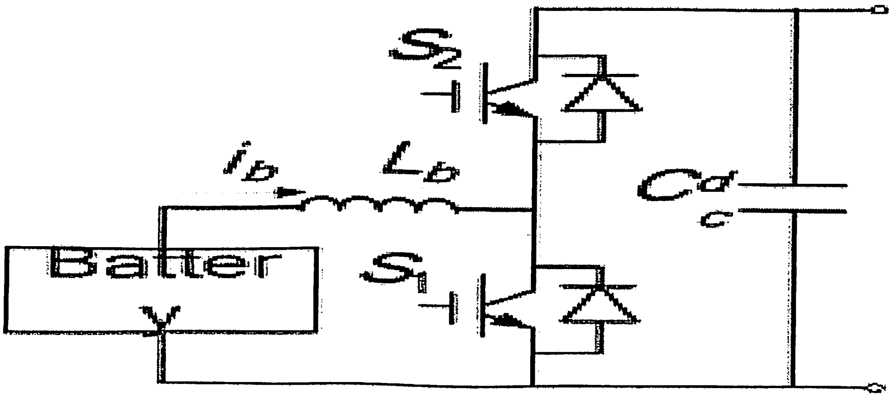


FIG4.5 (A): Bi-directional DC/DC converter

The primary aim of the battery converter is to maintain the common dc link voltageConstant without any fluctuation. Thus in this way , the ripple in the capacitor voltage is much less no matter the battery is charging or discharging and as aresult the voltage of the dc bus can be stable . When charging, switch Sfis activated and the converter works as a boost circuit. Otherwise,When discharging, switch S2 isactivated and the converter works asa buck circuit.

4.6 Simulation results:

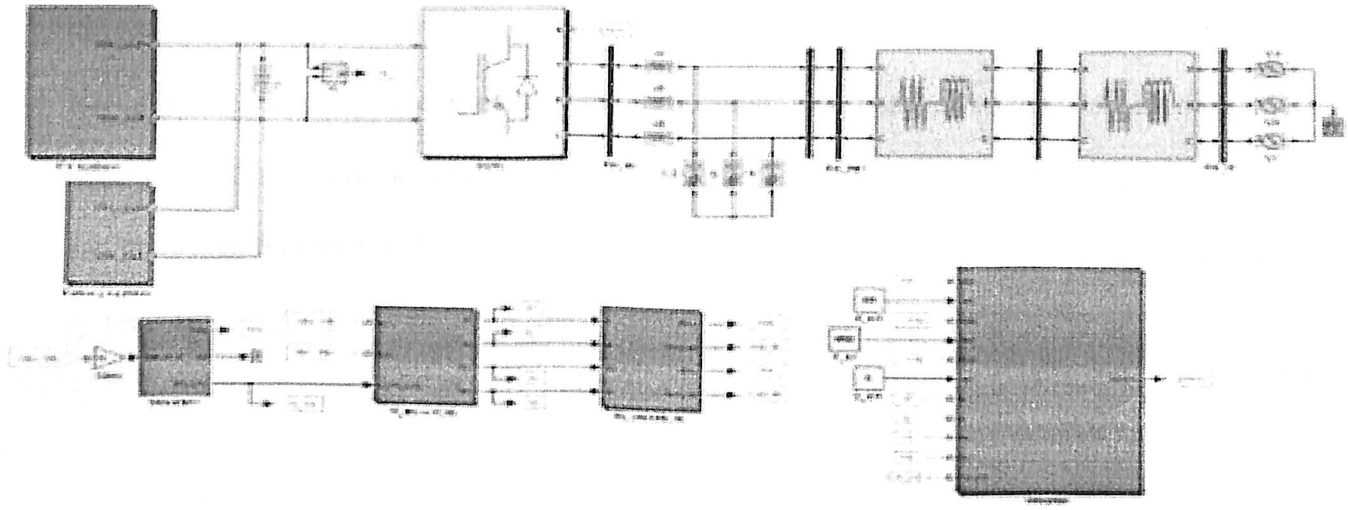


Figure 19 Simulation model of the hybrid Model

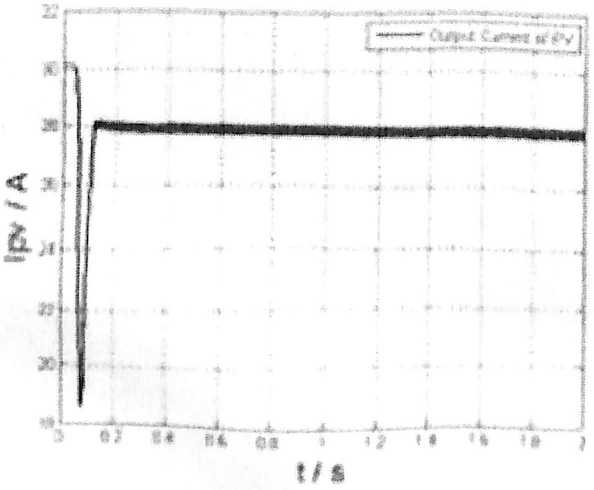


Fig 4.6(B)(a)output current of PV array

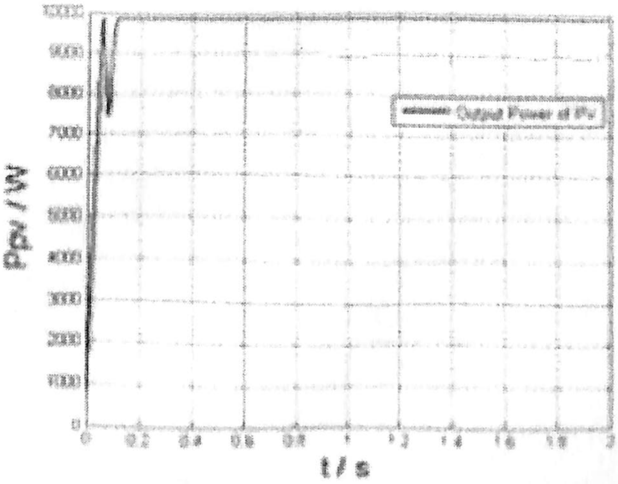


Fig 4.6(B) (b)output power of PV

array

In the above,a grid-connected hybrid PV /Battery generation system is studied. In orderto convert the solar energy effectively and efficiently, the maximum power point of the PV array should betracked to ensure the PV array to generate most power to utility grid. In order to change the modified variable-step P&Omethod can be used , consequently, both of thetracking speed and algorithmaccuracy are satisfied. PV generation will change when solar irradiance or temperature fluctuation occurs. In order to maintain the power balance between PV generation and demands, battery can be charged or discharge , and thus improve the stablity of the entire system.

CHAPTER 5

INVERTER MODULE

5.1 INTRODUCTION

The main function of an inverter circuit in a grid connected PV cell module is to convert the direct current (DC) into alternating current (AC). A common DC/AC inverter is used to connect the PV array with the AC grid .PWM (Pulse Width Modulation) mechanism is used in the inverter for current control to make the inductance current track the sinusoidal reference current closely and obtain a low THD (total harmonic distortion) injected current.

5.2 CONTROL OF THE GRID CONNECTED INVERTER

1) Uncoupled Watt-var method

In this method in order to understand the general case, the main principle is to connect an inverter to the network, through a resistor R and inductor L as indicated in the figure below:

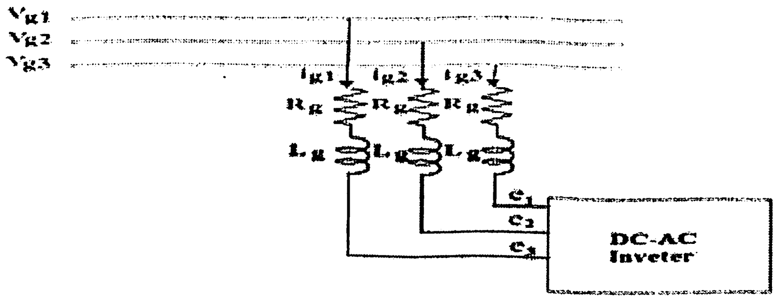


FIG5.2 (A): Simplified diagram of an inverter connected to the grid.

For better Explanation we need the following Equations

$$\frac{d}{dt}\begin{bmatrix} i_{g1} \\ i_{g2} \\ i_{g3} \end{bmatrix} = \begin{bmatrix} \frac{-R_g}{L_g} & 0 & 0 \\ 0 & \frac{-R_g}{L_g} & 0 \\ 0 & 0 & \frac{-R_g}{L_g} \end{bmatrix} \begin{bmatrix} i_{g1} \\ i_{g2} \\ i_{g3} \end{bmatrix} + \frac{1}{L_r}\begin{bmatrix} V_{g1} - e1 \\ V_{g2} - e2 \\ V_{g3} - e3 \end{bmatrix}$$

....

..........(a)

Where,

Vg=voltage of the grid

Ig=current of the grid

e = inverter voltage

Rg= resistance of the grid

Lg= inductance of the grid

By using different type of transformation such as abc to dq transformation of park, the equation (a) can be written as:

$$\frac{d}{dt}\begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} = \begin{bmatrix} \frac{-R_g}{L_g} & \omega \\ -\omega & \frac{-R_g}{L_g} \end{bmatrix} \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{gd} - e_d \\ V_{gq} - e_q \end{bmatrix}$$

....

......(b)

In the equation given below there are two new variables which are nothing but the output variables of the control system and has got two PI controllers:

$$X_1 = \frac{1}{L_g}\left(V_{gd} - e_d\right)$$

$$X_2 = \frac{1}{L_g}\left(V_{gq} - e_q\right)$$

…………………………………………(c

)

In the equation below the value are

Id.ref=active current

Iq,ref=reactive current

$$X_1 = (K_P + \frac{K_I}{S}\left(I_{d,ref} - i_{gd}\right) - \omega i_{gq}$$

$$X_1 = (K_P + \frac{K_I}{S}\left(I_{q,ref} - i_{gq}\right) - \omega i_{gd}$$

………………

……………(d)

Now by applying laplacetransformatiom to equation (a) and also to equation (b) and (c), we get the transfer function as given in the equation below:

$$F(S) = \frac{i_{gd}}{i_{d,ref}} = \frac{i_{gq}}{i_{q,ref}} = \frac{K_I + SK_P}{K_I + S\left(\frac{R_g}{L_g} + K_P + S^2\right)}$$

……………………

……..(e).

The control is optimum when both Kp and Ki are maximum.

The figure below represents the diagram of control by the method of “uncoupled watt-var method”.

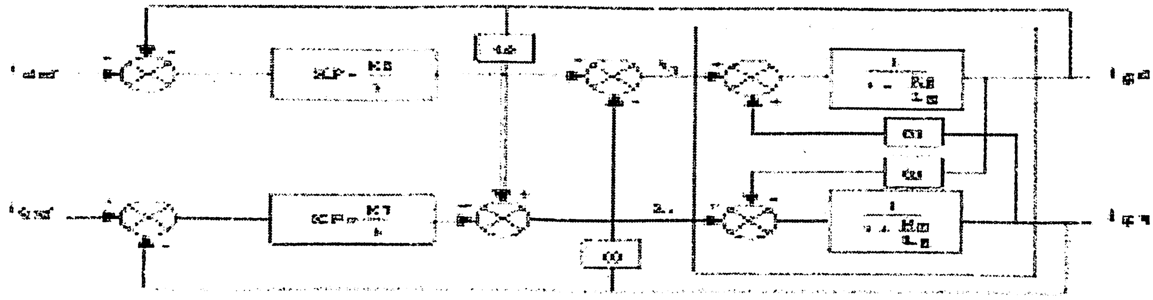


FIG 5.2 (B): Uncoupled Watt-var method

The next figure shows the total diagram of identification of the references and regulation of the current by this method

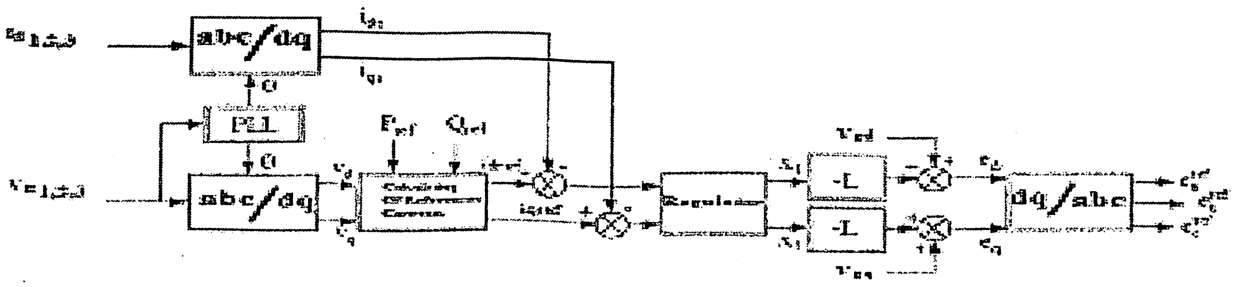


FIG5.2(C): Total diagram of control

The main aim of this control system is to impose the values of active and reactive powers injected into the electric grid.

2)DC Bus voltage controller

Whenever we provide or absorb active power to the grid the regulation of this voltage is carried out. Its when we add an active fundamental current into the reference current, the correction factor can be achieved. The regulation of the DC Bus voltage can be done by taking the difference between U2 dcref and U2 dc which gives power as Pref on the regulator output side and is then added to the fluctuating output power and this results to an active fundamental current. This is how the regulation of the DC bus voltage is done.

We can either take proportional regulator or a proportional integral regulator for obtaining the Pref signal. The static errors are better removed by this proportional integral regulator. The figure below shows the schematic diagram of calculating and regulating the standard DC bus voltage.

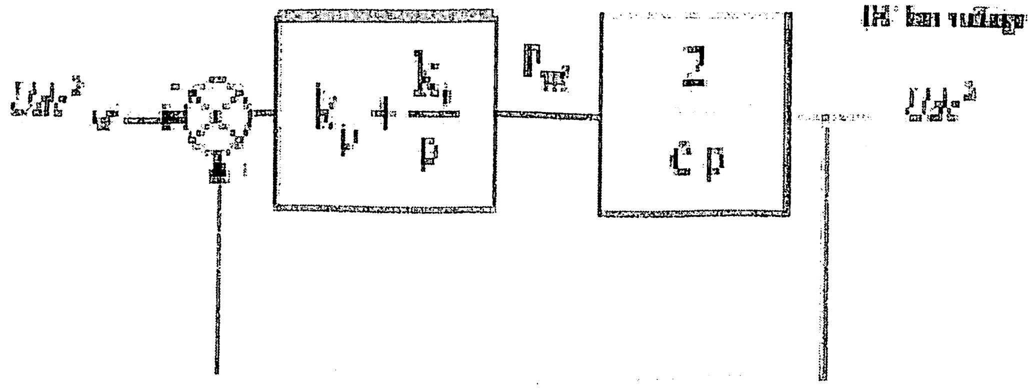


FIG5.2(D): Schematic diagram of the DC link controller.

5.3 Proposed Inverter Topology

The proposed inverter topology consists of PV array, DC/DC boost converter , an inverter which is a 5 level H bridge and is grid connected.

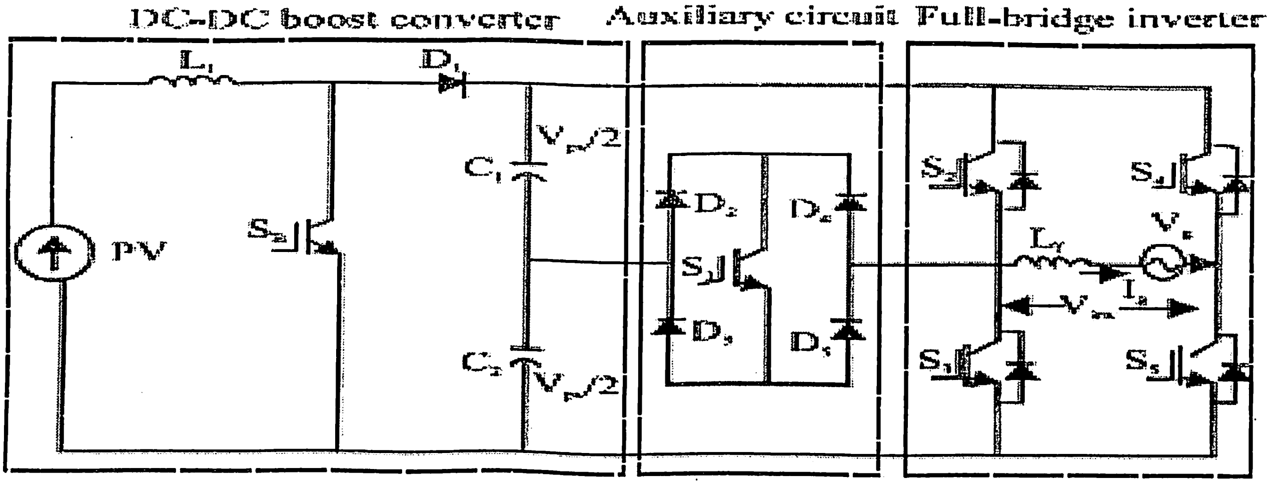


Figure 20 Proposed inverter topology.

DC supply is generated by the PV array with the help of solar energy; it's a low level DC output. As it is a low level output .it can be stepped up to a high level voltage through DC_DC boost converterwith the help of DC bus capacitors. The normal step up ratio is 1:2. For conversion of DC to AC voltage ,the five level inverter is used. This AC voltage is connected to grid system that is utility feeder through filtering inductor. The input current is sinusoidal with least harmonic distortion. The loads that are considered are primarily inductive and resistive load

(A)MODULATION TECHNIQUE AND OPERATION OF PROPOSED INVERTER

A sinosudal pulse width modulation (PWM) is used as it is one of the most efficient technology.figure below shows the proposed PWM strategy. It considers two reference signals Vref1 and Vref2 and a triangular carrier signal named Vcarrier was used in order to generate the PWM switching signals. Modulation Index is maintained between the values of 0 to 1. The output voltage produced is expressed as a fourier series coefficient which is produced as a result of comparision between the two refernce signal and the carrier signal.

$$V_0(\theta)=A_0+\sum_{n=1}^{\infty}(A_n\cos n\theta+B_n\sin n\theta)$$

n-even number, so $A_o= 0$, $B_n= 0$

$$V_0(\theta)=\sum_{n=1,3}^{\infty}(A_n\cos n\theta)$$

$$A_n=\frac{4V_{pv}}{n\pi}\sum_{m-1}^{p}[(-1)^m\sin(n\alpha_m)]$$

Where:

m = Apulse number

α = The phase angle displacement

In this research, 2 reference modulation techniques is incorporated into the sinusoidal Pulse width modulation technique to produce PWM switching signals for full-bridge inverter switches and auxiliary switch.

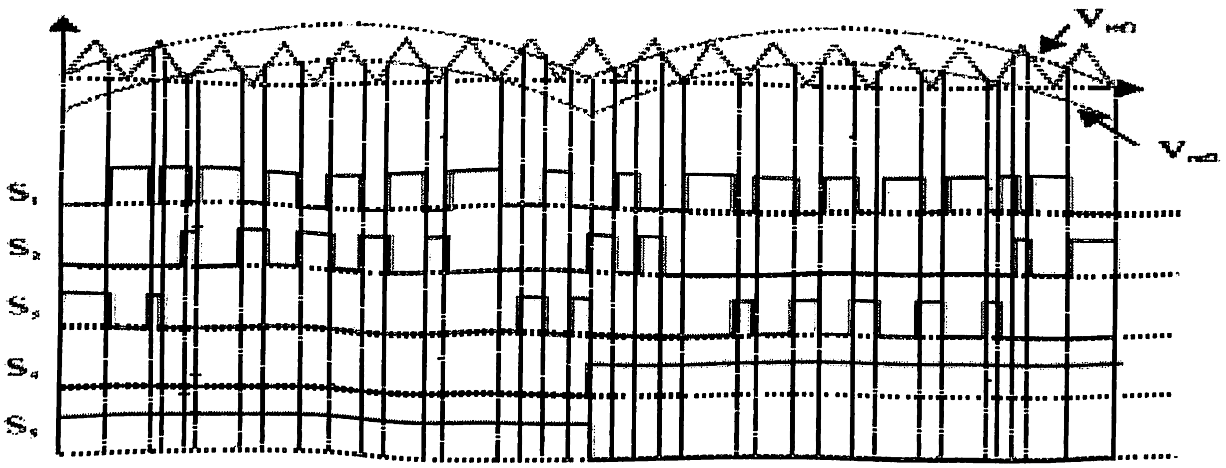


FIG5.3 (B): switching for the five level single phase inverter

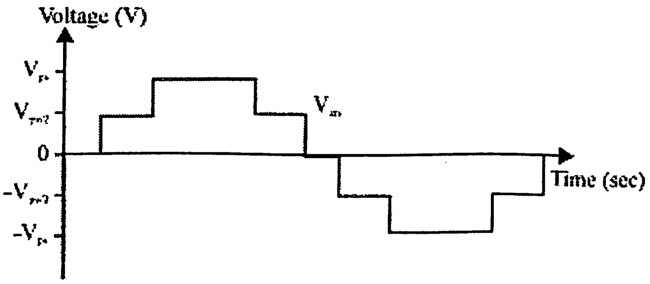


FIG A2:Ideal five level inverter voltage.

Table 4 : Inverter voltage during five level S1-S5 switch on –off.

S_1	S_2	S_3	S_4	S_5	V_{inv}
ON	OFF	OFF	OFF	ON	$+V_{pv}/2$
OFF	ON	OFF	OFF	ON	$+V_{pv}$
OFF	OFF	OFF	ON	ON	-
	or	or	or	or	0
	ON	ON	OFF	OFF	-
ON	OFF	OFF	ON	OFF	$-V_{pv}/2$
OFF	OFF	ON	ON	OFF	$-V_{inv}/2$

The above inverter produces five level of output voltage ie,

0

+Vpv/2

+Vpv

-Vph/2 and

-Vpv.

The auxiliary circuit present consists of four diodes and a switch represented by S1 and it generates half level of PV supply which is given by +Vph/2 and -Vph/2. The five level inverter output voltage Vin is shown in the figure A1 and A2. The table 1 given above shows the level of Vin during S1-S5 switch ON and OFF.

(B)PROPOSED CONTROL SYSTEM AND ALGORITHM

The inverter that is proposed is used in the grid –connected PV system. So the power that is injected to the grid should have a unity power factor .The amount of electric power generated by the solar module is always changing through out the day because of changing weather conditions. Maximum power point tracking algorithm is mainly used to overcome this problem. The maximum power from the PV module is extracted using the perturb and observe algorithm

Table 5: Rules based on five membership function

$\Delta\omega'/\Delta\omega$	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NS	NS	ZO	NS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PB	PB	PB

FUZZI-PI algorithm is used for feedback controller whenever there is a separate inverter topology to be controlled. The proposed inverter is the current injected into grid. The grid current Ig is sensed and feedback to the comparator. The comparator compares the reference current Iref with Ig. The value of Iref is obtained by sensing the grid voltage and converting it to reference current and multiplying it with constant m. This is to ensure that the value of the grid voltage Vg is in phase with Ig and always at near unity power factor. Actaully all the algorithms are developed in the C++ language and is implemeted in MATLAB version 7.5.The PI algorithm can be written as:

$$u(t)=K_p e(t)+K_i\int_0^t e(\tau)\,d\tau$$

(C) Fuzzy logic control:

The following steps are present in the process of fuzzy logic controller design.

Fuzzification : This is the process of representing inputs as suitable linguistic variables.

Decision making: The appropriate control action that is to be carried out needs to be based on knowledge.

Defuzzification: This process changes the fuzzified outputs into crisp values. The fuzzy logic controller firstly converts the crisp errors and changes in error variables into fuzzy variables.After this the values are mapped into the linguistic labels. In the table below we can see the membership function associated with each labels. Basically the linguistic groups are divided into 7 groups,namely:

1 . nl-negative large

2 . nm-negative medium

3 . ns-negative small

4 . z-zero

5 . ps-positive small

6 . pm-positive medium

7 . pl-positive large.

Each of the input and outputs must contain membership function with all the given seven linguistics avaiable.

(D) SIMULATION RESULT

This proposed system was performed by using MATLAB and the output of the PhotoVoltaic array is 115 V and the voltage is applied DC-DC boost converter from PV array.

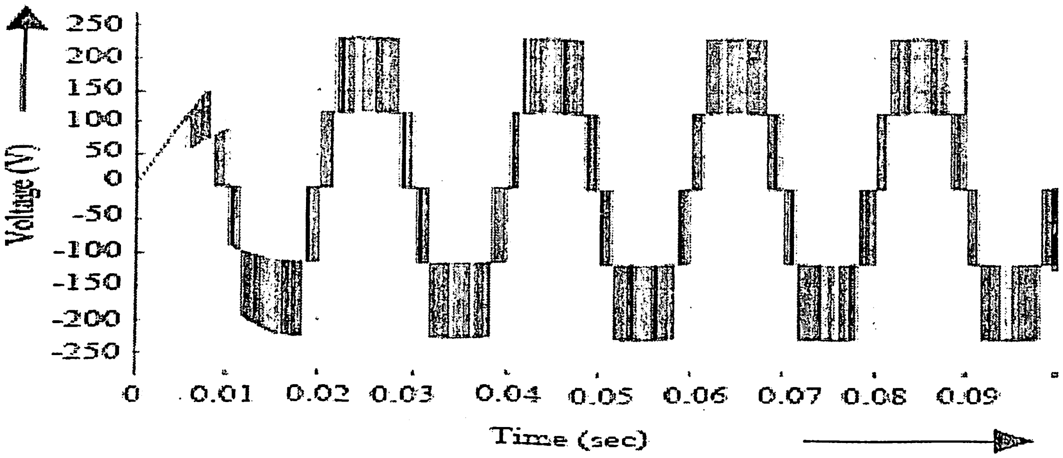


FIG5.3 (D) 1:Proposed inverter output voltage

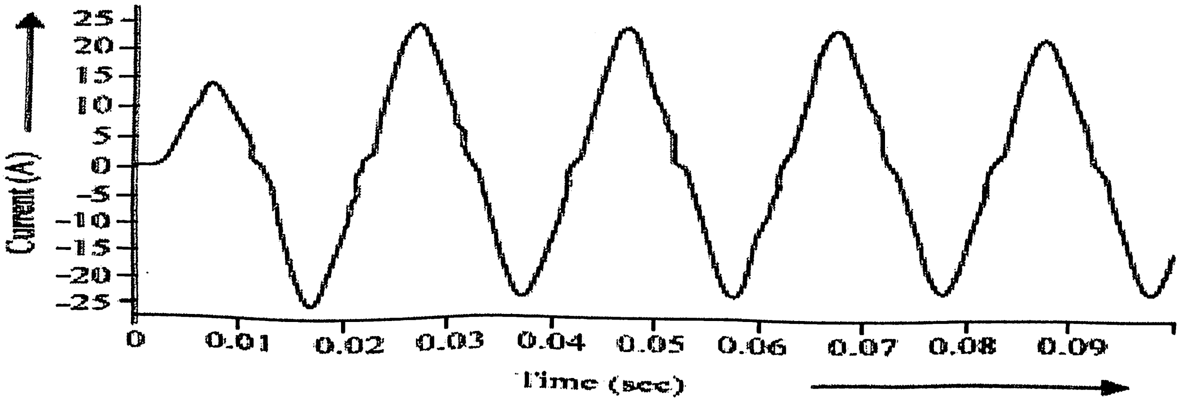


FIG5.3 (D)2: Grid Current

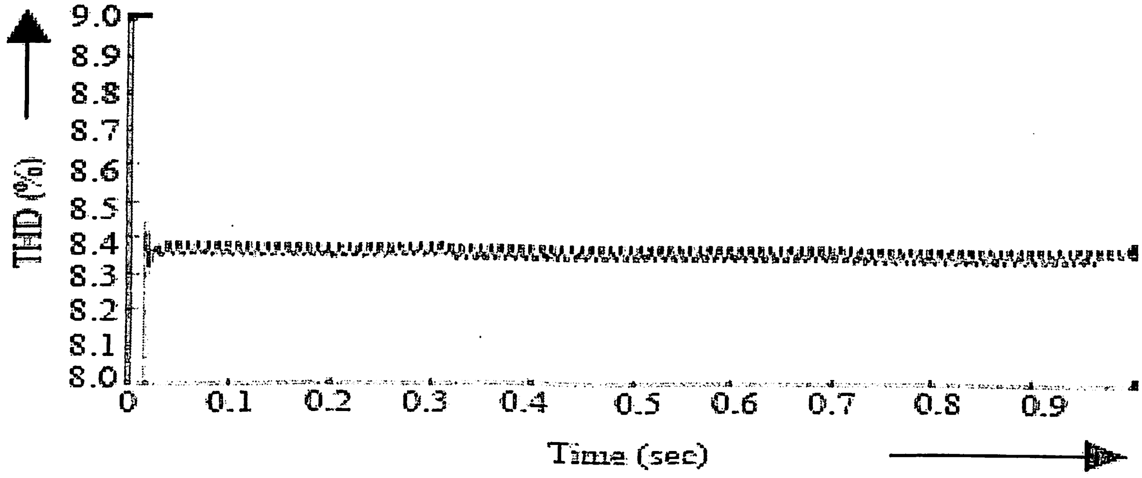


FIG 5.3 (D)3: THD in Fuzzy PI control scheme.

We are getting output voltage from DC-DC boost converter 230 V and here we see five-level inverter inverts DC supply to AC supply. This outputs of the inverter are 230 V and 50 H_2 for voltage and frequency, respectively. The simulation five-level output as shown in figure D1. This grid current is almost a pure sine wave as shown in fig D2. This grid current depends upon load and is a variable one . The total harmonic distortion can be observed in PI and FUZZY PI current control scheme that are present. It was observed that FUZZY-PI current controller produce low harmonic distortion and improved sudden step response compare to PI current controller as shown in figure D3 and D4 . The power factor can be calculated using mathematical calculation and is taken as power factor is 0.96. So the power factor is near unity.

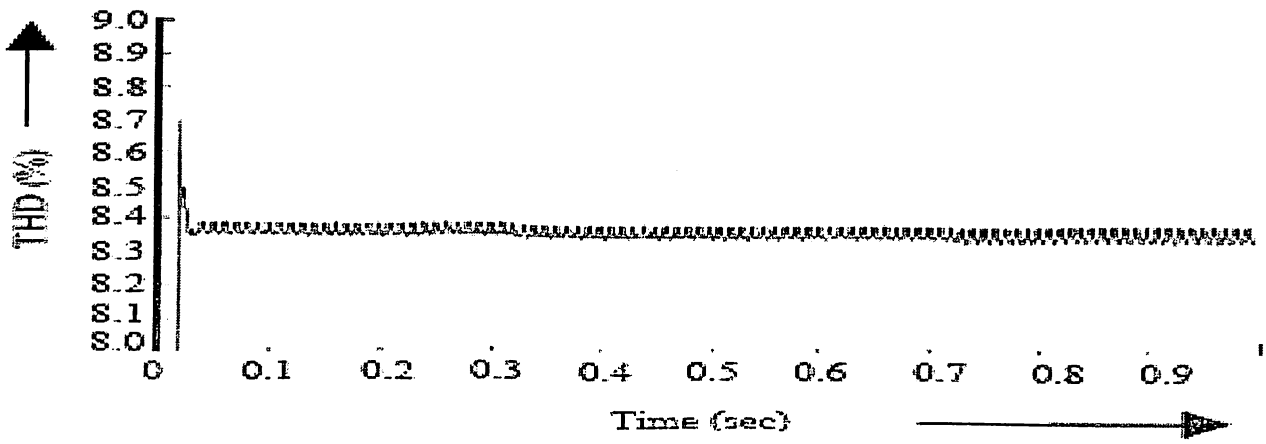


FIG5.3(D)4: THD in PI controller scheme.

The study basically represents a single-phase five-level Photo-Voltaic (PV) inverter topology for grid-connected application. The represented photovoltaic models, operation of proposed inverter topology, control system algorithm, modulation technique and simulation results were observed carefully. The control system algorithms were carefully developed in C++ language and it's implemented in MATLAB version9.The FUZZ-PI current controller was used basically to produce low harmonic distortion and improved sudden step response compare to PI current controller. Thus the output which is the grid current is almost sine wave and the power factor also near unity. Further, in the system will be implemented to real time application and for this purpose a filter circuit after the inverter is highly recommended.

CHAPTER 6

RESULTS AND DISCUSSIONS

Using MATLAB the main block of the required module is prepared with much attention and care. The main block mainly consists on some "goto" commands and basically an inverter circuit made mainly with the help of MOSFET (field effect transistors). These MOSFET are mainly used as a switch and thus does not hampers the output greatly as a transistors.For every phase we are using four MOSFETs and as out input ia a 3 phase input ,a total of twelve [4(for each phase)× 3(total no. of phases)=12] MOSFETs are incorporated. Input signals for each phases are different and are indicated by different nomenclatures.

Phase 1 input signals	[L1a],[L1b],[L1c],[L1d]
Phase 2 input signals	[L2a],[L2b],[L2c],[L2d]
Phase 3 input signals	[L3a],[L3b],[L3c],[L4d]

These signals mentioned above which are input to the MOSFETs present in the inverter circuit are mainly produced by 180 degree pulse width modulation. The details about the 180 degree PWM will be discussed later.

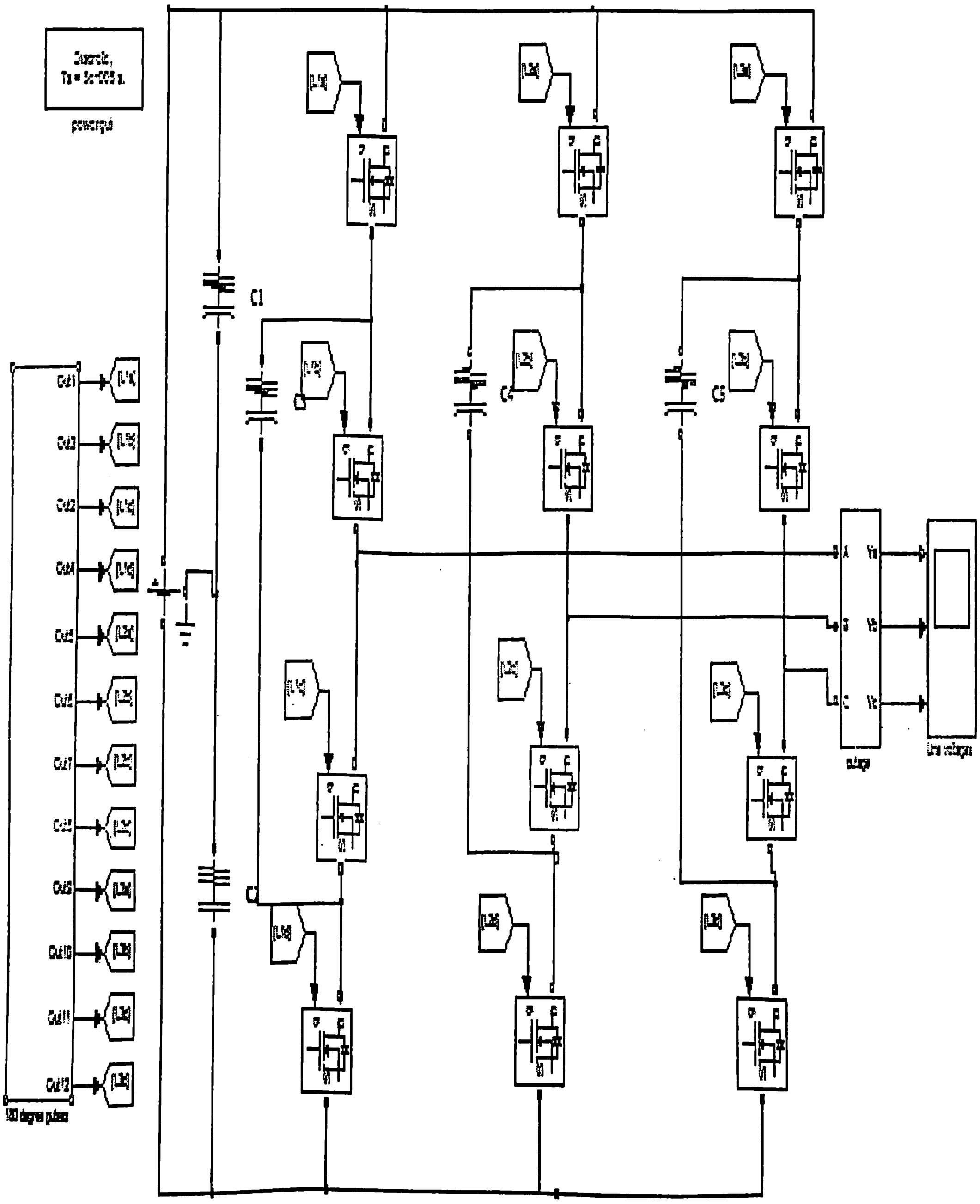


Figure 21Main circuit diagram .

6.1 Types of signals

Basically three types of input signals can be introduced in MATLAB programming. They are :

a) Discrete signals

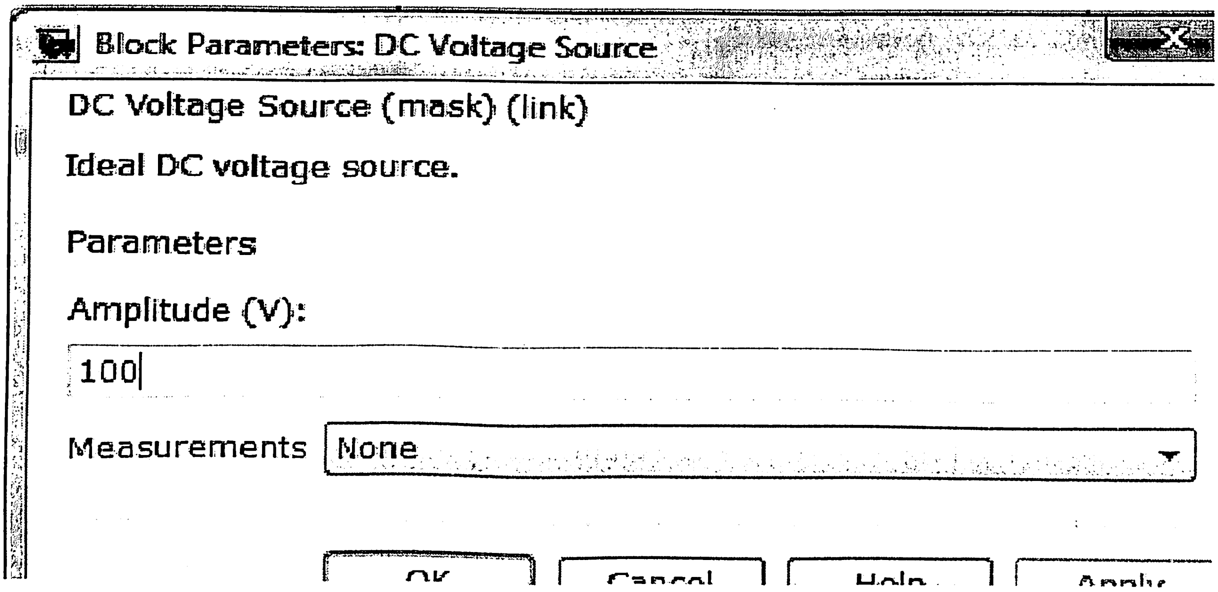
b) Continuous signals

c) Phasor signals

In this project since we are dealing with pulses by using 180 degree pulse width modulation , so ww choose to go for discrete type of signal with Ts= 5×e-005 sec. This is already mentioned in the block diagram.

6.2 Battery

It has been asumed that the pv array which is made by series and parallel combination of various pv cells produces an output voltage of 100volts. Thus the battery acts as an voltage source of 100volts and by considering all the required constant parameters.this 10volts voltage source is a DC source which needs to be converted to an AC signal.



DC Voltage Source (mask) (link)

Ideal DC voltage source.

Parameters

Amplitude (V):

100

Measurements None

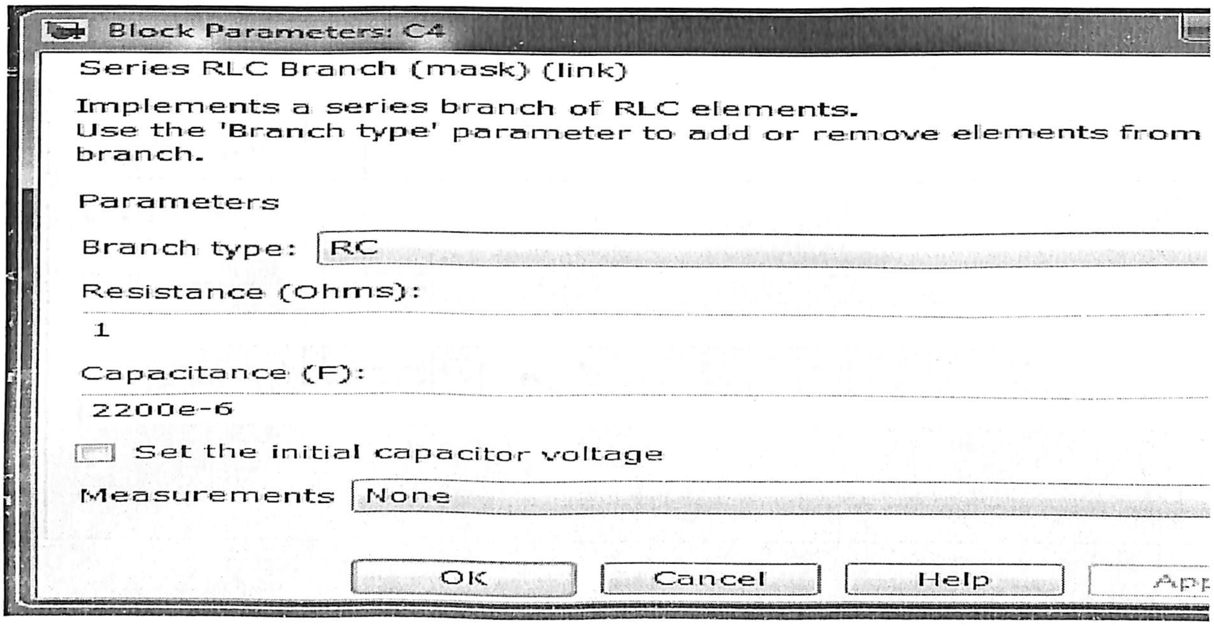
Figure 6.2 :Snapshot of Battery output voltage

6.3 LOAD

For any circuit to run , it must be connected to some load. Normally resistances are pure resistive load which are in phase that is voltage and current are in the same phase ,ie ,zero phase differnce.. The capacitors are loads with 90 degree phase leading while inductors are 90 degree phase lagging ,that is ,in case of capacitor the current leads behind voltage by 90 degree while inductor current laggs behind voltage by 90 degree. Different combinations of resistance R, capacitance C and inductor L can be used as per our requirement. In this we have used a load of a combination of both resistance amd capacitance .

Resistance = 1 ohm

Capacitance = 2200×10-6 farrad .



Series RLC Branch (mask) (link)

Implements a series branch of RLC elements.
Use the 'Branch type' parameter to add or remove elements from
branch.

Parameters

Branch type: RC

Resistance (Ohms):
1

Capacitance (F):
2200e-6

☐ Set the initial capacitor voltage

Measurements None

Figure 6.3: snapshot of the values of load in the circuit of R and C

The combination of this load values are connected as per requirement in the 3 different phases as shown in figure 6.

6.4 Outage:

The output from each of the three phase of the inverter circuit is feed to the outage as shown in figure 6 .It has got an input signal of A, B and C and the output signalof Va, Vb and Vc respectively which are feed to the line voltages to get the required output sinosuidal wasveform. The waveform produced is not a pure sine wave due to presence of distortion and and other harmonics and disturbances. Howevwe this can be made pure sine wave by connecting a filter of required capacity before feeding to the scope to get the output wavwform.

The inner circuit behind the outage is given below:

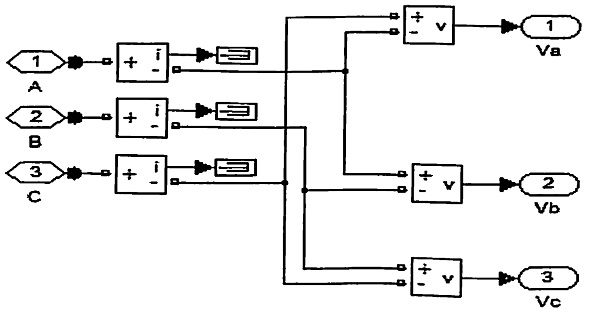


Figure 6.4 : outage circuit which gives the output voltages Va, Vb and Vc .

This basically takes input current from the inverter output circuit from the three phases respectively and gives the output voltages Va,Vb and Vc respectively. Inorder to get the required sinosuidal waveform we connect a scope to it which is represented by the line voltages in figure 6.

6.5 output waveform from the line voltage block

Although a pure sinosudal waveform is expected but practically it is not possible because of the harmonics present. However a filter connection at the end can reduce this problem to a great extend ,thus producing pure sive waves.

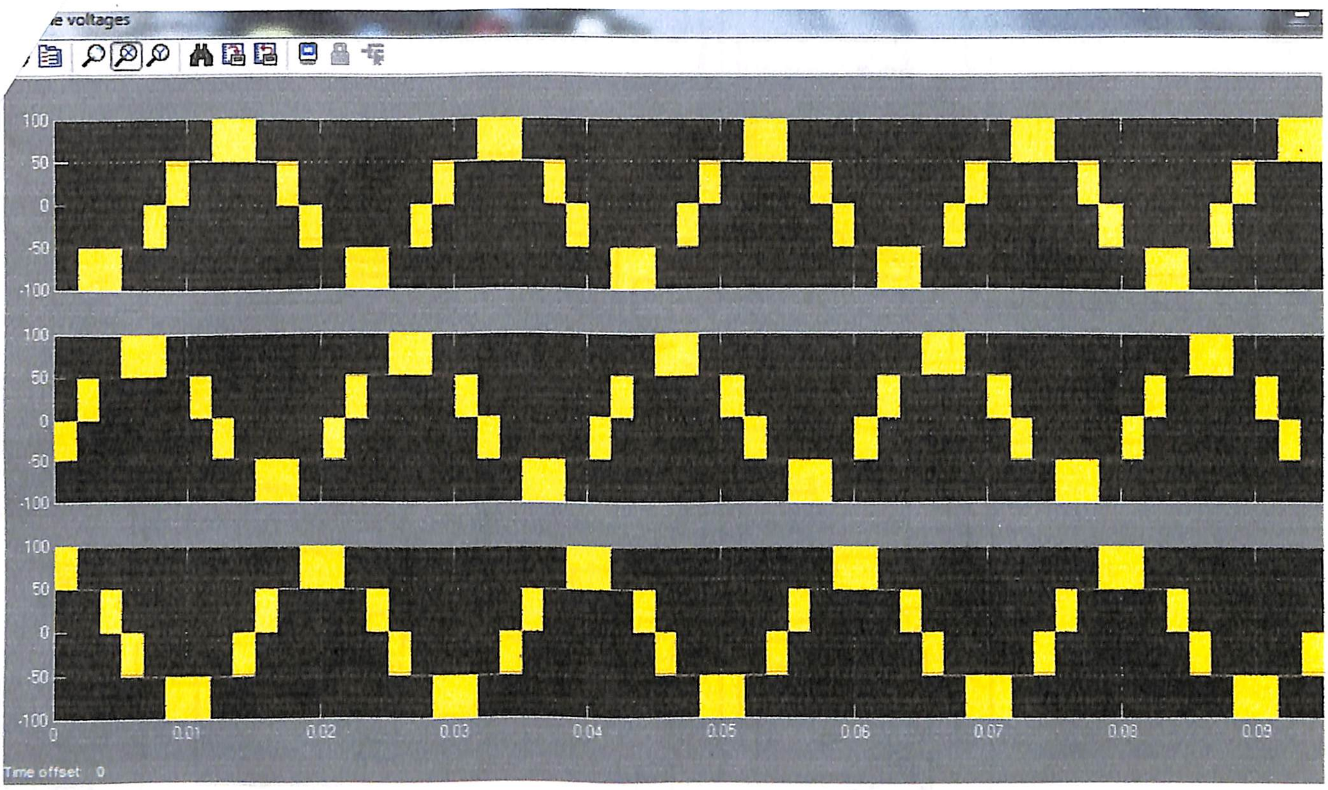


Figure 6.5: Snapshot of Final output waveform (which is an approximatelt sine waveform)

It can be seen that the output waveform is an AC signal which has an maximum positive and negative peak of +100v and -100v respectively as per the battery output voltage of 100v DC produced from the PV array. Thus the 100v DC signal has been changed to an AC signal. It can also be observed that all the 3 waveform has the required phase differnce of 120 degree.

6.6 180 degree pulse width generator

The actual inner circuit of the 180 degree pulse generator is given below

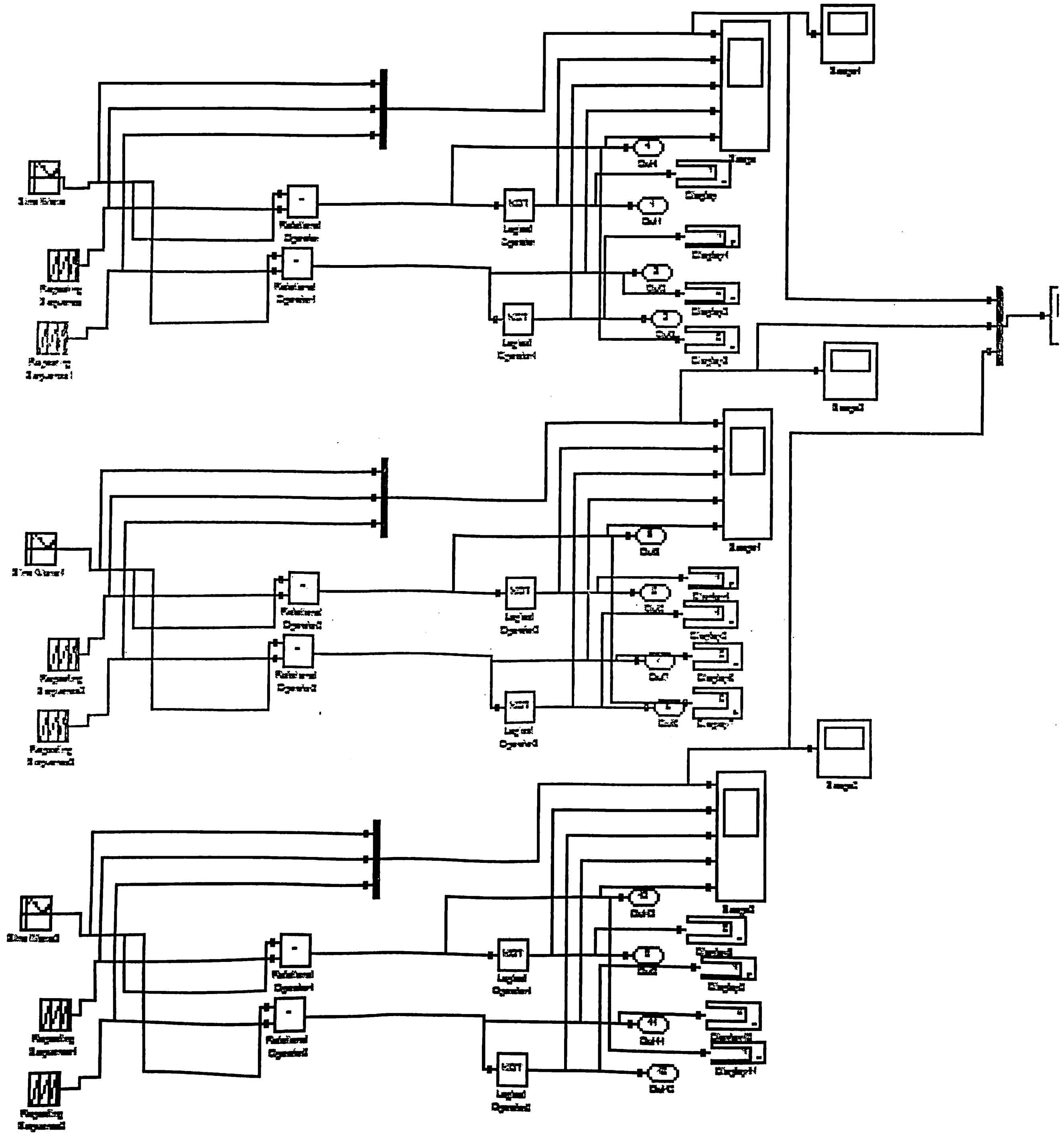


Figure 6.6: circuit diagram of 180 degree PWM

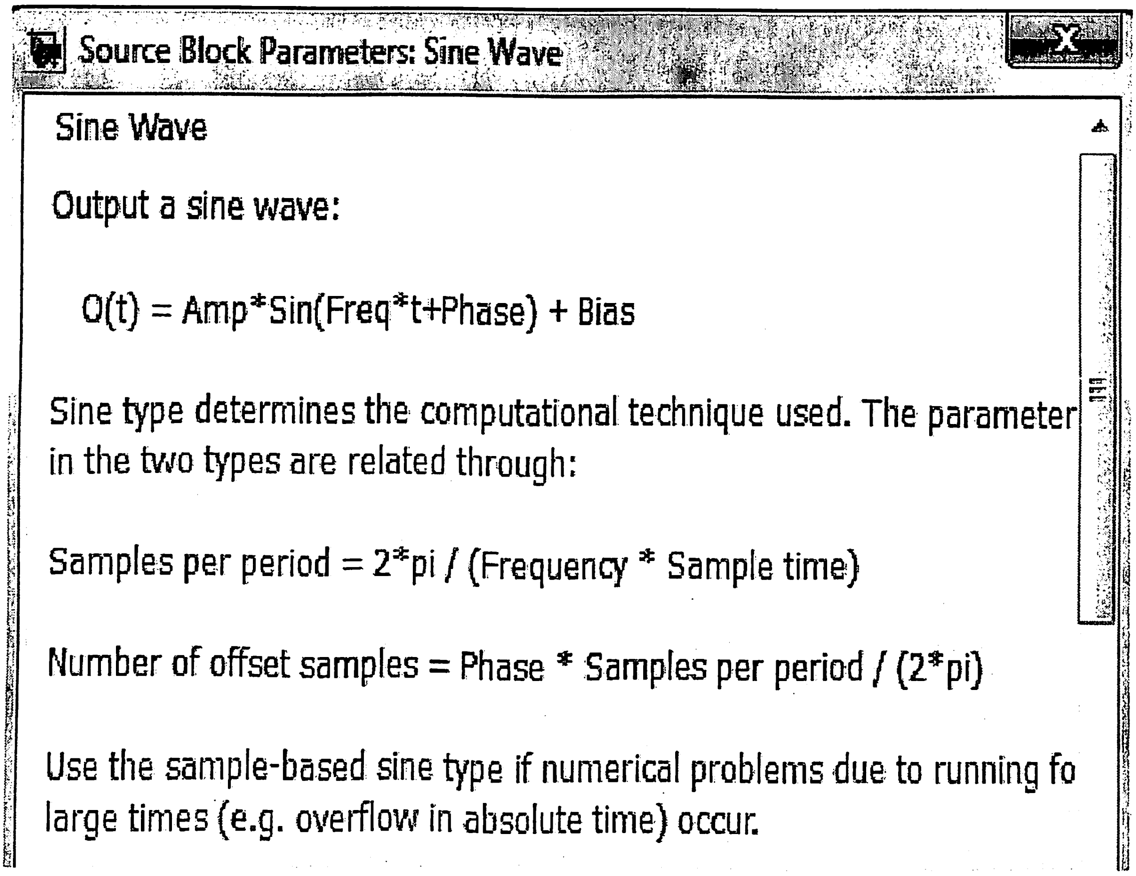
It can be seen that the input waveform for each phase of the whole 180 degree PWM circuit are

1) A sinosudal wave
2) 1st sawtooth waveform accounting for 0 to 5
3) 2nd sawtooth waveform accounting for 5to 10

This single sinewave and the two repeatating sawtooth waves are applied to each phase of the 3-phase network. Thus a total of three sinosuidal waveform with phase differnce are applied with the above two mentioned sawtooth waveforms.

SINOSUIDAL WAVEFORMS:

The sinosuidal waveforms taken have a general formula with general values and equation.



Sine Wave

Output a sine wave:

O(t) = Amp*Sin(Freq*t+Phase) + Bias

Sine type determines the computational technique used. The parameter in the two types are related through:

Samples per period = 2*pi / (Frequency * Sample time)

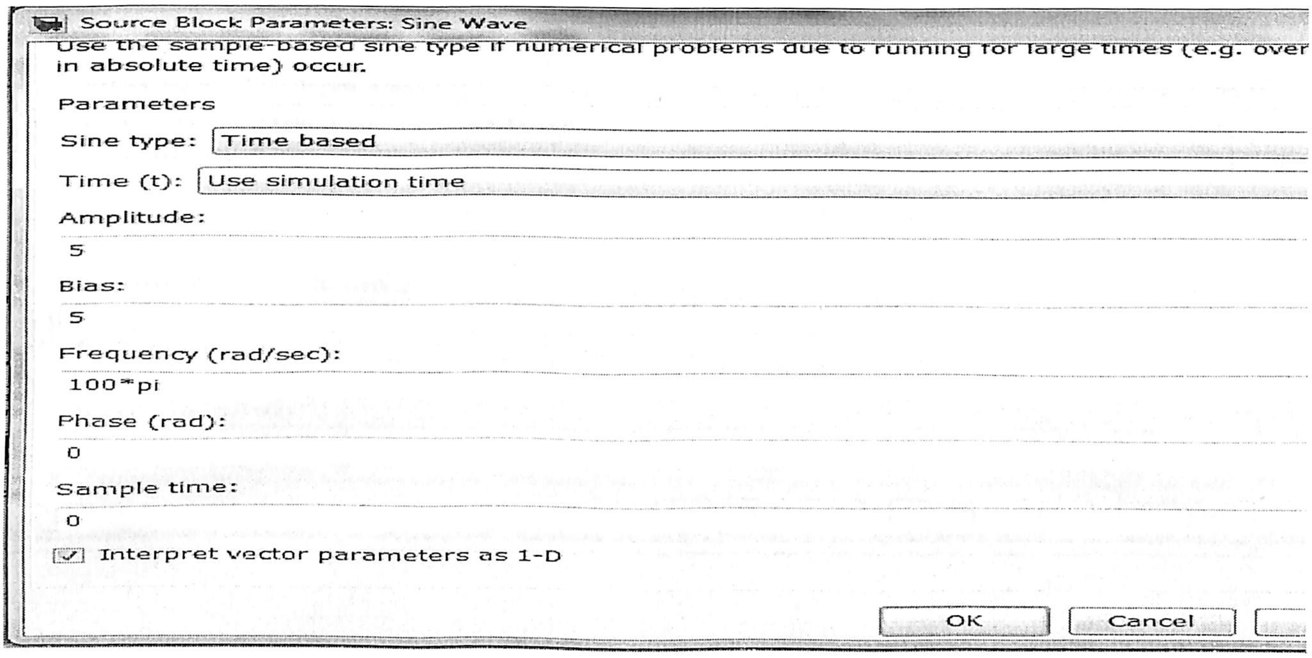
Number of offset samples = Phase * Samples per period / (2*pi)

Use the sample-based sine type if numerical problems due to running fo large times (e.g. overflow in absolute time) occur.

Figure 6.6.1 : snapshot of sinewave Equations

These sine waveforms have the same value of frequency which is 100π but has got different phase angle.

Sinewave 1:



Use the sample-based sine type if numerical problems due to running for large times (e.g. over
in absolute time) occur.

Parameters

Sine type: Time based

Time (t): Use simulation time

Amplitude:

5

Bias:

5

Frequency (rad/sec):

100*pi

Phase (rad):

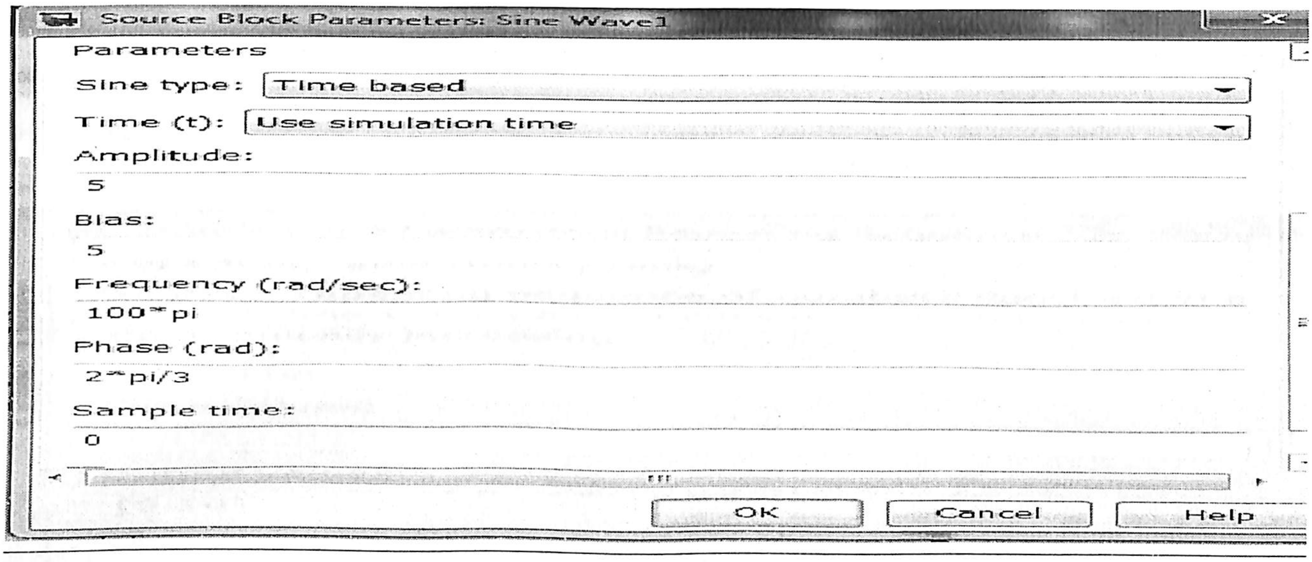
0

Sample time:

0

☑ Interpret vector parameters as 1-D

Sinewave 2:



Parameters

Sine type: Time based

Time (t): Use simulation time

Amplitude: 5

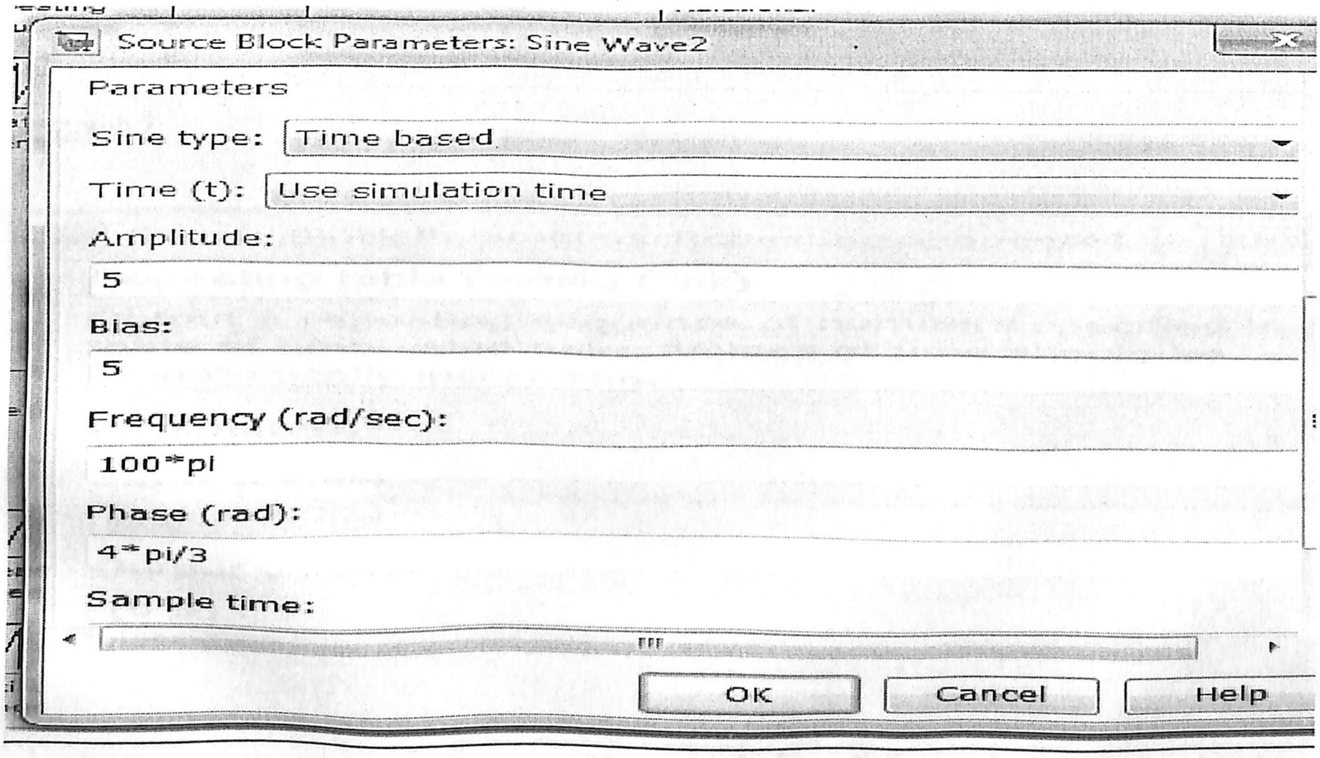
Bias: 5

Frequency (rad/sec): 100*pi

Phase (rad): 2*pi/3

Sample time: 0

Sinewave 3:



Parameters

Sine type: Time based

Time (t): Use simulation time

Amplitude: 5

Bias: 5

Frequency (rad/sec): 100*pi

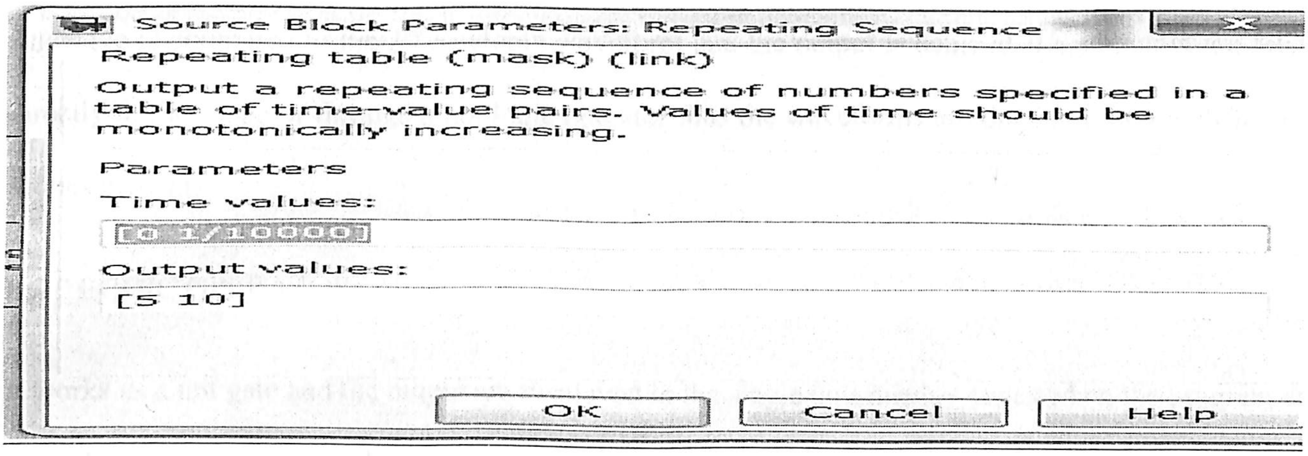
Phase (rad): 4*pi/3

Sample time:

SAWTOOTH WAVEFORM

The two different type of sawtooth input given are :

Sawtooth 1:


Source Block Parameters: Repeating Sequence

Repeating table (mask) (link)

Output a repeating sequence of numbers specified in a table of time-value pairs. Values of time should be monotonically increasing.

Parameters

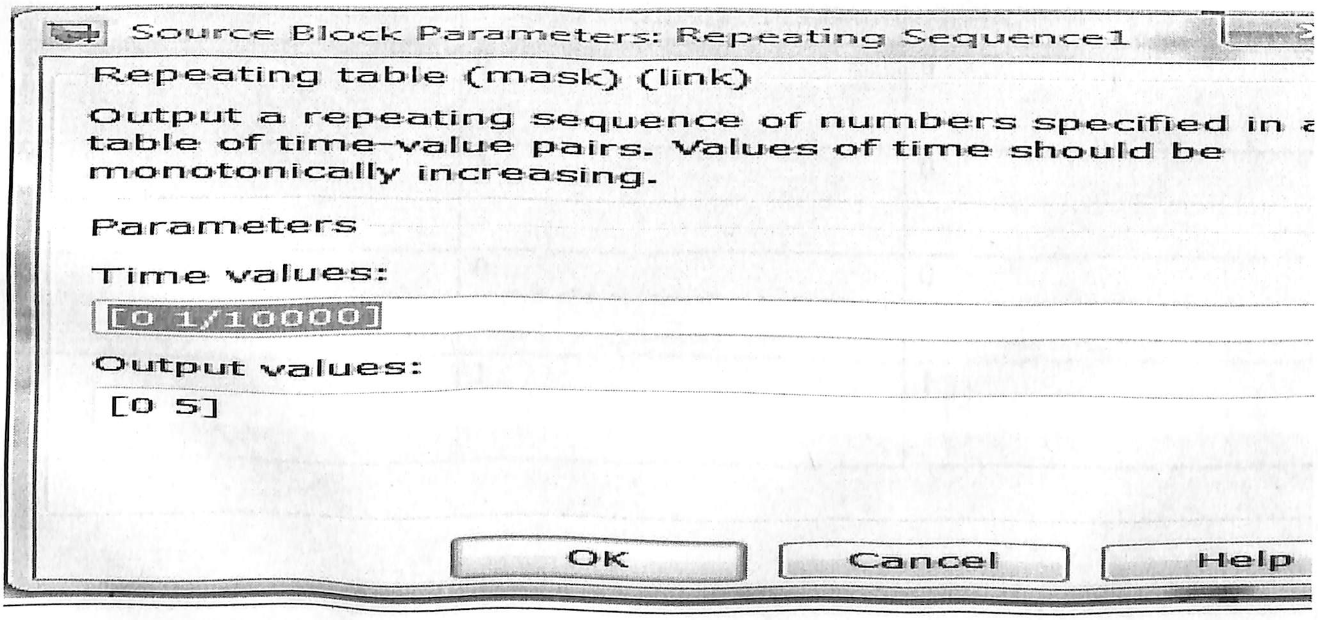
Time values:

[0 1/10000]

Output values:

[5 10]

Sawtooth 2:


Source Block Parameters: Repeating Sequence1

Repeating table (mask) (link)

Output a repeating sequence of numbers specified in a table of time-value pairs. Values of time should be monotonically increasing.

Parameters

Time values:

[0 1/10000]

Output values:

[0 5]

RELATIONAL OPERATOR:

For each phase two relational operators are used which has got two input waveforms. Thus a total of six relational opeartors are used for the 3 phase . For a single phase a single relational operatot is used to compare the sinewaveform with the 1st sawtooth waveform and gives the output. Similarly the same sinewave is compared to the 2nd sawtooth waveform and the output is achived. These output are feed directly to the scope or througe a not logic operator thus the waveforms are displayed on the different scopes present.

NOT LOGIC OPERATOR:

It works as a not gate and the output are displayed in the single unit display boxes when the program is runned. The principle on which this gate operates is:

Input signal 1	Input signal 2	output
0	0	0
0	1	0
1	0	0
1	1	1

1st phase:

INPUT SINOSUIDAL SIGNAL WITH ZERO PHASE DELAY AND THE TWO SAWTOOTH WAVEFORMS

For the first phase the scope 4 represents the three input signal waveform which are connected to it through a common buswhich is also known as Demux. The scope represents the output waveform of the input signals along with the output from relational operator and the not logic operated output. The waveform is as shown below:

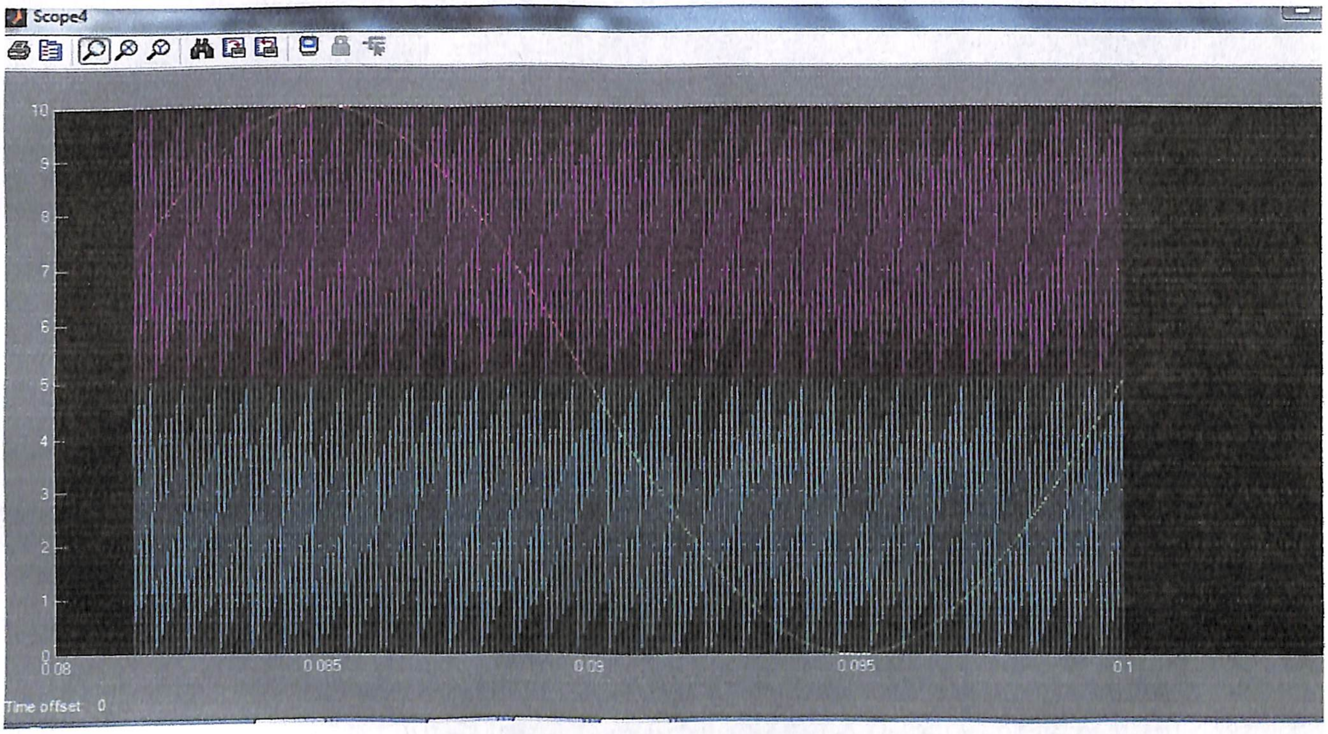


Figure 6.6.1: Snapshot of the input singles of the 1st phase

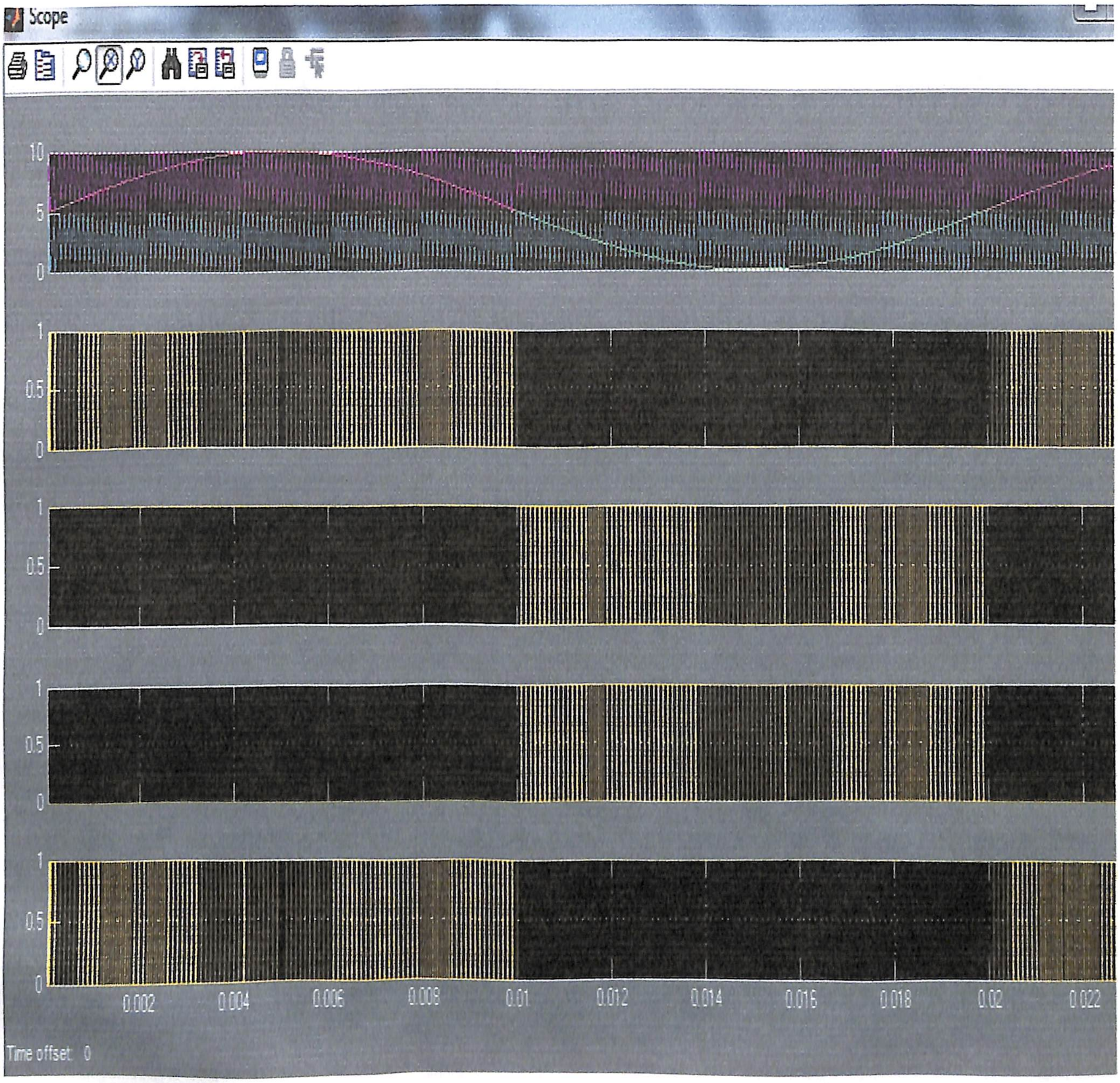


Figure 6.6.2: Snapshot of the output of scope as per the circuit diagram

Phase 2:

INPUT SINOSUIDAL SIGNAL WITH 120 DEGREE PHASE DELAY AND THE TWO SAWTOOTH WAVEFORMS

Output from scope 3 represents the input signal waveform in a similar manner as the phase 1 but the only difference is the phase difference of the sine wave. The waveform as shown in scope 3 :

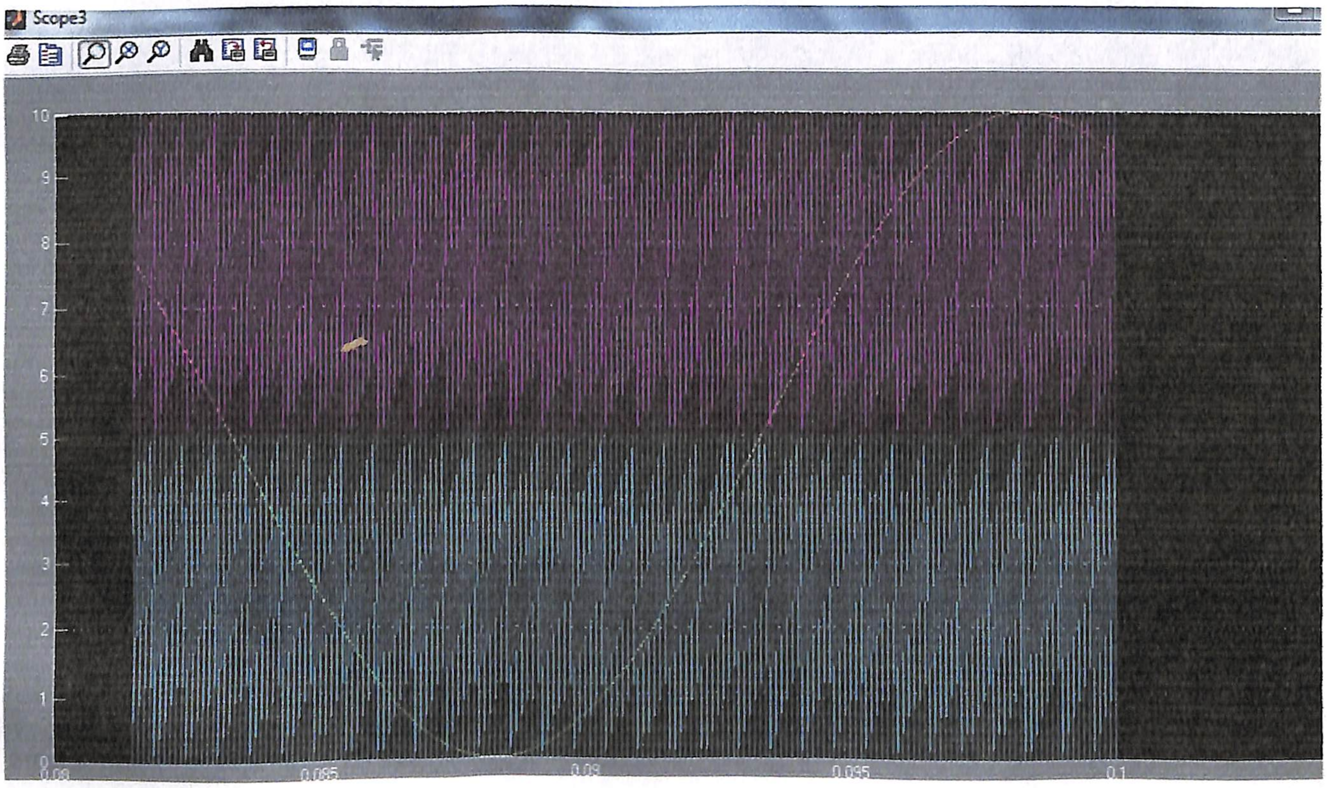


Figure 6.6.3: Snapshot of the input singles of the 2nd phase

Scope 1 represents the output wave similarly.

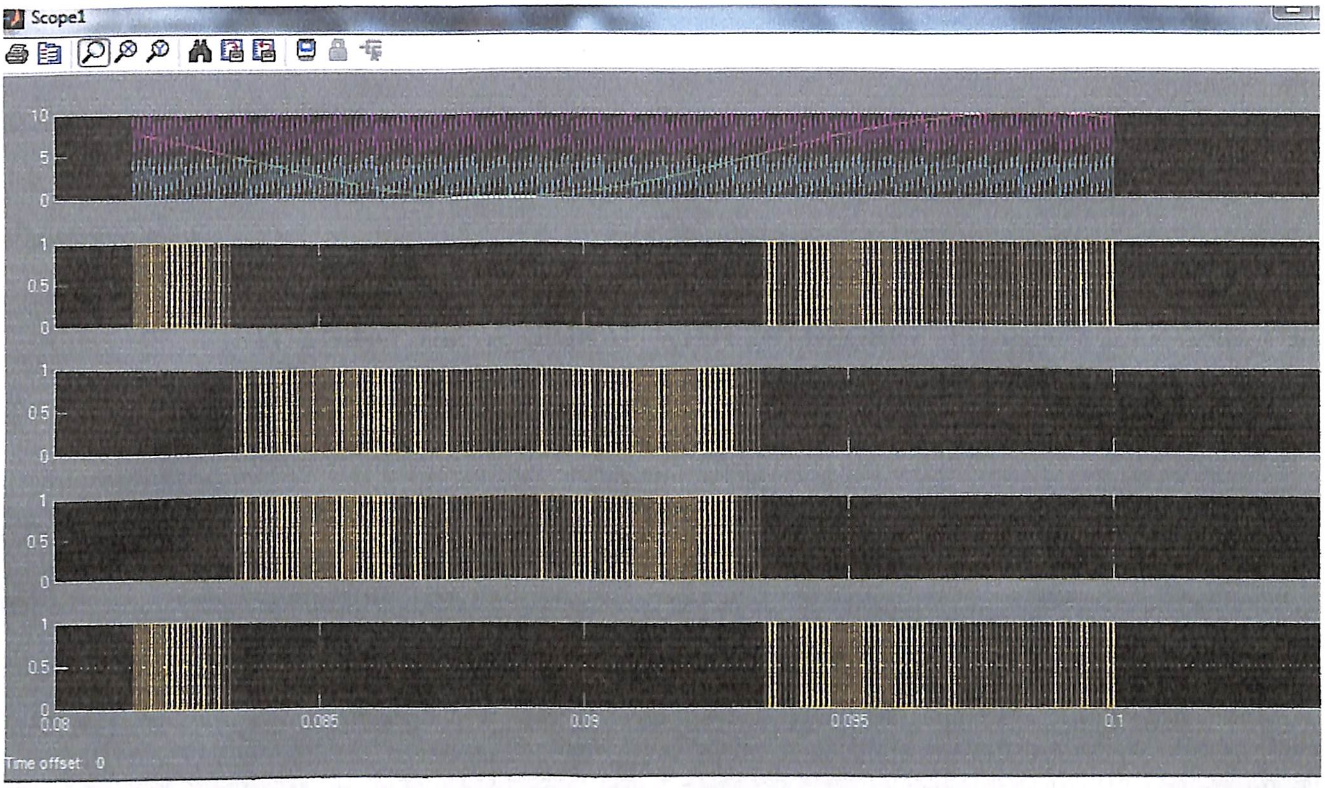


Figure 6.6.4: Snapshot of the output of scope 1 as per the circuit diagram .

Phase 3:

INPUT SINOSUIDAL SIGNAL WITH 240 DEGREE PHASE DELAY AND THE TWO SAWTOOTH WAVEFORMS

Similarly the input signal waveform from scope5 is

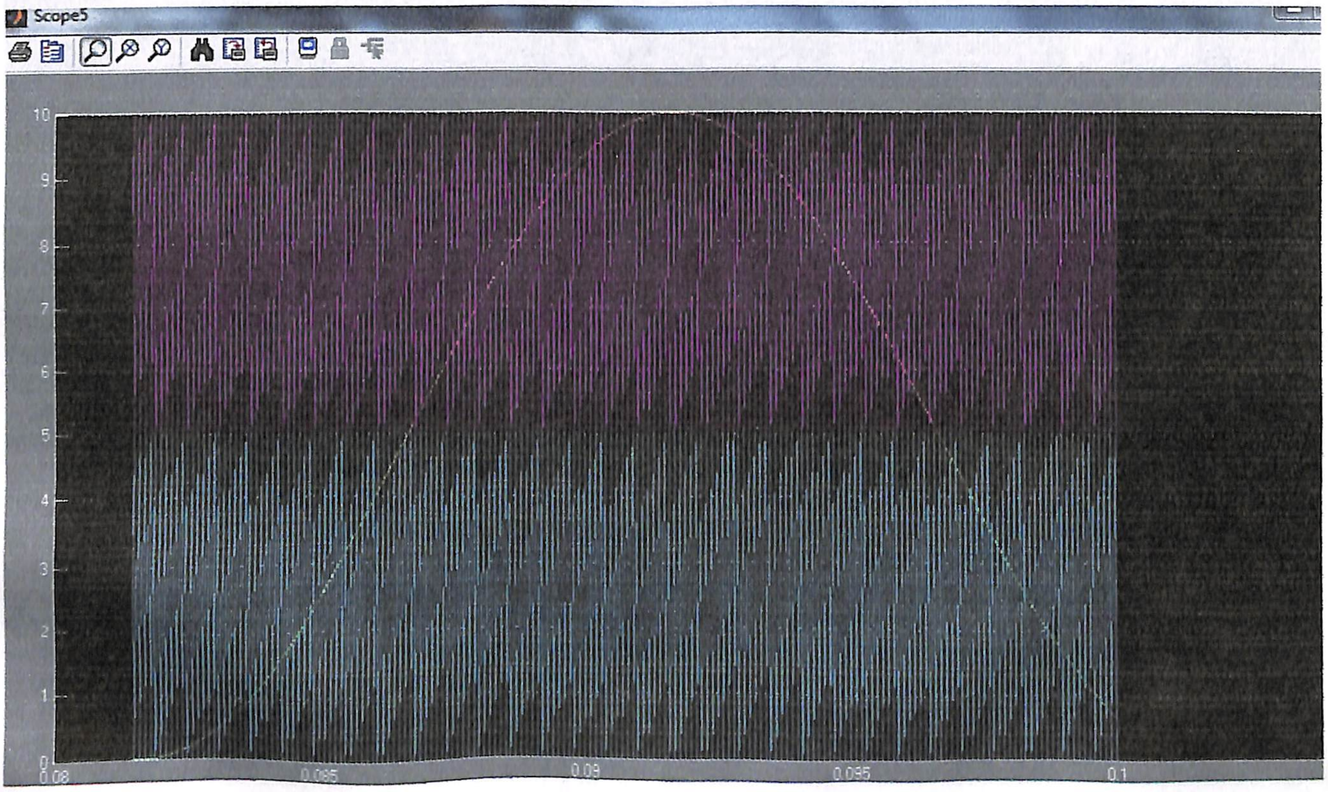


Figure 6.6.5: Snapshot of the input singles of the 3rd phase

Similarly the output waveform from scope 2 is

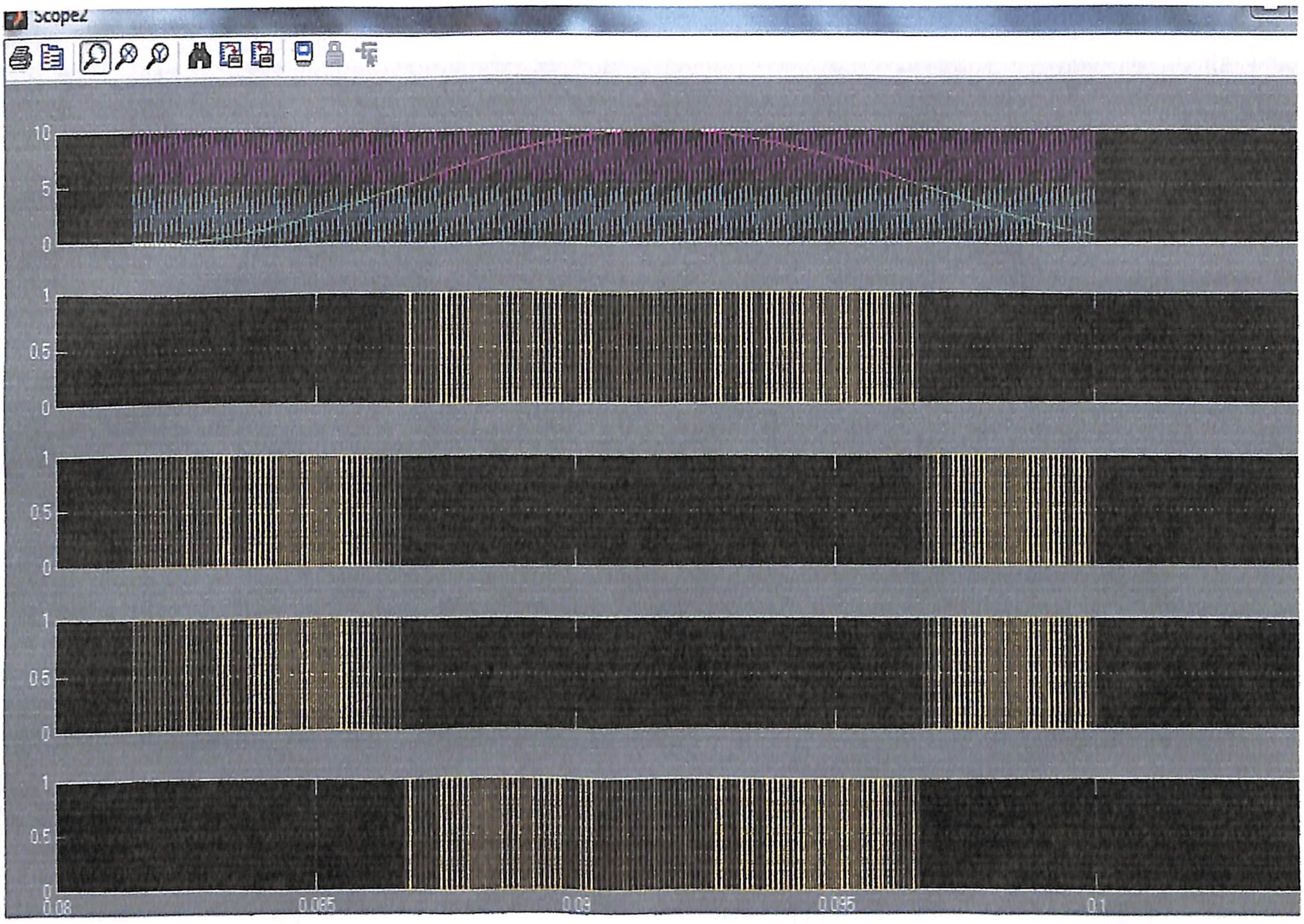
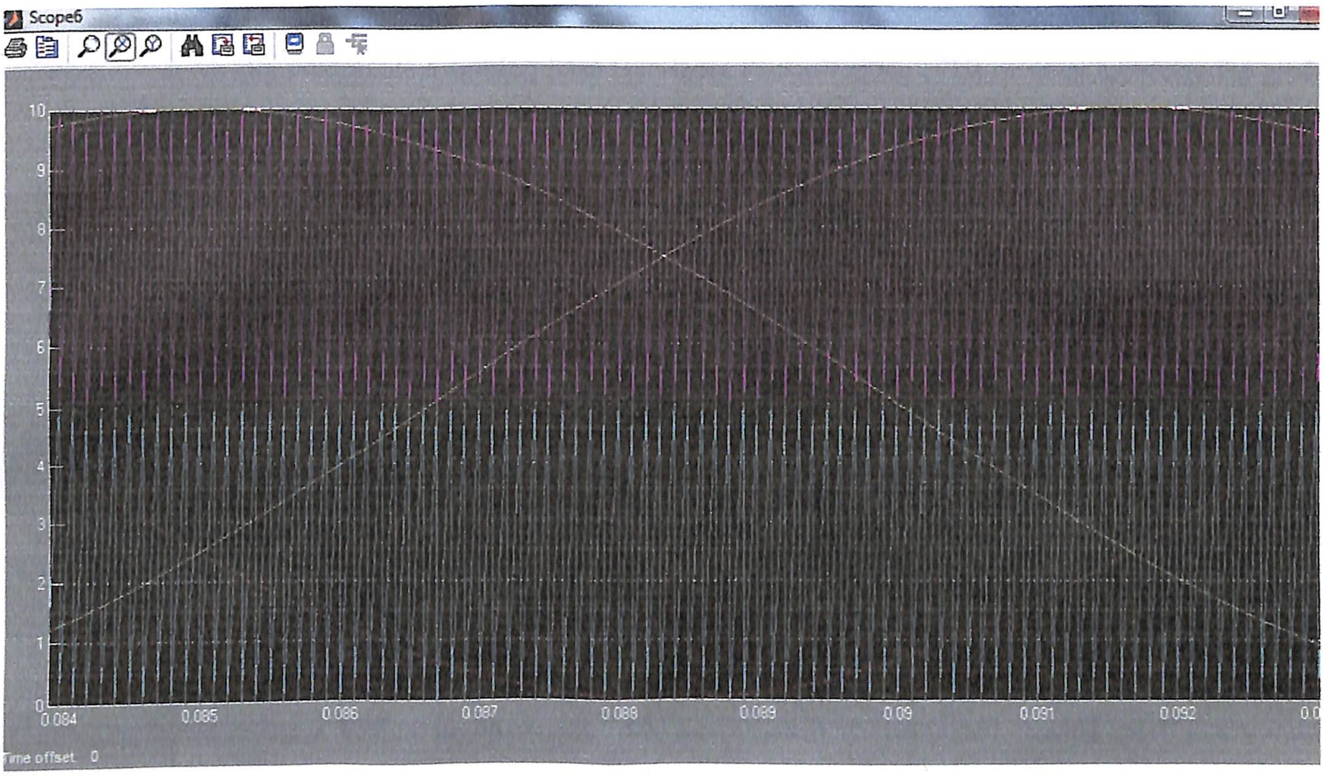


Figure 6.6.6: Snapshot of the output of scope 2 as per the circuit diagram

Scope 6: THE COMPLETE 3 PHASE INPUT SIGNAL



CHAPTER 7

CONCLUSION AND RECOMMENDATION

The study basically represents a single-phase five-level Photo-Voltaic (PV) inverter topology for grid-connected application. The represented photovoltaic models, operation of proposed inverter topology, control system algorithm, modulation technique and simulation results were observed carefully. The control system algorithms were carefully developed in C++ language and it's implemented in MATLAB version9.The FUZZ-PI current controller was used basically to produce low harmonic distortion and improved sudden step response compare to PI current controller. Thus the output which is the grid current is almost sine wave and the power factor also near unity. Further, in the system will be implemented to real time application and for this purpose a filter circuit after the inverter is highly recommended.

Thus, grid-connected PV system based on MATLAB has been proposed. Based on the accurate modeling system, maximum power point tracking (MPPT) and fault analysis are studied. The control consists of a current control strategy and a voltage control strategy. The Current control strategy permits dc-link voltage regulation and enables power factor control. Moreover, the current –control strategy significantly decouples dynamics of the PV system from those of the distribution network and loads. Furthermore, it is expected that the current control strategy renders the PV system protected against external faults. Voltage control strategy can achieve the maximum power point tracking and maximization of the real power output of the PV system. MATLAB/SIMULINK model of grid connected photovoltaic (PV) system is useful to understand and master the performance of PV systems and also to optimizing the design and lowering costs. It is also useful for shorten development cycles as well as improve system reliability and efficiency.

REFERENCES:

1. Darren M. Bagnall, Matt Boreland, "Photovoltaic technologies", Energy Policy, Vol 36, pp. 4390-4396, 2008.

2. C.Hua,C.Shen,:"Comparative Study of Peak Power Tracking Technique for solar storage system, "IEEE Applied power electronics conference and Exposition proceeding,Vol.2,Feb.1998

3. C.Hua and CShen, "Study of Maximum Power Tracking Technique and controlof DC/DC CONVERTER FOR Photovoltaic system ,IEEE Computer soc.press,New York,USA,1998

4. S. Oh, M. Sunwoo, "Variable structure PWM controller for high efficient PV inverters," IEEE International Conference on Sustainable Energy Technologies, pp. 24-27, Nov. 2008.

5. . A. Bellini, S. Bifaretti, V. Iacovone, "Resonant DC-DC converters for photovoltaic energy generation systems," International Symposium on Power Electronics, Electrical Drives, Automation and Motion, pp. 815-820, Jun. 2008.

6. O.Wasynczuk, N. A. Anwah, "Modeling and dynamic performance of a self-commutated photovoltaic inverter system," IEEE Transaction on Energy Conversion, vol.4, no.3, pp. 322-328, Sep. 1989.

7. A. Yazdani and P.P. Dash, "A Control Methodology and Characterization of Dynamics for a Photovoltaic (PV) System Interfaced With a Distribution Network" IEEE Trans. Power Del., vol. 24, no. 3, pp.1538–1551, Jan. 2009.

8. A.Yazdani and R.Iravani, “An accurate model for the dc-side voltage control of the neutral point diode clamped converter,” IEEE Trans.Power Del., vol. 21, no. 1, pp. 185–193, Jan. 2006.
9. . Hussein K H, Muta I, Hoshimo T, Oskada M, “Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions, generation, transmission and distribution,” IEE Proceedings, vol.142, no.1, pp. 59-64, 1995.