

BRAC UNIVERSITY

Design of photovoltaic power conditioning incorporating maximum power point tracking of solar cell

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Thesis Supervised By

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DECLARATION

We hereby declare that this thesis is based on the results found by ourselves . Materials of work found by other researcher are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

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Chapter 1

INTRODUCTION

Human civilization started thousand years back But major inventions took place only in last few centuries. Out of all the inventions – the inventions of electricity has pushed the civilization to a greater height. At such a point, let us imagine a day when all known energy resources i.e. fossil fuel of the ‘Mother Earth’ will finally be exhausted. No electricity will be there to eliminate our houses and street, to operate household appliances and gazettes. Industries, cars, buses, aero planes finally be immobilized and come to stand still. Civilization will come at stake. To avoid such a disaster and civilization process, to continue scientists have started to explore on two major issues – firstly, improve the efficiency of present power conversion and utilization system. Secondly, develop efficient energy renewable energy generation and conservation systems to supplement conventional fossil fuel based energy supply and eventually replace it. Amongst the renewable energy – solar energy ranks the top. As offers promising solution to problems of obtaining and adequate energy source. It has got advantages over more disadvantages.

Solar Energy or photovoltaic energy has been the number one power supply of choice for many purposes. The reasons that made its popularity are – non-polluting renewable energy, clean and silent, ability to regenerate, efficiency of conversion is independent. Besides that it has got disadvantages like - low efficiency, high cost, maintenance difficulties. Having such problems sill the application of solar energy is increasing day by day. With the present research, the costs of solar cells are expected to go down as it became impossible to fulfill the electricity demand.

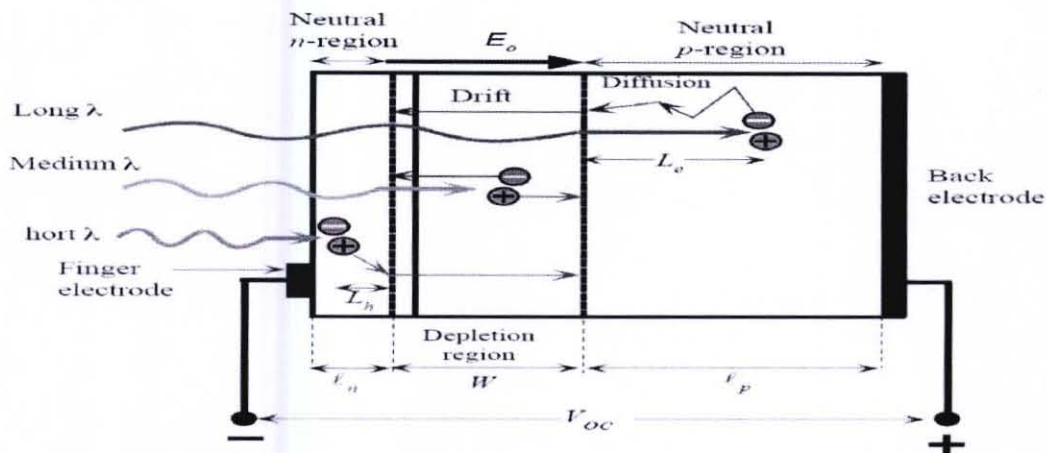
The electric power that is used in house is A.C. power. The solar energy is known as the D.C power and here to use this energy this D.C power is converted into A.C through an inverter. By using a controller maximum power is tracked and use as the A.C power.

Chapter 2

Solar Cell

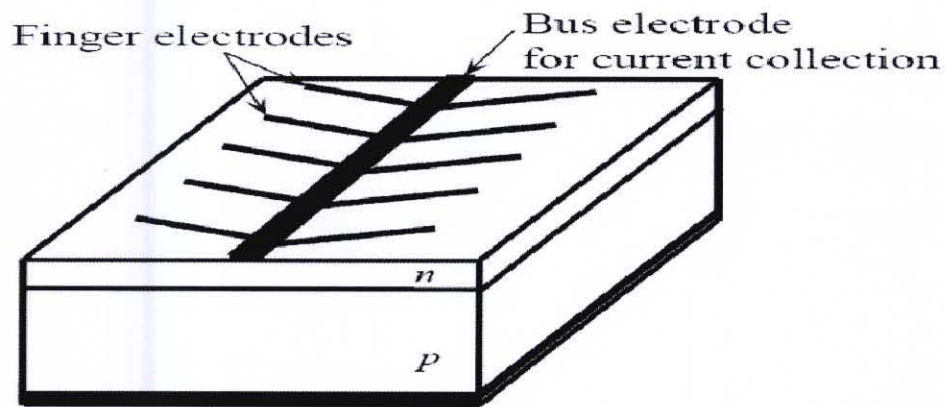
Solar cell or photovoltaic cell is the device that converts solar energy to the electrical energy .

2.1-Construction

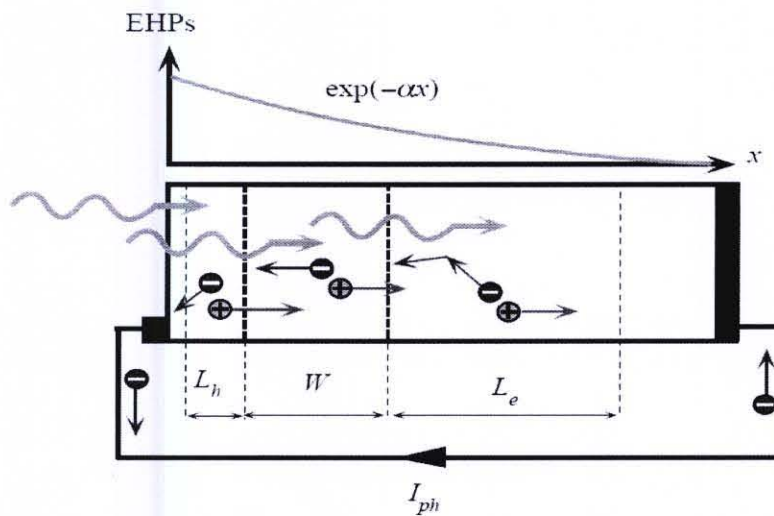


The principle of operation of the solar cell (exaggerated features to highlight principles)

In this above schematic diagram of p-n junction of solar cell , there are narrowly and heavily doped n region and lightly doped p region . Between p and n region there are depletion (space charge layer) region . The depletion region tends to p region .There is a built in voltage , E_o in the depletion region .Electrodes attached to the n type must allow the photon to enter to the device . The electrodes has the shape of finger . There is an anti-reflection coating on the surface that allows light to enter into the device .



2.2 Principle of Solar Cell



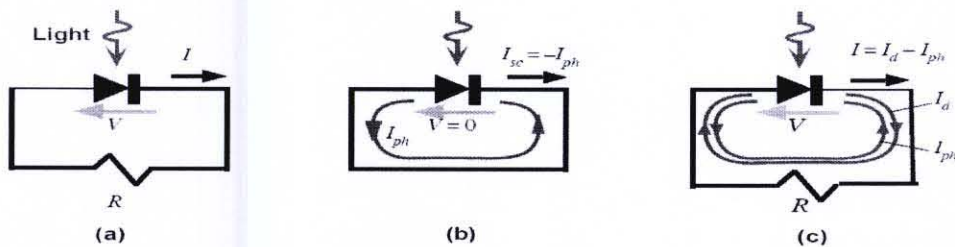
Photogenerated carriers within the volume $L_h + W + L_e$ give rise to a photocurrent I_{ph} . The variation in the photogenerated EHP concentration with distance is also shown where α is the absorption coefficient at the wavelength of interest.

Photons entered into the device are absorbed in depletion and p region because the n region is very narrow. The built in voltage, E_0 make the EHP (electron hole pair) to be separated that made in this depletion region. The electrons drift to neutral n+ side and holes drift to neutral p side to make the side negative and

positive respectively . An open circuit voltage develops between the two sides . If external load is connected , the excess electrons travel to the p side and recombine with the excess holes of p side .

The EHPs photogenerated by long wavelengths are absorbed in this neutral p side as there is no electric field .

2.3 Current Conduction In Solar Cell



(a) The solar cell connected to an external load R and the convention for the definitions of positive voltage and positive current. (b) The solar cell in short circuit. The current is the photocurrent, I_{ph} . (c) The solar cell driving an external load R . There is a voltage V and current I in the circuit.

We consider to connect a load to a solar cell as in the above figure a .The current (I) and the voltage (v) in this figure convention for the direction of positive current and positive voltage . If the load is short circuit , the current generated by light is called photocurrent I_{ph} . Photocurrent depends on EHPs that is generated in the depletion . If load R is not short circuited like in figure C , the positive voltage occurs in the load as the current passes .This voltage decreases the built in voltage of the p-n junction and leads the minority carrier injection and diffusion just like normal diode . There also occurs a diode current I_d in the circuit which arises voltage across R .

In an open circuit the net current is zero . Diode current develops when there is positive voltage and photocurrent . The total current is now shown below

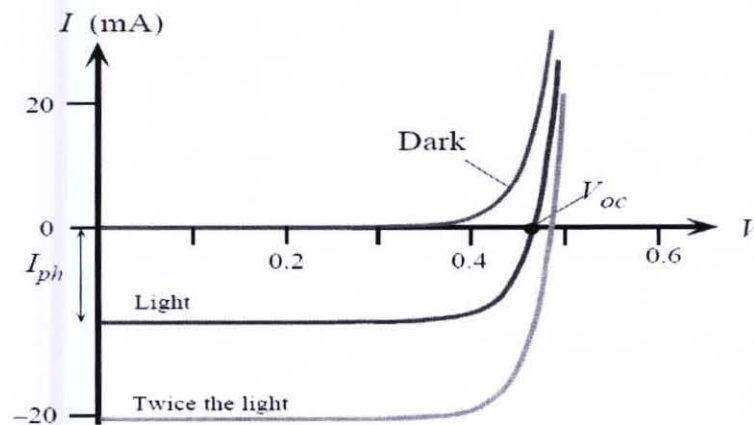
$$I = -I_{ph} + I_0 \left[\exp\left(\frac{eV}{nk_B T}\right) - 1 \right]$$

Here n is the 'ideality factor' which depends on the material .

2.4 I-V Characteristic Curve

The I-V characteristics curve is shown below . We can see that the normal dark characteristics has been shifted by the photocurrent I_{ph} . The open circuit output voltage , V_{oc} is shown by the point where I-V curve intersects the V-axis .

Approximately , the open circuit voltage V_{oc} is 0.4 to 0.6 v .



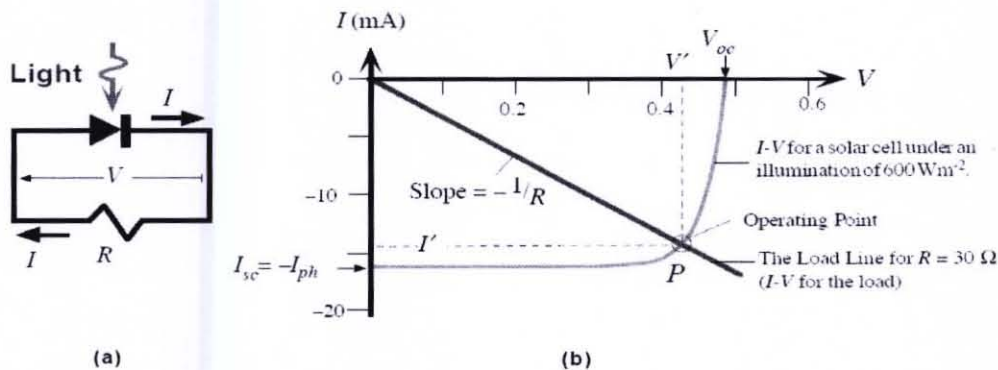
Typical I - V characteristics of a Si solar cell. The short circuit current is I_{ph} and the open circuit voltage is V_{oc} . The I - V curves for positive current requires an external bias voltage. Photovoltaic operation is always in the negative current region.

From the above equation (1), load and solar cell has the same voltage . But the current flows through the load has the opposite direction of the voltage and it flows from the high potential to the low potential .

$$I = -V/R \dots \dots \dots (2)$$

The actual current and voltage must satisfy both equation (1) and (2). We can Find the actual current and voltage by solving both equations but it is not an analytical procedure . We can solve this equations graphically by the solar cell characteristics .

The actual current and voltage in the solar cell are easily found by the load line construction . I-V characteristics of equation (2) is a negative slope curve which is shown in the figure below . The load line intersects with solar cell characteristics at P . At P , we have the same current and voltage . Point P satisfies the both equation (1) and (2) and this point is called the operating point of the circuit .



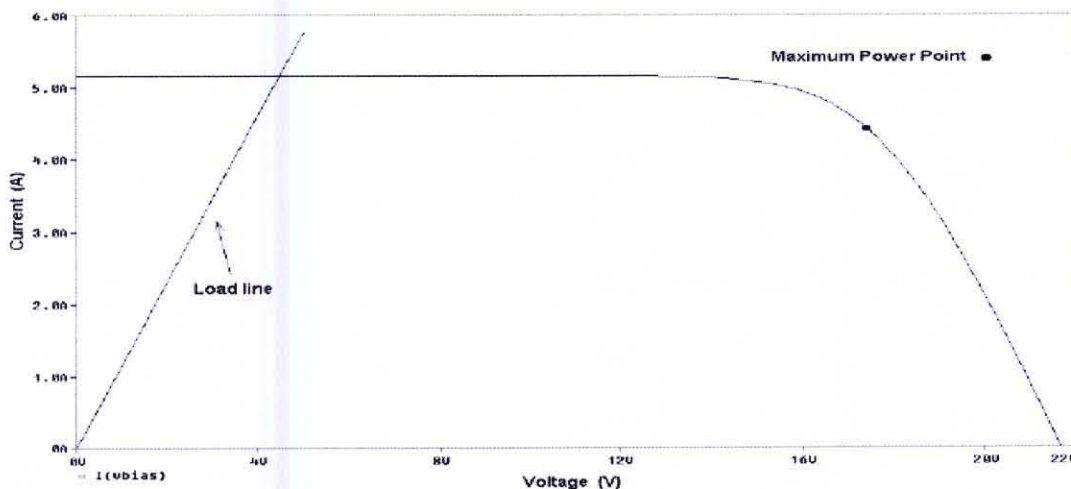
(a) When a solar cell drives a load R , R has the same voltage as the solar cell but the current through it is in the opposite direction to the convention that current flows from high to low potential. (b) The current I' and voltage V' in the circuit of (a) can be found from a load line construction. Point P is the operating point (I', V'). The load line is for $R = 30 \Omega$.

Chapter 3

Maximum Power Point Tracking

Maximum power point is the point for where we get the highest power in the solar cells. If the operating point goes through the maximum power point, we get the maximum power. If the operating point goes slightly below or above the MPP we will not get the maximum power.

We can see in the picture below that though the load line intersects the solar cell characteristics but can not give the maximum power. It is away from the maximum power point. So, the operating point is not the maximum power point in many cases.



There are so many researches based on maximum power point tracking. These are given below –

1. Perturb and Observe (P & O) Algorithm
2. Incremental Conductance Algorithm
3. Parasitic Capacitance Algorithm
4. Constant Voltage Algorithm

Comparing all the algorithms it is seen that P&O algorithms is more favourable than other algorithms.

Chapter 4

INVERTER

Inverter or power inverter is a device that converts the DC sources to AC sources. Inverters are used in applications such as adjustable-speed ac motor drivers; uninterruptible power supplies (UPS) and ac appliances run from an automobile battery.

Power inverters produce one of the three different types of wave output:

1. Square Wave
2. Modified Square Wave (Modified Sine Wave)
3. Pure Sine Wave (True Sine Wave)

The three different wave signals represent three different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most devices. Square wave inverters were the first type of inverters made.

4.1 Modified Sine Wave:

Modified sine wave inverters were the second generation of power inverter. The modified sine wave inverter provides a cheap and easy solution to powering device that need AC power. Modified sine wave inverters approximate a sine wave and have low enough harmonics that do not cause problem with household equipments. It does have some drawbacks as not all the devices work properly on a modified sine wave, product such as computer and medical equipment need pure sine wave inverter. The main disadvantage of the modified sine wave inverter is that peak voltage varies with the battery voltage.

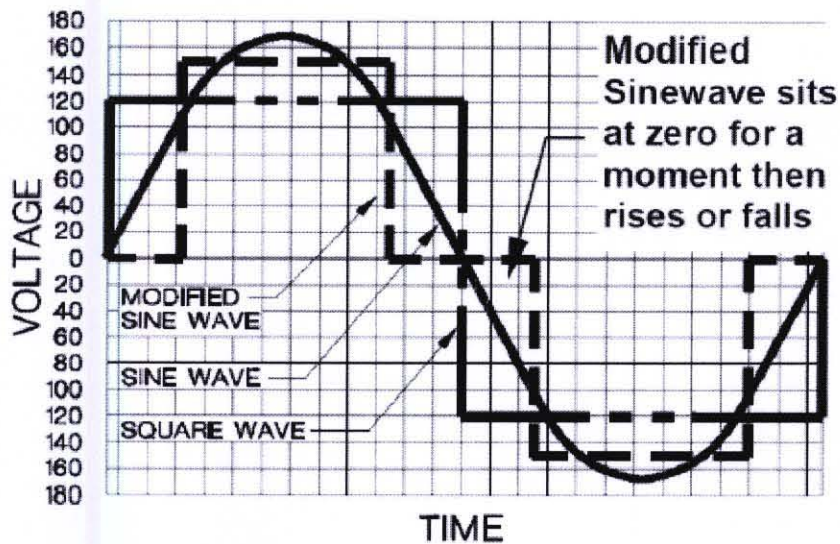


Figure: Square, Modified and Pure Sine Wave

4.2 True Sine Wave:

True sine wave inverter represents the latest inverter technology. The waveform produced by these inverters is same as or better than the power delivered by the utility. Usually sine wave inverters are more expensive than the modified sine wave inverters due to there added circuitry.

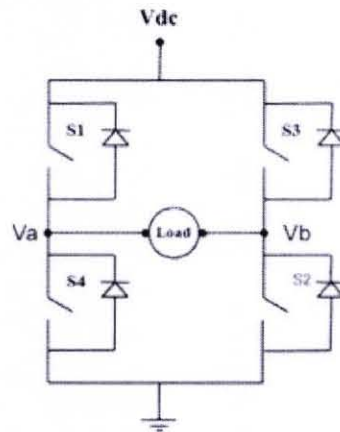
4.3 Pulse Width Modulation:

Pulse width modulation (PWM) is a powerful technique for controlling analog with a processor's digital outputs. The applications of PWM are wide variety used like ranging from measurement and communications to power control and conversion. In PWM inverter harmonics will be much higher frequencies than for a square wave, making filtering easier.

In PWM, the applitude of the output voltage can be controlled with the modulating waveforms. Reduced filter requirments to decrease harmonics and the control of the output voltage amplitude are two distinct advantages of PWM. Disadvantages include

more complex control circuits for the switches and increased losses due to more frequent switching.

Control of the switches for sinusoidal PWM output requires (1) a reference signal, sometimes called a modulating or control signal, which is a sinusoidal in this case; and (2) a carrier signal, which is a triangular wave that controls the switching frequency.



FigureX: A full bridge inverter

4.4Bipolar Switching:

When the instantaneous value of the sine reference is larger than the triangular carrier, the output is at $+V_{dc}$, and when the reference is less than the carrier, the output is at $-V_{dc}$.

$$V_0 = +V_{dc} \quad \text{for} \quad V_{sin} > V_{tri}$$

$$V_0 = -V_{dc} \quad \text{for} \quad V_{sin} < V_{tri}$$

This version of PWM is bipolar because the output alternates between plus and minus the dc power supply voltage.

From figureX we can see that

S1 and S2 are on when $V_{sin} > V_{tri}$

S3 and S4 are on when $V_{sin} < V_{tri}$

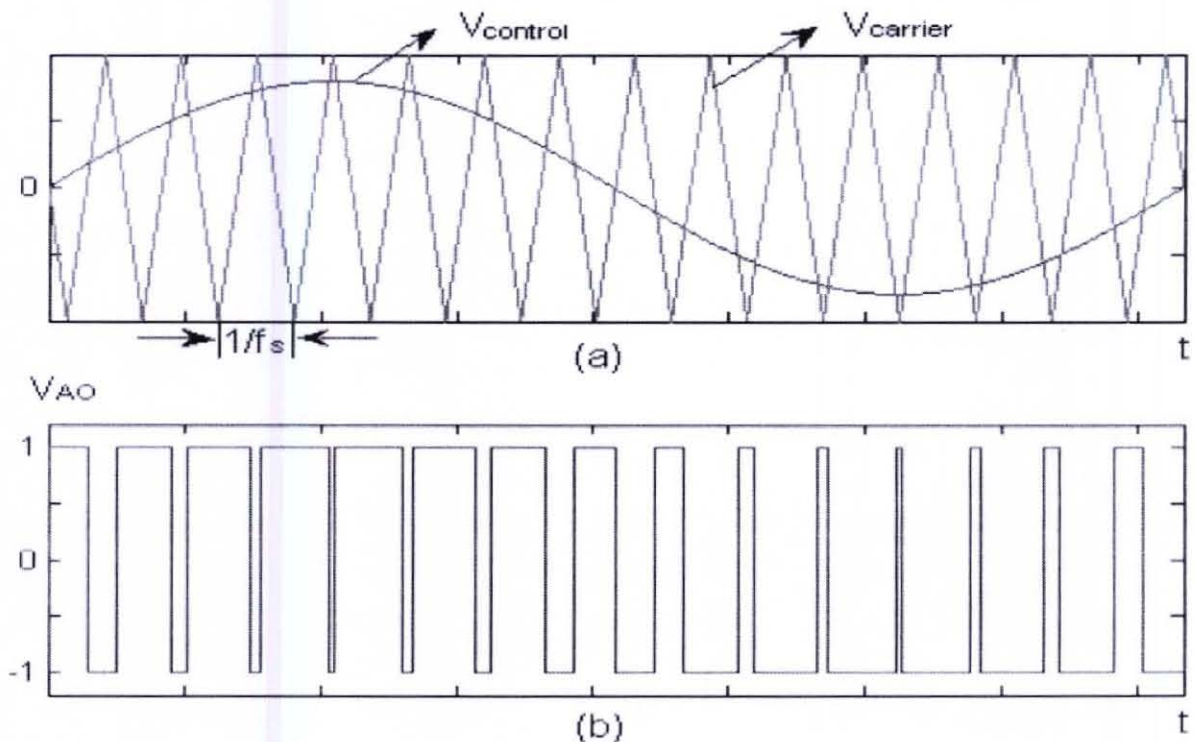


Figure: Bipolar pulse width modulation. (a) Sinusoidal reference and triangular carrier.
 (b) Output is $+V_{dc}$ when $V_{\text{sin}} > V_{\text{tri}}$ and is $-V_{dc}$ when $V_{\text{sin}} < V_{\text{tri}}$.

4.5 Unipolar Switching:

In a unipolar switching scheme for pulse width modulation, the output is switched from either high to zero or low to zero, rather than between high and low, as in bipolar switching. For unipolar switching control as follows:

S1 is on when $V_{\text{sin}} > V_{\text{tri}}$

S2 is on when $-V_{\text{sin}} < V_{\text{tri}}$

S3 is on when $-V_{\text{sin}} > V_{\text{tri}}$

S4 is on when $V_{\text{sin}} < V_{\text{tri}}$

Here we can see that switch pair (S1,S4) and (S2,S3) are complementary.

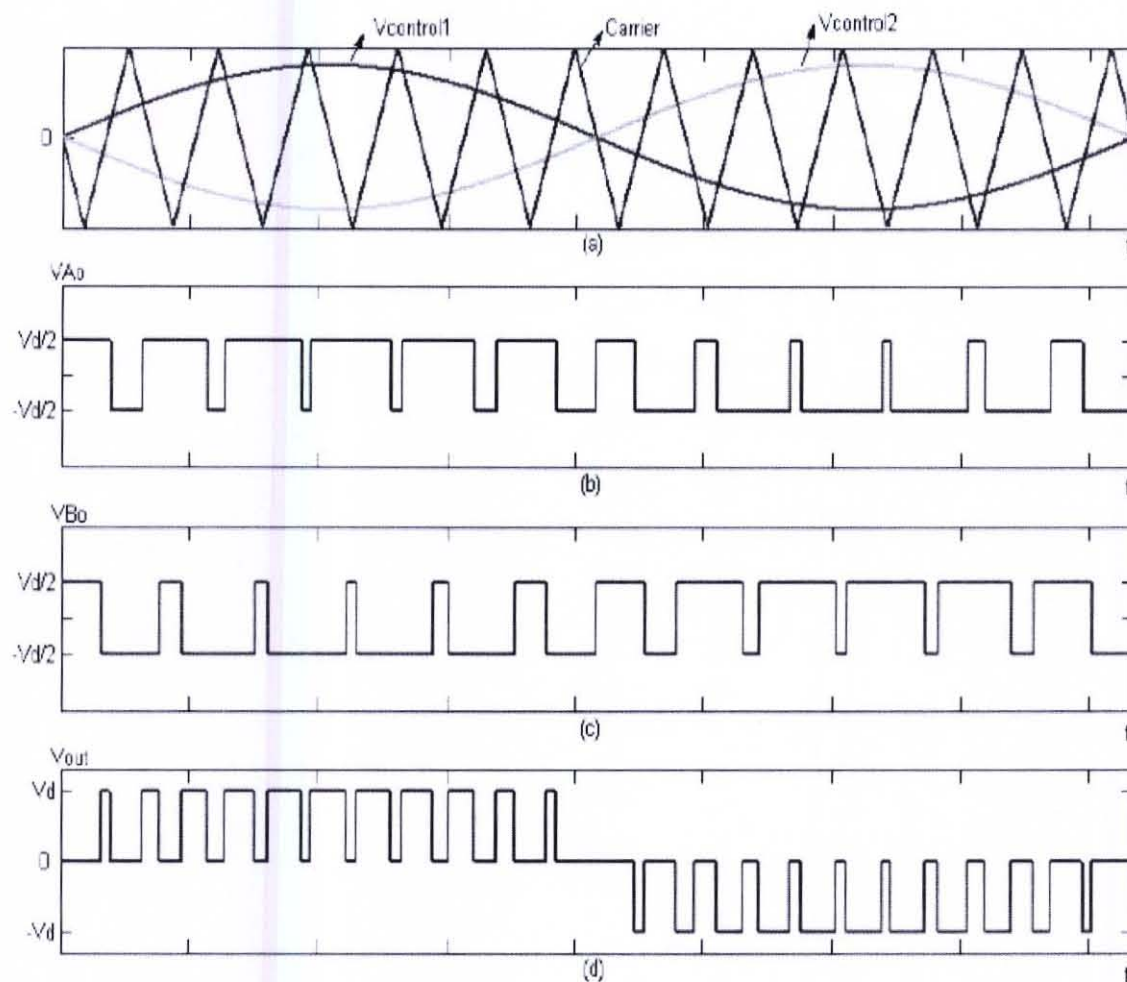


Figure: Unipolar PWM scheme and output voltage.

4.6 Modified Unipolar Switching:

In modified unipolar PWM approach two arm switch at different frequencies: one is at fundamental frequency while the other one is at carrier frequency, thus having two high frequency switches and two low frequency switches. It also produces unipolar output voltage waveform changing between 0 and $+V_{dc}$ or between 0 and $-V_{dc}$.

In this switching scheme,

S1 is on when $V_{sin} > V_{tri}$ (high frequency)

S4 is on when $V_{sin} < V_{tri}$ (high frequency)

S2 is on when $V_{sin} > 0$ (low frequency)

S3 is on when $V_{sin} < 0$ (low frequency)

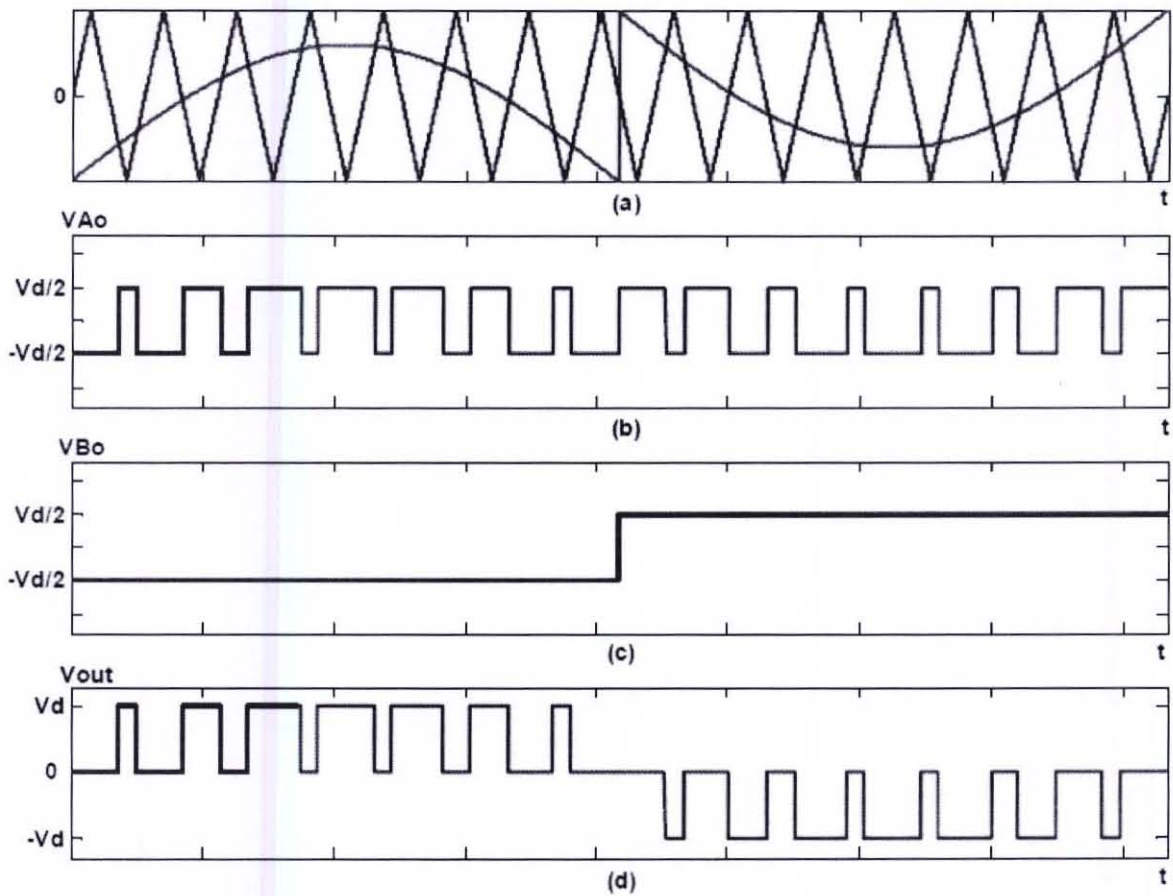
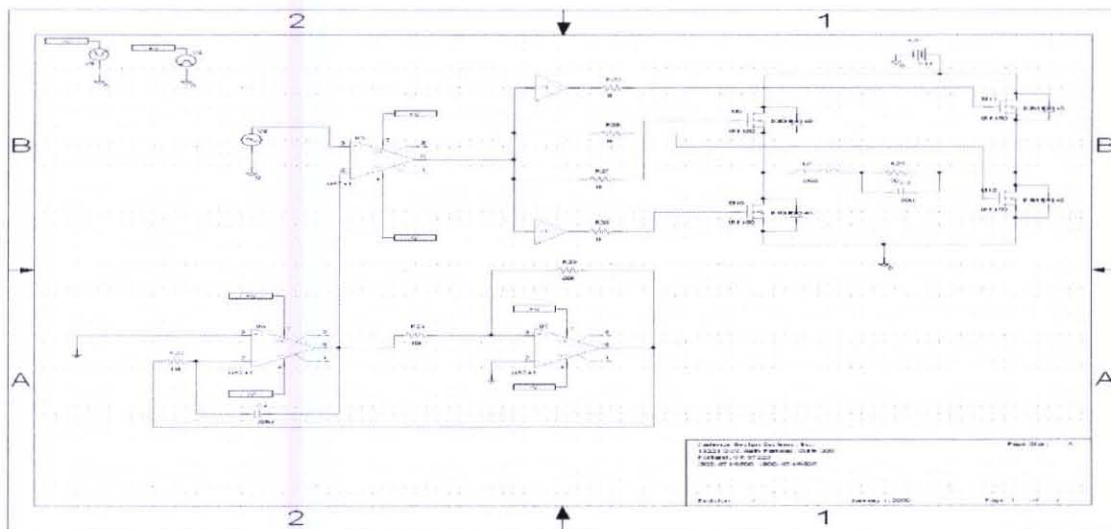


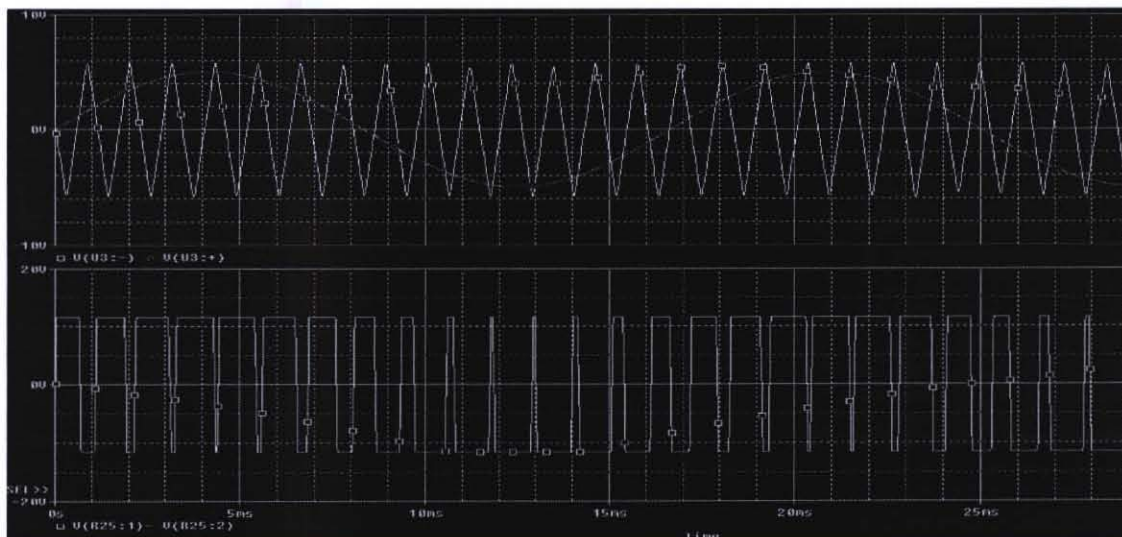
Figure: Modified Unipolar PWM scheme and output voltage

Chapter 5 Simulation

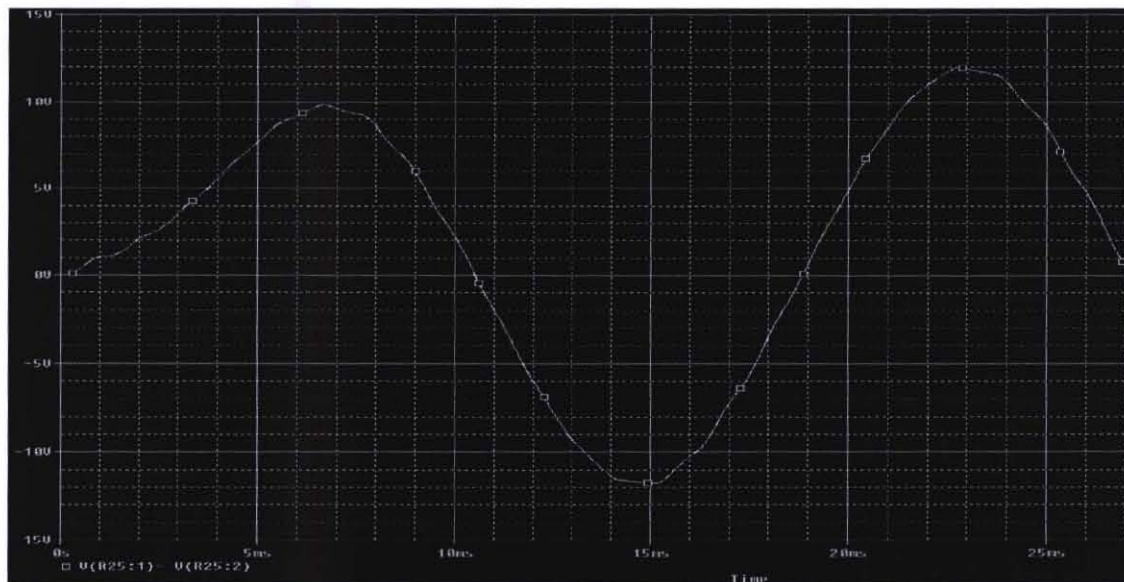
In simulation process we use ORCAD program. For the bipolar PWM approach as we have seen earlier we need triangular wave generator and a sign wave generator. But in ORCAD we don't have to use sign wave generator as we get built in there. Then we connect it with H-bridge inverter. The figure is shown below:



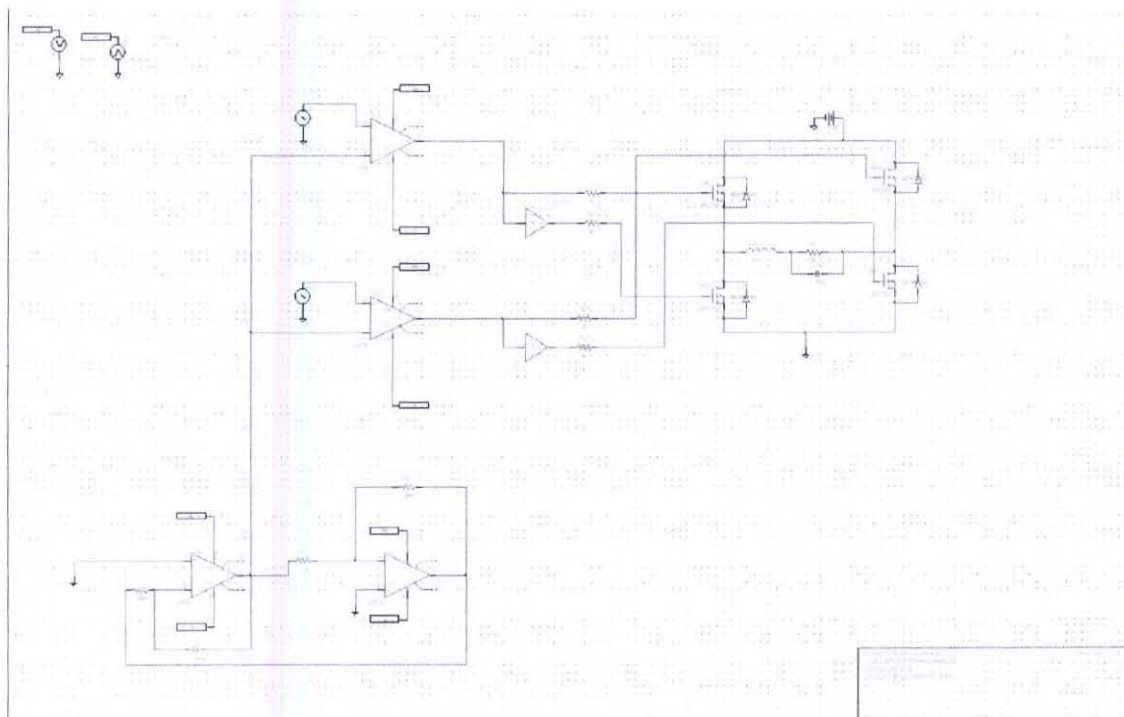
Gate Voltages:



After Low Pass filter:

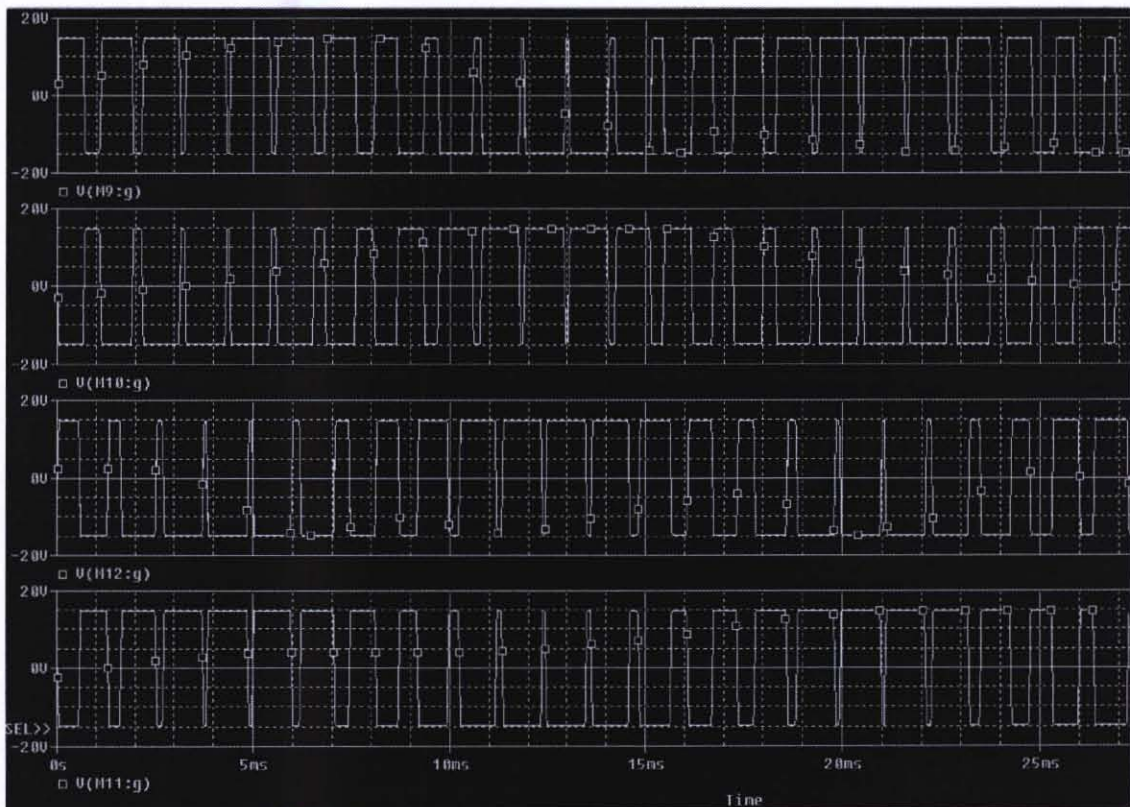


Unipolar:

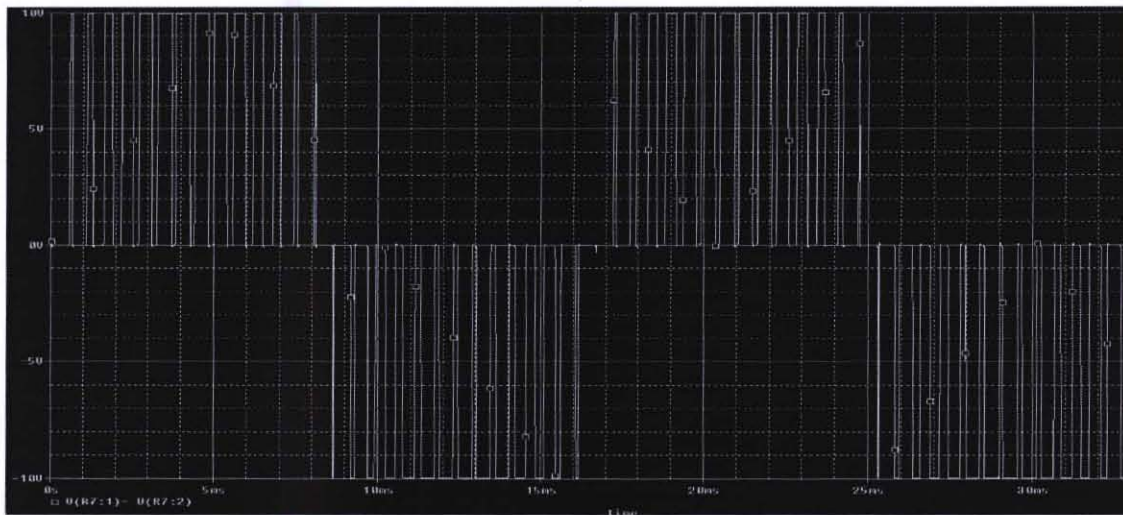




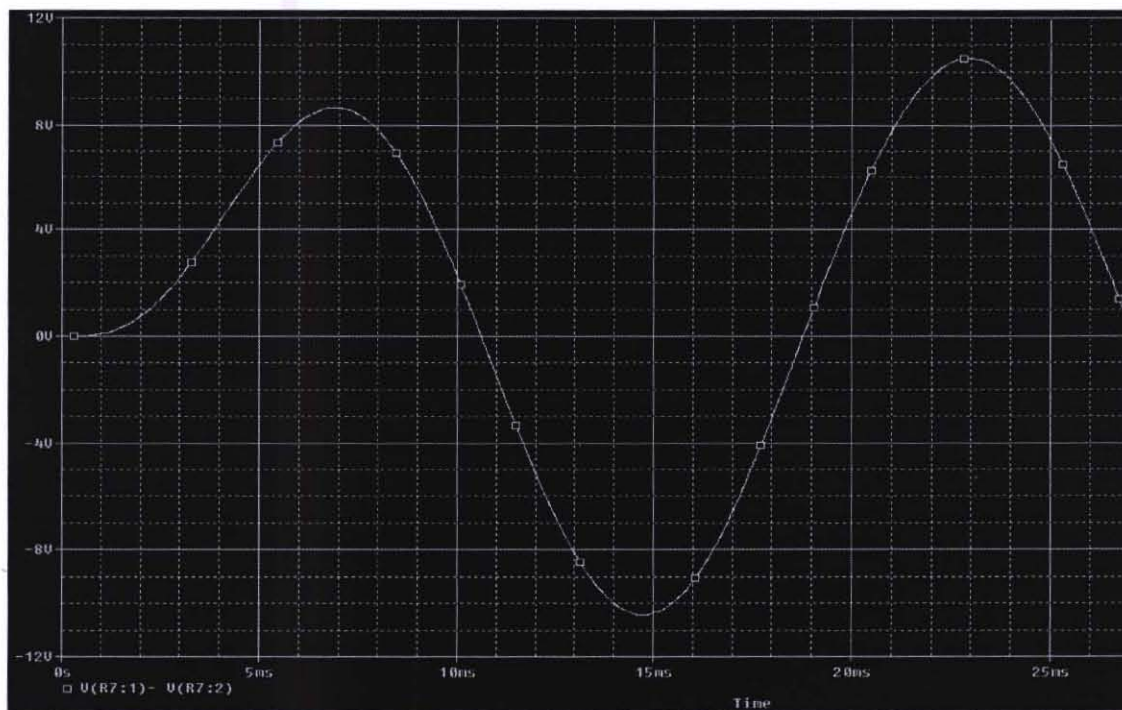
Gate voltages :



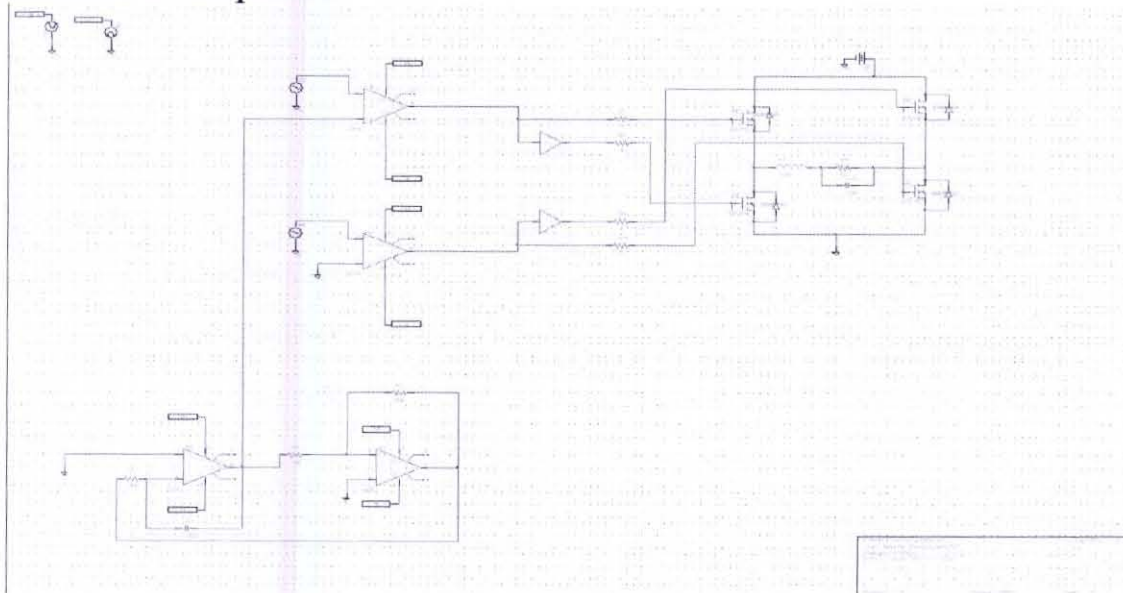
Before LC filter :



Using LC Filter :



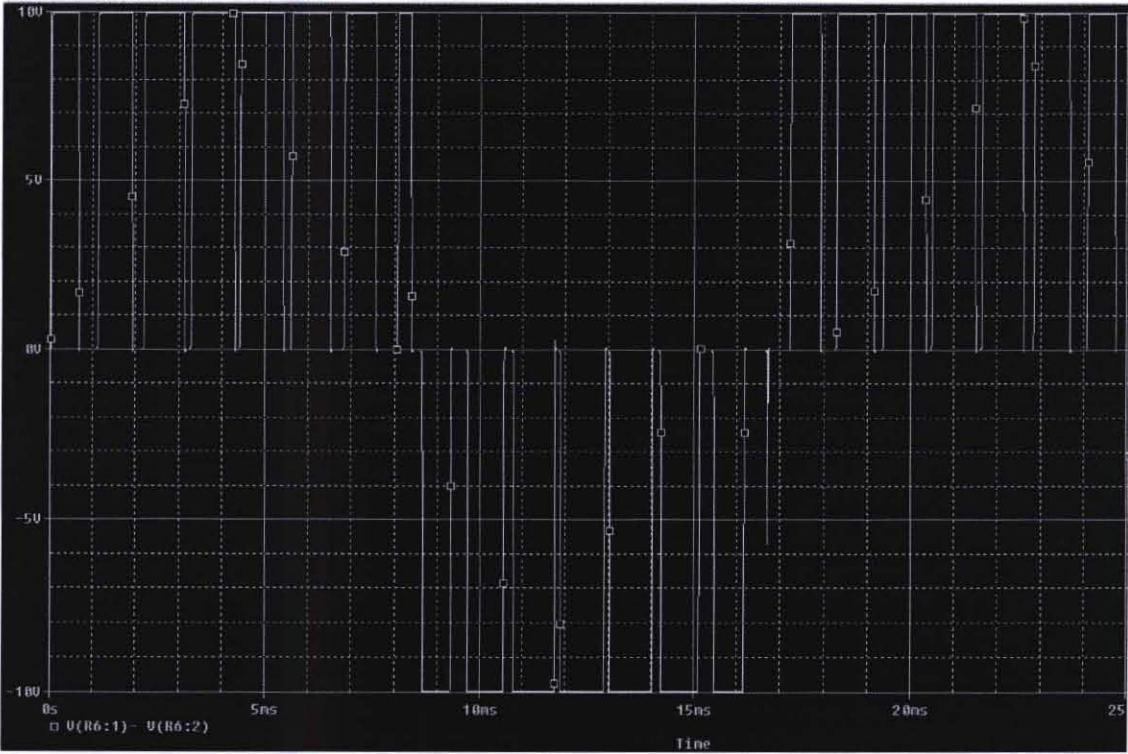
Modified Unipolar:



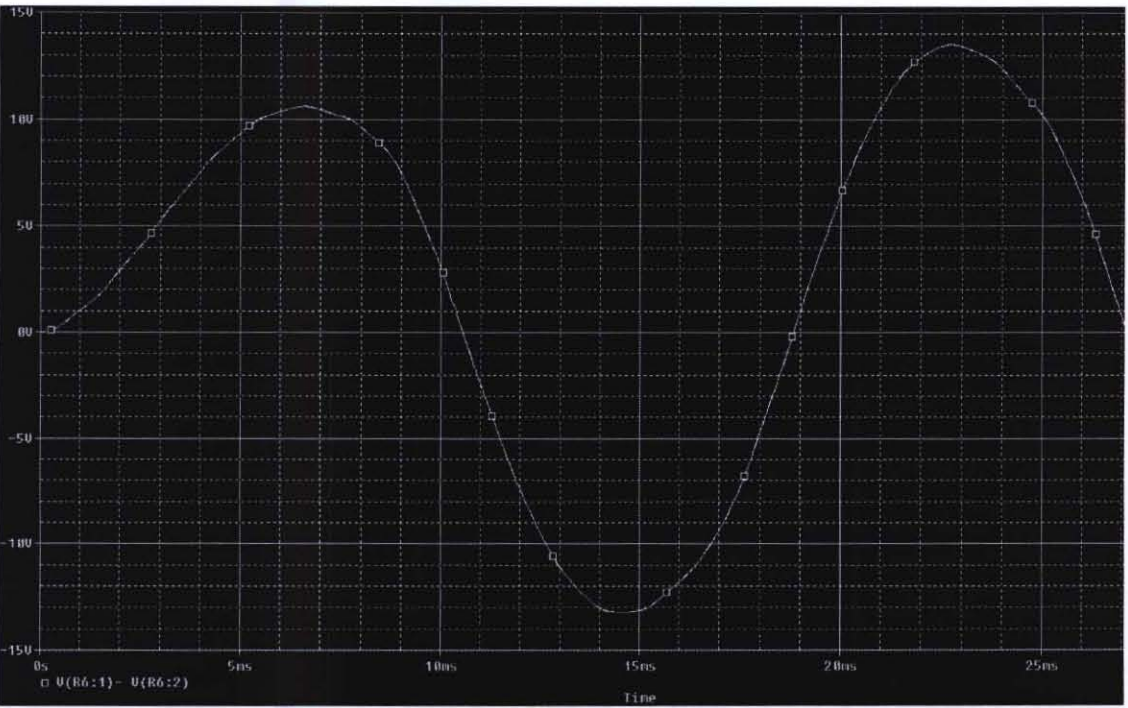
Gate Voltages :



Before LC filter :



After LC Filter :



Chapter 6

Future work

MPPT (Maximum Power Point Tracking)

The maximum power tracking control permits extraction of maximum available power from the solar array in steady state operation. What we will see that it requires no special sensors to detect the solar radiation level and temperature and is applicable to any type of solar cell. We will show an equation from which we can see that we can track the maximum power point tracking by controlling both modulation and phase angle of the PWM inverter output voltage or by keeping one of the parameter constant and varying the other. Though decreasing modulation will decrease inverter efficiency we will keep modulation factor constant while phase angle will changing. To implement this control system we can consider two methods. Method 1 is calculating the solar cell output characteristics in ahead of different values of radiation and temperature. Then for different values of temperature and radiation, controlling the solar cell operating point in optimum position. Method 2 is detecting the solar cell output current and voltage simultaneously and driving the operating point at optimum position by continuous time feedback control. Method 1 has the demerits that the solar cell output characteristics differ foe different types of solar cell. Special flux and temperature detecting sensor is also necessary for this method We will implement the Method 2.

Hardware Implementation:

We will implement the whole PWM inversion circuit and the control circuit in hardware level. Though we get a very good output voltage in software simulation but in hardware level implementation we can face any problem that we will have to overcome.

Transformer:

As we have not get enough AC voltage from the inverter output to run the home utilities, we will use a step up transformer to increase the output voltage.

Chapter 7

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