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**Novel Voltage Controller for Stand – Alone
Induction Generator Using Modified**



SPWM - VSI

A Project Report

Submitted by

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in partial fulfillment for the award of the degree

of

Master of Engineering

in

Power Electronics and Drives

**DEPARTMENT OF ELECTRICAL & ELECTRONICS
ENGINEERING**

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(An Autonomous Institution Affiliated to Anna University, Coimbatore.)

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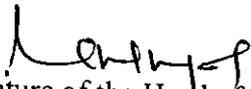
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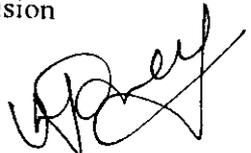
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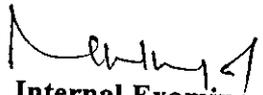
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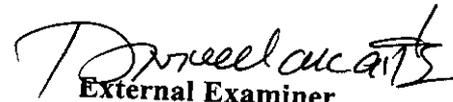
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ABSTRACT

A system based on a stand alone self excited induction generator and presents a constant voltage controller for the stand alone wind energy conversion system using an induction generator is proposed in this thesis.. The system uses a modified sinusoidal pulse width modulated voltage source inverter (modified sine PWM – VSI). One of the disadvantage of having stand alone wind energy conversion system with self excited induction generator (SEIG) is the poor voltage regulation which takes place due to the change in speed and load condition. To overcome this drawback, a voltage controller is developed which makes the voltage constant when SEIG is subjected to sudden change in load So that it is now possible to operate the SEIG at constant voltage in any load condition. The amplitude of the terminal voltage of the SEIG is regulated by adjusting the modulation index of the modified Sine PWM – VSI. Here the system requires only the sensing of the dc link voltage. To predict the performance of the developed system, a MATLAB/ SIMULINK - based simulation study is carried out. The simulated results shows the good performance of the system under different wind velocities conditions. The proposed controller is implemented in hardware and tested. Micro controller PIC16F887 is used to generate the pulses for the switching devices of the inverter and auxiliary semiconductor power switches in the voltage controller module.

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ABBREVIATIONS

DC	Direct Current
AC	Alternating Current
PWM	Pulse Width Modulation
MSPWM	Modified sinusoidal pulse width modulation
THD	Total Harmonic Distortion
ASD	Adjustable Speed Drive
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electro technical Commission
VSI	Voltage Source Inverter
CSI	Current Source Inverter
C	Capacitor
L	Inductor
LV	Low Voltage
MV	Medium Voltage
HV	High Voltage
EHV	Extra High Voltage
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
IGBT	Insulated Gate Bipolar Transistor
PIC	Peripheral Interface Controller

LIST OF SYMBOLS

A_r	Amplitude of reference signal
A_c	Amplitude of carrier signal
f_c	Carrier frequency
E_{dc}	Output voltage
C_3 & C_4	dc link power capacitor
L_{r2} & C_{r2}	energy storage devices
S_{a2} & S_{c2}	auxiliary semi-conductor power switch

CHAPTER 1

CHAPTER 1

INTRODUCTION OF THE PROJECT

1.1 OBJECTIVE OF THE PROJECT:

The aim of this project is

- To design and simulate a constant voltage controller for stand alone wind energy conversion system using an induction generator.
- To implement the modified sinusoidal pulse width modulation control technique.
- Hardware implementation of voltage controller using PIC 16F887.

1.2 ORGANISATION OF THE PROJECT:

Chapter 1 deals with the introduction of the project.

Chapter 2 deals with the stand alone wind energy conversion system.

Chapter 3 gives the overview of pulse width modulation.

Chapter 4 deals about the induction generator.

Chapter 5 deals with VSI.

Chapter 6 deals with the methodology employed in this project.

Chapter 7 deals with the simulation results of the project.

Chapter 8 deals with the hardware implementation .

Chapter 9 deals with the conclusion of the project and future scope.

CHAPTER 2

CHAPTER 2

STAND ALONE WIND ENERGY CONVERSION SYSTEM

2.1 STAND ALONE SYSTEM:

A system that operates independently of, or is not connected to, an electric transmission distribution network. This is in contrast to a grid-connected system. Powering homes or small businesses using small renewable energy systems that can function separately from the electricity grid can have both economic and environmental advantages. In addition to purchasing photovoltaic panels (also known as solar panels or solar modules), a wind turbine, or a small hydropower system, you will need to invest in some additional equipment called balance-of-system to condition and safely transmit the electricity to the load that will use it.

The amount of equipment you will need to buy depends on what you want your system to do. In the simplest systems, the current generated by, for example, your wind turbine is connected directly to the load. However, if you want to store power for use when your turbine isn't producing electricity, you will want to purchase batteries and a charge controller. Depending on your needs, balance-of-system equipment could account for half of your total system costs.

2.2. WIND ENERGY :

'Wind' refers that,

- Air in motion is called ' Wind'
- It has a mass and a mass in motion has a momentum
- Momentum is a form of energy that can be harvested and wind is the conversion of potential energy of the atmosphere into the kinetic energy due to pressure gradient.

Recently, mainly due to the technology innovation and cost reduction, renewable wind energy is enjoying a rapid growth globally to become an important green electricity source to

replace polluting and exhausting fossil fuel. Due to clean and economical energy generation, a huge number of wind farms are going to be connected with the existing network in the near future.

2.3. ADVANTAGES OF WIND ENERGY :

Some of the advantageous features of the wind energy are listed as follows:

- A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use.
- Clean and safe production of electricity.
- Fastest growing renewable energy source.
- Environment friendly and pollution free.
- Wind energy will never run out.
- It is freely available in nature.

2.4. EVOLUTION OF WIND ENERGY SYSTEM:

It is not a new technology and the evolution of wind energy system can be given as follows:

- 9th Century – Milling grain.
- 13th Century – Post wind mill by Germans.
- 16th Century – Dutch type wind mill by Holland.
- 17th Century – Euler conducted aerodynamic experiments.
- 1890 – Poul La Cour came with aerodynamic blade design.
- 1891 – First electricity producing wind turbine.
- 1910 – Wind mill becomes popular in Europe.
- 1980 – Green energy decade for California.
- 1986 – First wind mill installed in India (Gujarat).

CHAPTER 3

CHAPTER 3

PULSE WIDTH MODULATION

3.1 FEATURES OF PWM:

Pulse Width Modulation (PWM) is normally used as a controller in power conversion and motion control. There are various kinds of modulating modes available such as sinusoidal PWM, space vector PWM, current tracking PWM, harmonic elimination PWM and others. These techniques have merits and demerits but the most widely used in industrial applications are the sinusoidal PWM and space vector PWM. Digital Signal Processors (DSP) and/or Microcontrollers, where reprogramming of the carrier Frequencies are simple. The Sinusoidal Pulse Width Modulation (SPWM) is a well known wave shaping technique. For realization, a high frequency triangle carrier signal (W shape), V_c , is compared with a sinusoidal reference signal, V_r , as desired frequency. The crossover points are used to determine the switching instants.

3.2 OUTPUT VOLTAGE CONTROL:

One of the major applications of inverters is AC motor control. In order to control the speed of an induction motor one of the following strategies is used.

1. Variable voltage fixed voltage control
2. Variable voltage variable frequency control

Thus for ac motor control applications it is necessary to have a variable voltage at the output of the inverter.

The most effective method of controlling the output voltage is to incorporate pulse width modulation control within the inverters. In this method, a fixed DC input voltage is supplied to the inverter and a controlled AC output voltage is obtained by adjusting the on and off periods of the inverter devices. The PWM control has the following advantages.

1. The output voltage control can be obtained without any additional components.

2. With this type of control, lower order harmonics can be eliminated and the filtering requirements are minimized as higher order harmonics can be filtered easily.

3.3 PWM TECHNIQUES:

The commonly used PWM control techniques are,

1. Single pulse width modulation,
2. Multiple pulse width modulation,
3. Sinusoidal pulse width modulation,
4. Modified sinusoidal pulse width modulation.

3.4. PROPOSED MODULATION TECHNIQUE:

The modulation technique proposed for this project is modified sinusoidal pulse width modulation technique (MSPWM). The widths of pulses nearer the peak of the sine wave do not change significantly with the variation of the modulation index. This is due to the characteristics of a sine wave, and the SPWM technique can be modified so that the carrier wave is applied during the first and last 60 degree intervals per half cycle (e.g., 0 degree to 60 degree and 120 degree and 180 degree).

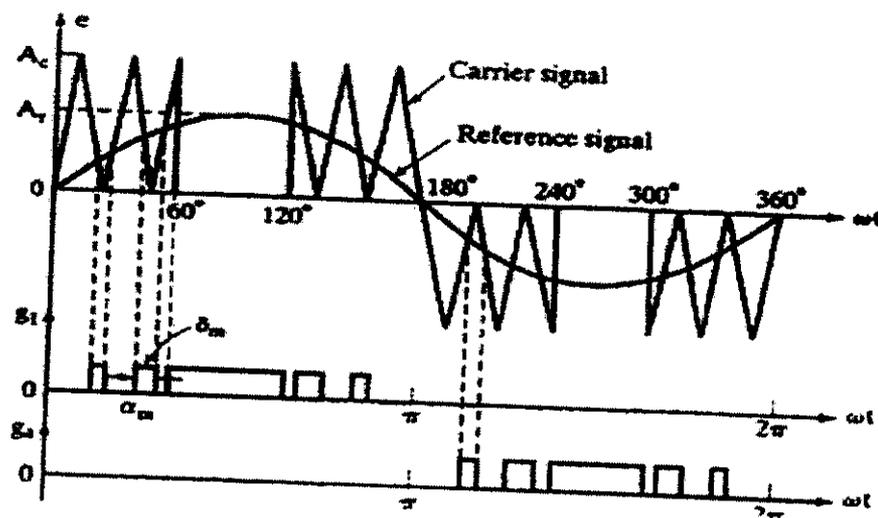


Figure 3.1 Modified sinusoidal pulse width modulation.

3.5. ADVANTAGES OF MSPWM TECHNIQUE:

The main advantages of the MSPWM technique is given as follows:

- The fundamental component is increased and its harmonic characteristics are improved,
- It reduces the number of switching of power devices,
- And it also reduces switching losses.

3.6. MODULATION INDEX:

Modulation index is the ratio of peak magnitudes of the modulating waveform and the carrier waveform. It relates the inverter's dc-link voltage and the magnitude of pole voltage (fundamental component) output by the inverter. Now let ' $V_m \sin(\omega t)$ ' be the modulating signal and let the magnitude of triangular carrier signal vary between the peak magnitudes of $+V_c$ and $-V_c$. The ratio of the peak magnitudes of modulating wave (V_m) and the carrier wave (V_c) is defined as modulation-index (m). In other words: $m = \frac{V_m}{V_c}$.

3.7. OVER MODULATION:

When the peak magnitude of modulating signal exceeds the peak magnitude of carrier signal (resulting in $m > 1$), the PWM inverter operates under over-modulation. During over-modulation the fundamental component of the pole voltage increases slightly with increase in modulation index but the linear relation between them, no longer continues. Also, lower frequency harmonics crop up in the pole-output waveform. It may easily be seen that for ' m ' very high (say = infinity), the pole voltage shape will be identical to the square wave shape. Over modulation is generally not preferred because of the introduction of lower frequency harmonics in the output waveform and subsequent distortion of the load current.

CHAPTER 4

CHAPTER 4

OVERVIEW OF INDUCTION GENERATOR

4.1. INTRODUCTION:

An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip. In most cases, a regular AC asynchronous motor is used as a generator, without any internal modifications.

4.2. PRINCIPLE OF OPERATION:

Induction generators and motors produce electrical power when their shaft is rotated faster than the synchronous frequency. For a typical four-pole motor (two pairs of poles on stator) operating on a 60 Hz electrical grid, synchronous speed is 1800 rotations per minute. Similar four-pole motor operating on a 50 Hz grid will have synchronous speed equal to 1500 rpm.

In normal motor operation, stator flux rotation is faster than the rotor rotation. This is causing stator flux to induce rotor currents, which create rotor flux with magnetic polarity opposite to stator. In this way, rotor is dragged along behind stator flux, by value equal to slip.

In generator operation, certain prime mover (turbine, engine) is driving the rotor above the synchronous speed. Stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, active current is produced in stator coils, and motor is now operating as a generator, and sending power back to the electrical grid if it is connected to any grid.

4.3. EXCITATION:

Induction generators are not, in general, self-exciting, meaning they require an electrical supply, at least initially, to produce the rotating magnetic flux (although in practice an induction generator will often self start due to residual magnetism.) The electrical supply can be supplied from the electrical grid or, once it starts producing power, from the generator itself. The rotating magnetic flux from the stator induces currents in the rotor, which also produces a magnetic field. If the rotor turns slower than the rate of the rotating flux, the machine acts like an induction motor. If the rotor is turned faster, it acts like a generator, producing power at the synchronous frequency. Note that a source of excitation current for magnetizing flux (reactive power) for stator is still required, to induce rotor current.

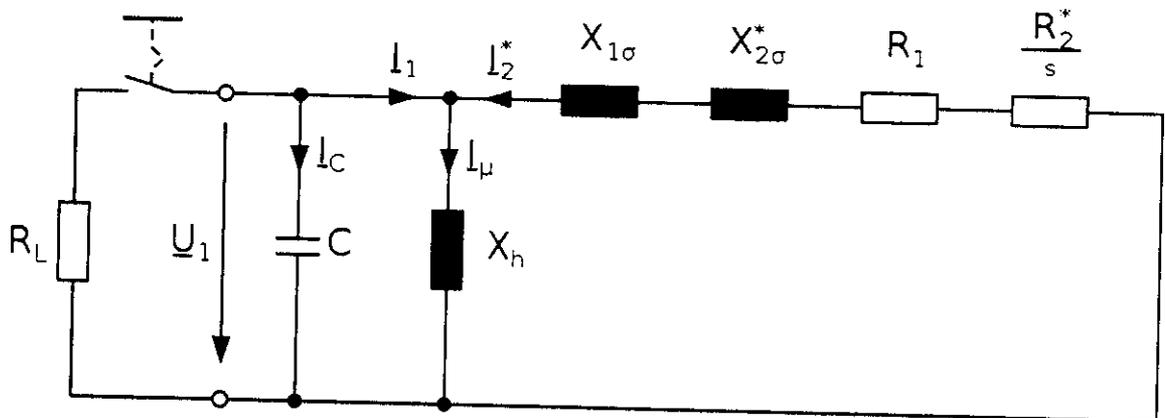


Figure 4.1. Equivalent Circuit of Induction Generator.

4.4. THE ROTATING MAGNETIC FIELD:

The principle of operation of the induction machine is based on the generation of a rotating magnetic field. Let us understand this idea better by assuming the following steps:

- Consider a cosine wave from 0 to 360°. This sine wave is plotted with unit amplitude.
- Now allow the amplitude of the sine wave to vary with respect to time in a sinusoidal fashion with a frequency of 50Hz. Let the maximum value of the amplitude is, say, 10 units. This waveform is a pulsating sine wave.

$$i_{apk} = I_m \cos \omega.t \quad (4.1)$$

Now consider a second sine wave, which is displaced by 120° from the first (lagging) and allow its amplitude to vary in a similar manner, but with a 120° time lag.

$$i_{bpk} = I_m \cos (\omega.t - 120^\circ) \quad (4.2)$$

Similarly consider a third sine wave, which is at 240° lag and allow its amplitude to change as well with a 240° time lag. Now we have three pulsating sine waves.

$$i_{cpk} = I_m \cos (\omega.t - 240^\circ) \quad (4.3)$$

Let us see what happens if we sum up the values of these three sine waves at every angle. The result really speaks about Tesla's genius. What we get is a constant amplitude travelling sine wave. In a three phase induction machine, there are three sets of windings — phase A winding, phase B and phase C windings. These are excited by a balanced three-phase voltage supply. This would result in a balanced three phase current. Note that they have a 120° time lag between them. Further, in an induction machine, the windings are not all located in the same place. They are distributed in the machine 120° away from each other (more about this in the section on alternators). The correct terminology would be to say that the windings have their axes separated in space by 120°. This is the reason for using the phase A, B and C since waves separated in space as well by 120°. When currents flow through the coils, they generate mmfs. Since mmf is proportional to current, these waveforms also represent the mmf generated by the coils and the total mmf. Further, due to magnetic material in the machine (iron), these mmfs generate magnetic flux, which is proportional to the mmf (we may assume that iron is infinitely permeable

and non-linear effects such as hysteresis are neglected). Thus the waveforms seen above would also represent the flux generated within the machine. The net result as we have seen is a travelling flux wave. The x-axis would represent the space angle in the machine as one travels around the air gap. The first pulsating waveform seen earlier would then represent the a-phase flux, the second represents the b-phase flux and the third represents the c-phase.

4.5. PRINCIPLES OF TORQUE PRODUCTION:

Let us consider a rotor, which is placed in this field. Let the rotor have a coil such that the coil sides are placed diametrically opposite each other. This is shown in the fig. 1. Since the flux generated by the stator rotates flux linked by this rotor coil also changes.

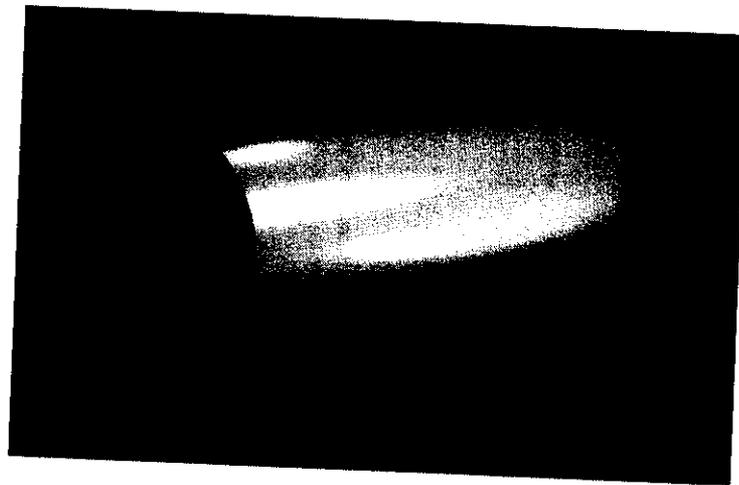


Figure 4.2. A Coil on the rotor.

Since the flux pattern is varying sinusoidally in space, as the flux waveform rotate the flux linkage varies sinusoidally. The rate of variation of this flux linkage will then be equal to the speed of rotation of the air gap flux produced. This sinusoidal variation of the flux linkage produces a sinusoidal induced emf in the rotor coil. If the coil is short circuited, this induced emf will cause a current flow in the coil as per Lenz's law.



Now imagine a second coil on the rotor whose axis is 120° away from the first. This is shown in fig. 4.3. The flux linkage in this coil will also vary sinusoidally with respect to time and therefore cause an induced voltage varying sinusoidally with time. However the flux linkages in these two coils will have a phase difference of 120° (the rotating flux wave will have to travel 120° in order to cause a similar flux linkage variation as in the first coil), and hence the time varying voltages induced in the coils will also have a 120° phase difference. A third coil placed a further 120° away is shown in fig. 4.4. This will have a time varying induced emf lagging 240° in time with respect to the first.

When these three coils are shorted upon themselves currents flow in them as per Lenz's law. The mechanism by which torque is produced may now be understood as follows. Here the positive current is said to flow in these coils when the current flows out of the phases a, b, and c

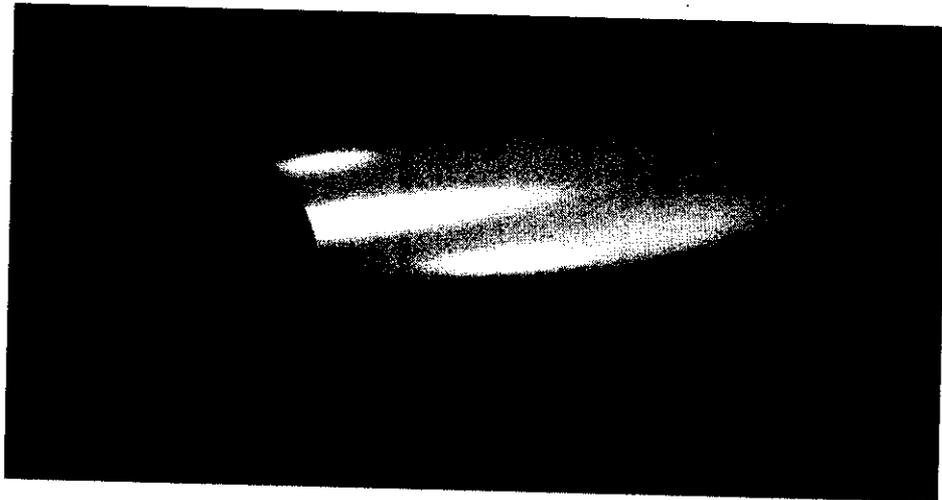


Figure 4.3. A coil displaced 120° from the figure 4.2.

conductors and into a', b' and c' respectively. If we look at the voltage induced in these coils as phasors. The main flux is taken as the reference phasor. Considering that the induced emf is

$-d\psi/dt$ where ψ is the flux linkage, the diagram is drawn as shown. As usual, the horizontal component of these phasors gives the instantaneous values of the induced emf in these coils.

Let these coils be purely resistive. Then these emf phasors also represent the currents flowing in these coils. If we consider the instant $t = 0$, it can be seen that,

- The field flux is along 0° axis.
- The current in a phase coil is zero.
- The current in b phase coil is $-\sqrt{3}/2$ units.
- The current in c phase coil is $+\sqrt{3}/2$ units.

These currents act to produce mmf and flux along the axes of the respective coils. Let us consider the space around b' and c coil sides. The resulting flux pattern causes a tendency to move in the anticlockwise direction. This is easy to see through the so called whiplash rule. Alternatively, since the force on a current carrying conductor is,

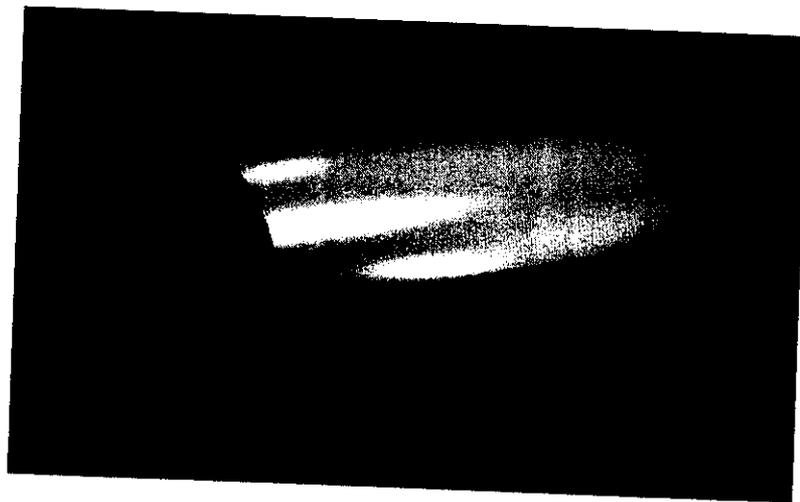


Figure 4.4. A coil displaced 240° from the figure 4.2.

$F = q(v \times B)$, it can be seen that the torque produced tends to rotate the rotor counter-clockwise. The magnitude of the torque would increase with the current magnitude in the coils. This current

is in turn dependent on the magnitude of the main field flux and its speed of rotation. Therefore one may say that motion of the main field tends to drag the rotor along with it. When the rotor is free to move and begins moving, the motion reduces the relative speed between the main field and the rotor coils. Less emf would therefore be induced and the torque would come down. Depending on the torque requirement for the load, the difference in speed between the rotor and the main field settles down at some particular value.

4.6. ACTIVE POWER:

Active power delivered to the line is proportional to slip above the synchronous speed. Full rated power of the generator is reached at very small slip values (motor dependent, typically 3%). At synchronous speed of 1800 rpm, generator will produce no power. When the driving speed is increased to 1860 rpm, full output power is produced. If the prime mover is unable to produce enough power to fully drive the generator, speed will remain somewhere between 1800 and 1860 rpm range.

4.7. REQUIRED CAPACITANCE:

Capacitor bank must supply reactive power to the motor when used in stand-alone mode. Reactive power supplied should be equal or greater than the reactive power that machine normally draws when operating as a motor. Terminal voltage will increase with capacitance, but is limited by iron saturation.

4.8. GRID AND STAND ALONE CONNECTIONS:

In induction generators the magnetizing flux is established by a capacitor bank connected to the machine in case of stand alone system and in case of grid connection it draws magnetizing current from the grid. For a grid connected system, frequency and voltage at the machine will be dictated by the electric grid, since it is very small compared to the whole system. For stand-alone systems, frequency and voltage are complex function of machine parameters, capacitance used for excitation, and load value and type.

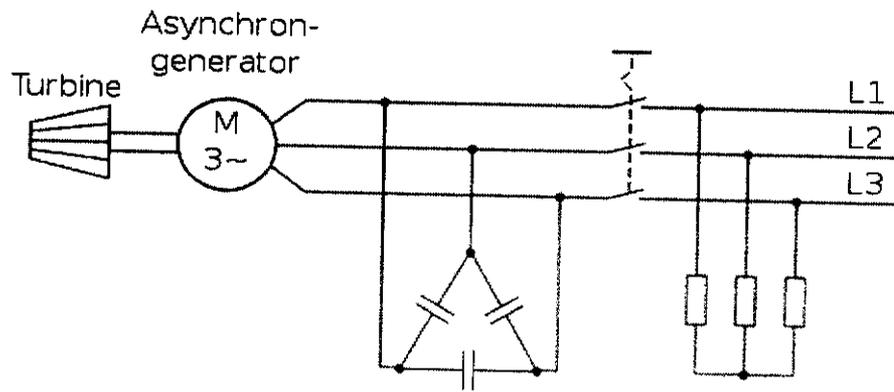


Figure 4.5. Typical connection when used as a stand alone generator.

4.9. USES OF INDUCTION GENERATOR:

The uses of the induction generator are given as follows:

- Induction generators are often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying rotor speeds.
- Induction generators are mechanically and electrically simpler than other generator types.
- They are also more rugged, requiring no brushes or commutators.
- Induction generators are particularly suitable and usually used for wind generating stations as in this case speed is always a variable factor, and the generator is easy on the gearbox.

4.10. TYPES OF INDUCTION GENERATOR USED FOR WIND FARMS:

An induction motor is an asynchronous AC motor where power is transferred to the rotor by electromagnetic induction. An induction motor resembles a rotating transformer, because the stator (stationary part) is essentially the primary side of the transformer and the rotor (rotating part) is the secondary side. Polyphase induction motors are widely used in industry.

Induction motors may be further divided into squirrel-cage motors and wound-rotor motors. Squirrel-cage motors have a heavy winding made up of solid bars, usually aluminum or copper, joined by rings at the ends of the rotor. Currents induced into this winding provide the rotor magnetic field. The shape of the rotor bars determines the speed-torque characteristics. At low speeds, the current induced in the squirrel cage is nearly at line frequency and tends to flow in the outer parts of the rotor cage. As the motor accelerates, the slip frequency becomes lower, and more current flows in the interior of the winding. By shaping the bars to change the resistance of the windings portions in the interior and outer parts of the cage, effectively a variable resistance is inserted in the rotor circuit.

In a wound-rotor motor, the rotor winding is made of many turns of insulated wire and is connected to slip rings on the motor shaft. An external resistor or other control devices can be connected in the rotor circuit. Resistors allow control of the motor speed, although significant power is dissipated in the external resistance. A converter can be fed from the rotor circuit and return the slip-frequency power that would otherwise be wasted back into the power system.

The wound-rotor induction motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low supply current from zero speed to full speed. This type of motor also offers controllable speed.

Motor speed can be changed because the torque curve of the motor is effectively modified by the amount of resistance connected to the rotor circuit. Increasing the value of resistance will

move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced.

When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation and net efficiency is also very poor.

4.11. SLIP - TORQUE CHARACTERISTICS OF INDUCTION MACHINE:

The torque speed curve is approximately symmetric about synchronous speed. (The magnitude of the peak negative torque is larger than the positive torque, the difference being a function of stator resistance). The torque-speed curve breaks down into three operating regions:

1. Braking region ($n_m < 0, s > 1$):

Torque is positive whilst speed is negative. Considering the power conversion equation,

$$P_{\text{conv}} = (1-S) P_{\text{gap}}$$

it can be seen that if the power converted is negative (from $P = \tau \omega$) then the airgap power is positive. i.e. the power is flowing from the stator to the rotor and also into the rotor from the mechanical system. This operation is also called plugging. This mode of operation can be used to quickly stop a machine. If a motor is travelling forwards it can be stopped by interchanging the connections to two of the three phases.

Switching two phases has the result of changing the direction of motion of the stator magnetic field, effectively putting the machine into braking mode in the opposite direction.

2. Motoring region ($0 < n_m < n_s, 1 > s > 0$):

Torque and motion are in the same direction. This is the most common mode of operation.

3. Generating region ($n_m > n_s, s < 0$):

In this mode, again torque is positive whilst speed is negative. However, unlike plugging,

$$P_{conv} = (1-S) P_{gap}$$

indicates that if the power converted is negative, so is the air gap power. In this case, power flows from the mechanical system, to the rotor circuit, then across the air gap to the stator circuit and external electrical system.

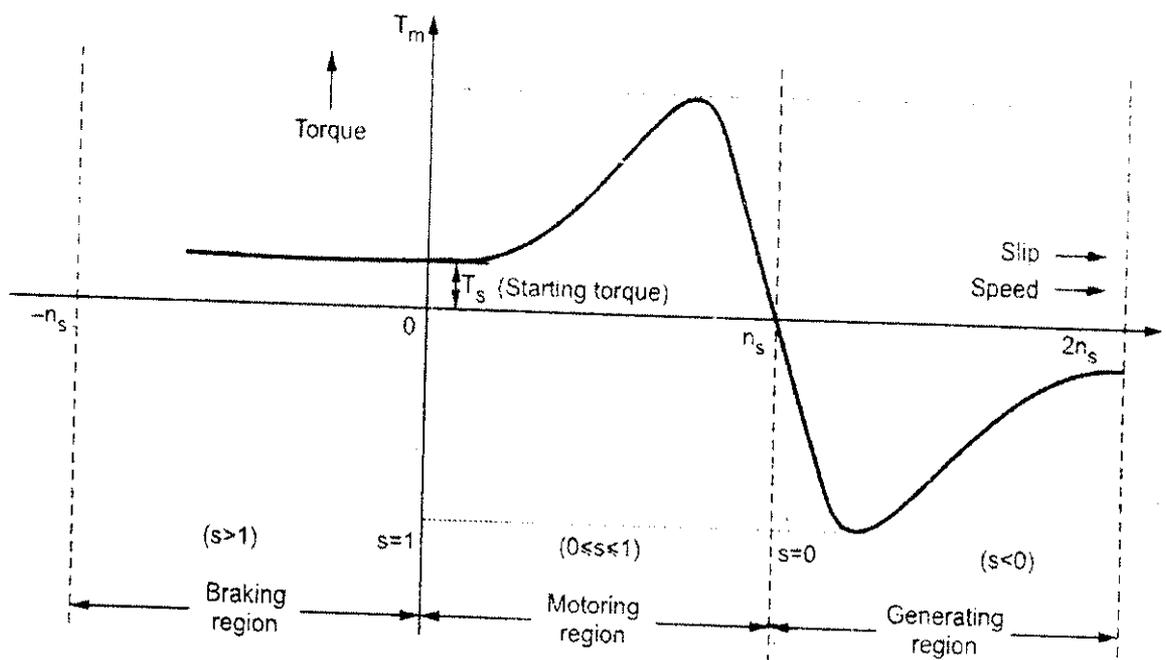


Figure 4.6. slip – torque characteristics of induction machine.

CHAPTER 5

CHAPTER 5

VOLTAGE SOURCE INVERTER

5.1. INTRODUCTION TO VSI:

The word 'inverter' in the context of power-electronics denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. The 'inverter' does reverse of what ac-to-dc 'converter' does (refer to ac to dc converters). Even though input to an inverter circuit is a dc source, it is not uncommon to have this dc derived from an ac source such as utility ac supply. Thus, for example, the primary source of input power may be utility ac voltage supply that is 'converted' to dc by an ac to dc converter and then 'inverted' back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply.

The simplest dc voltage source for a VSI may be a battery bank, which may consist of several cells in series-parallel combination. Solar photovoltaic cells can be another dc voltage source. An ac voltage supply, after rectification into dc will also qualify as a dc voltage source. A voltage source is called stiff, if the source voltage magnitude does not depend on load connected to it. All voltage source inverters assume stiff voltage supply at the input.

Some examples where voltage source inverters are used are: uninterruptible power supply (UPS) units, adjustable speed drives (ASD) for ac motors, electronic frequency changer circuits etc. Most of us are also familiar with commercially available inverter units used in homes and offices to power some essential ac loads in case the utility ac supply gets interrupted. In such inverter units, battery supply is used as the input dc voltage source and the inverter circuit converts the dc into ac voltage of desired frequency. The achievable magnitude of ac voltage is limited by the magnitude of input (dc bus) voltage. In ordinary household inverters the battery voltage may be just 12 volts and the inverter circuit may be capable of supplying ac voltage of

around 10 volts (rms) only. In such cases the inverter output voltage is stepped up using a transformer to meet the load requirement of, say, 230 volts.

5.1 TO GET AN AC OUTPUT FROM DC INPUT SUPPLY:

Consider the circuits using the transistor-switches, for generation of ac voltage from dc input supply. In these circuits, the transistors work in common emitter configuration and are interconnected in push-pull manner. In order to have a single control signal for the transistor switches, one transistor is of n-p-n type and the other of p-n-p type and their emitters and bases are shorted. Both circuits require a symmetrical bipolar dc supply. Collector of n-p-n transistor is connected to positive dc supply (+E) and that of p-n-p transistor is connected to negative dc supply of same magnitude (-E). Load, which has been assumed resistive, is connected between the emitter shorting point and the power supply ground.

In these circuits, the transistors work in active (amplifier) mode and a sinusoidal control voltage of desired frequency is applied between the base and emitter points. When applied base signal is positive, the p-n-p transistor is reverse biased and the n-p-n transistor conducts the load current. Similarly for negative base voltage the p-n-p transistor conducts while n-p-n transistor remains reverse biased. A suitable resistor in series with the base signal will limit the base current and keep it sinusoidal provided the applied (sinusoidal) base signal magnitude is much higher than the base to emitter conduction-voltage drop. Under the assumption of constant gain (h_{fe}) of the transistor over its working range, the load current can be seen to follow the applied base signal. This particular figure also shows the switch power loss for n-p-n transistor. The other transistor will also be dissipating identical power during its conduction. Here the quantities are measured in per unit magnitudes where the base values are input supply voltage (E) and the load resistance (R).

Accordingly the base magnitudes of current and power are E/R and E^2/R respectively. Here the power loss in switches is a considerable portion of circuit's input power and hence such circuits are unacceptable for large output power applications.

The conducting switch remains fully on having negligible on-state voltage drop and the non-conducting switch remains fully off allowing no leakage current through it. The load voltage waveform output by switched-mode circuit is rectangular with magnitude $+E$ by the ON and OFF operation of the two transistors. The on and off durations of the two transistors are controlled so that (i) the resulting rectangular waveform has no dc component (ii) has a fundamental (sinusoidal) component of desired frequency and magnitude and (iii) the frequencies of unwanted harmonic voltages are much higher than that of the fundamental component. Therefore the fundamental sine wave is identical to the sinusoidal output voltage.

Both amplifier mode and switched mode circuits are capable of producing ac voltages of controllable magnitude and frequency, however, the amplifier circuit is not acceptable in power-electronic applications due to high switch power loss. On the other hand, the switched mode circuit generates significant amount of unwanted harmonic voltages along with the desired fundamental frequency voltage. Also, the frequency spectrum of these unwanted harmonics can be shifted towards high frequency by adopting proper switching pattern. These high frequency voltage harmonics can easily be blocked using small size filter and the resulting quality of load voltage can be made acceptable.

The magnitude, phase and frequency of the fundamental voltage is solely determined by the magnitude of supply voltage and the switching pattern of the push-pull circuit. Thus, as long as the transistors work in the switch-mode (fully on or fully off), the output voltage is essentially load-independent.

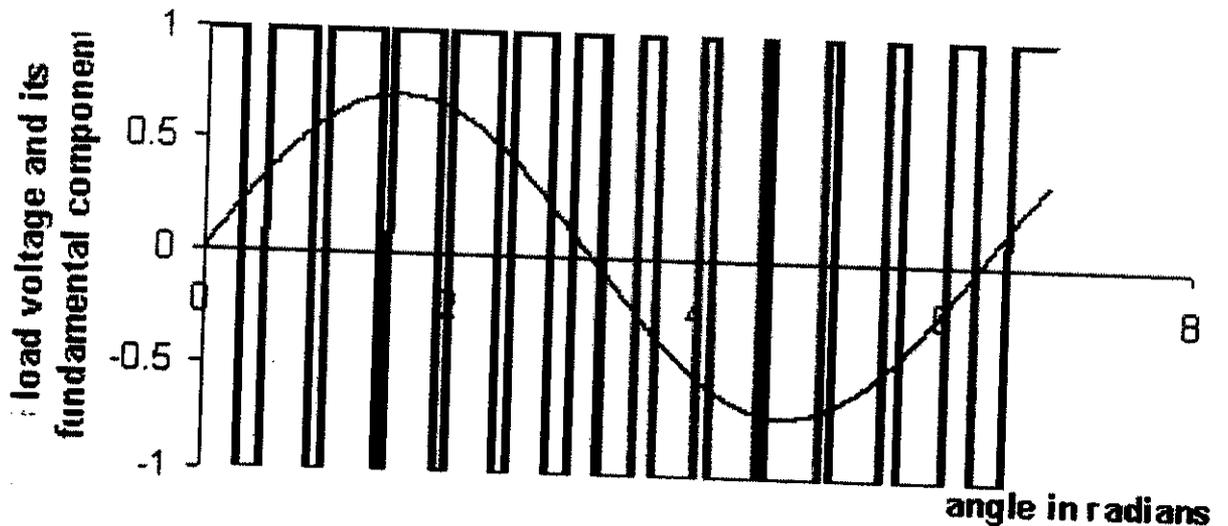


Figure 5.1. Switched mode (inverter) operation.

5.3. GENERAL STRUCTURE OF VSI:

Figs. 5.2 and 5.3 show the typical power-circuit topologies of a single-phase and a three-phase voltage source inverter respectively. These topologies require only a single dc source and for medium output power applications the preferred devices are n-channel IGBTs. 'E_{dc}' is the input dc supply and a large dc link capacitor (C_{dc}) is put across the supply terminals.

Capacitors and switches are connected to dc bus using short leads to minimize the stray inductance between the capacitor and the inverter switches. Needless to say that physical layout of positive and negative bus lines is also important to limit stray inductances. Q_1, Q_2, Q_3 etc. are fast and controllable switches. D_1, D_2, D_3 etc. are fast recovery diodes connected in anti-parallel with the switches. 'A', 'B' and 'C' are output terminals of the inverter that get connected to the ac load. A three-phase inverter has three load-phase terminals whereas a single-phase inverter has only one pair of load terminals.

The current supplied by the dc bus to the inverter switches is referred as dc link current and has been shown as ' i_{dc} ' in Figs 5.2 and 5.3. The magnitude of dc link current often changes in step (and sometimes its direction also changes) as the inverter switches are turned on and off. The step change in instantaneous dc link current occurs even if the ac load at the inverter output is drawing steady power. However, average magnitude of the dc link current remains positive if net power-flow is from dc bus to ac load. The net power-flow direction reverses if the ac load connected to the inverter is regenerating. Under regeneration, the mean magnitude of dc link current is negative.

The dc link current may conceptually be decomposed into its dc and ac components. The individual roles of the 'dc voltage source' and the 'dc link capacitor' may be clearly seen with respect to the dc and ac components of the dc link current. For the dc component of current the capacitor acts like open circuit. As expected, under steady state, the capacitor does not supply any dc current. The dc part of bus current is supplied solely by the dc source. A practical dc voltage source may have some resistance as well as some inductance in series with its internal emf. For dc component of bus current, the source voltage appears in series with its internal resistance (effect of source inductance is not felt). But for ac component of current, the internal dc emf of source appears as short and its series impedance (resistance in series with inductance) appears in parallel with the dc-link capacitor. Thus the ac component of current gets divided into these two parallel paths. However, the high frequency component of ac current mainly flows through the capacitor, as the capacitive impedance is lower at high frequencies. The step change in dc link current is associated with significant amount of high frequency components of current that essentially finds its path through the capacitor.

For an ideal input (dc) supply, with no series impedance, the dc link capacitor does not have any role. However a practical voltage supply may have considerable amount of output impedance. The supply line impedance, if not bypassed by a sufficiently large dc link capacitor, may cause considerable voltage spike at the dc bus during inverter operation. This may result in deterioration of output voltage quality, it may also cause malfunction of the inverter switches as the bus voltage appears across the non-conducting switches of the inverter. Also, in the absence

of dc link capacitor, the series inductance of the supply line will prevent quick build up or fall of current through it and the circuit behaves differently from the ideal VSI where the dc voltage supply is supposed to allow rise and fall in current as per the demand of the inverter circuit.

It may not be possible to reduce supply line inductance below certain limit. Most dc supplies will inherently have rather significant series inductance, for example a conventional dc generator will have considerable armature inductance in series with the armature emf. Similarly, if the dc supply is derived after rectifying ac voltage, the ac supply line inductance will prevent quick change in rectifier output current. The effect of ac line inductance is reflected on the dc side as well, unless this inductance is effectively bypassed by the dc side capacitor. Even the connecting leads from the dc source to the inverter dc bus may contribute significantly to the supply line inductance in case the lead lengths are large and circuit lay out is poor. It may be mentioned here that an inductance, in series with the dc supply, may at times be welcome. The reason being that for some types of dc sources, like batteries, it is detrimental to carry high frequency ripple current. For such cases it is advantageous if the dc source has some series inductance. Due to series inductance of the source, the high frequency ripple will prefer to flow through the dc link capacitor and thus relieve the dc source.

The dc link capacitor should be put very close to the switches so that it provides a low impedance path to the high frequency component of the switch currents. The capacitor itself must be of good quality with very low equivalent series resistor (ESR) and equivalent series inductor (ESL). The length of leads that interconnect switches and diodes to the dc bus must also be minimum to avoid insertion of significant amount of stray inductances in the circuit. The overall layout of the power circuit has a significant effect over the performance of the inverter circuit.

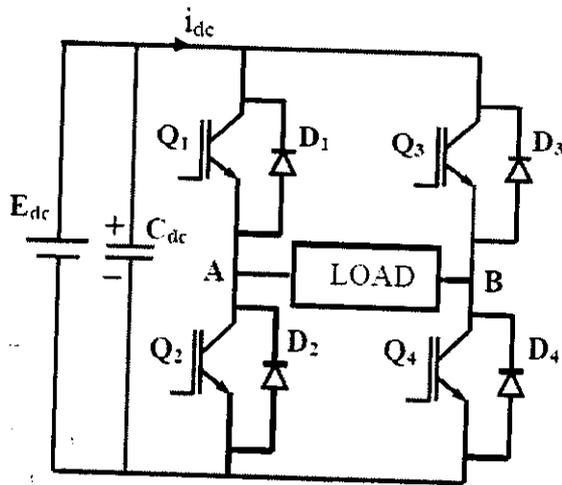


Figure 5.2. Topology of 1 – phase VSI.

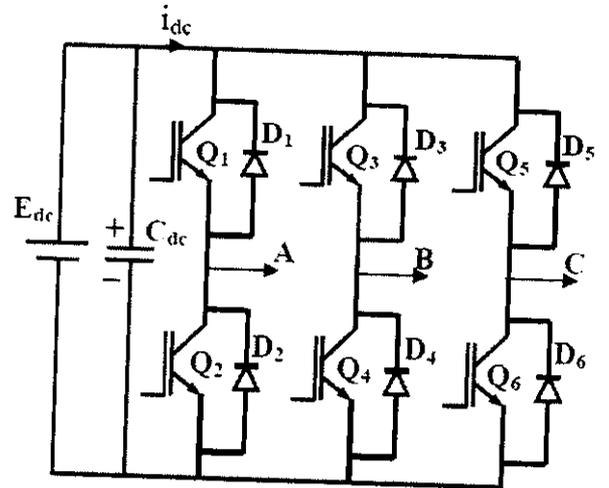


Figure 5.3. Topology of 3 – phase VSI.

One of the thumb rules for good circuit layout is to put the conductor pairs carrying same magnitude but opposite direction of currents close by, the minimum distance between them being decided only by their voltage isolation requirement. Thus the positive and negative terminals of the dc bus should run close by. A twisted wire pair may be an example of two closely running wires.

5.5. NEED FOR ISOLATED GATE – CONTROL SIGNALS FOR THE SWITCHES:

The Figs. 5.2 and 5.3 are need to be provided with isolated gate (or base) drive signals. The individual control signal for the switches needs to be provided across the gate (base) and source (or emitter) terminals of the particular switch. The gate control signals are low voltage signals referred to the source (emitter) terminal of the switch. For n-channel IGBT and MOSFET switches, when gate to source voltage is more than threshold voltage for turn-on, the switch turns on and when it is less than threshold voltage the switch turns off. The threshold voltage is generally of the order of +5 volts but for quicker switching the turn-on gate voltage magnitude is kept around +15 volts where as turn-off gate voltage is zero or little negative (around -5 volts). It is to be remembered that the two switches of an inverter-leg are controlled in a complementary manner. When the upper switch of any leg is 'on', the corresponding lower switch remains 'off'

and vice-versa. When a switch is 'on' its emitter and collector terminals are virtually shorted. Thus with upper switch 'on', the emitter of the upper switch is at positive dc bus potential. Similarly with lower switch 'on', the emitter of upper switch of that leg is virtually at the negative dc bus potential. Emitters of all the lower switches are solidly connected to the negative line of the dc bus. Since gate control signals are applied with respect to the emitter terminals of the switches, the gate voltages of all the upper switches must be floating with respect to the dc bus line potentials. This calls for isolation between the gate control signals of upper switches and between upper and lower switches. Only the emitters of lower switches of all the legs are at the same potential (since all of them are solidly connected to the negative dc bus) and hence the gate control signals of lower switches need not be isolated among themselves. As should be clear from the above discussion, the isolation provided between upper and lower switches must withstand a peak voltage stress equal to dc bus voltage. Gate-signal isolation for inverter switches is generally achieved by means of optical-isolator (opto-isolator) circuits. Fig.5.4 shows a typical opto-isolator circuit. The circuit makes use of a commercially available opto-coupler IC, shown within dotted lines in the figure. Input stage of the IC is a light emitting diode (LED) that emits light when forward biased. The light output of the LED falls on reverse biased junction of an optical diode. The LED and the photo-diode are suitably positioned inside the opto-coupler chip to ensure that the light emitted by the LED falls on the photo-diode junction. The gate control pulses for the switch are applied to the input LED through a current limiting resistor of appropriate magnitude. These gate pulses, generated by the gate logic circuit, are essentially in the digital form. A high level of the gate signal may be taken as 'on' command and a low level (at ground level) may be taken as 'off' command. Under this assumption, the cathode of the LED is connected to the ground point of the gate-logic card and anode is fed with the logic card output. The circuit on the output (photo-diode) side is connected to a floating dc power supply, as shown in Fig. 5.4. The control (logic card) supply ground is isolated from the floating-supply ground of the output. In the figure the two grounds have been shown by two different symbols. The schematic connection shown in the figure indicates that the photo-diode is reverse biased. A resistor in series with the diode indicates the magnitude of the reverse leakage current of the diode. When input signal to LED is high, LED conducts and the emitted light falls on the reverse biased p-n junction. Irradiation of light causes generation of significant number of electron-hole pairs in the depletion region of the reverse biased diode. As a result magnitude of

reverse leakage current of the diode increases appreciably. The resistor connected in series with the photo-diode now has higher voltage drop due to the increased leakage current. A signal comparator circuit senses this condition and outputs a high level signal, which is amplified before being output. Thus an isolated and amplified gate signal is obtained and may directly be connected to the gate terminal of the switch (often a small series resistor, as suggested by the switch manufacturer, is put between the output signal and the gate terminal of the switch).

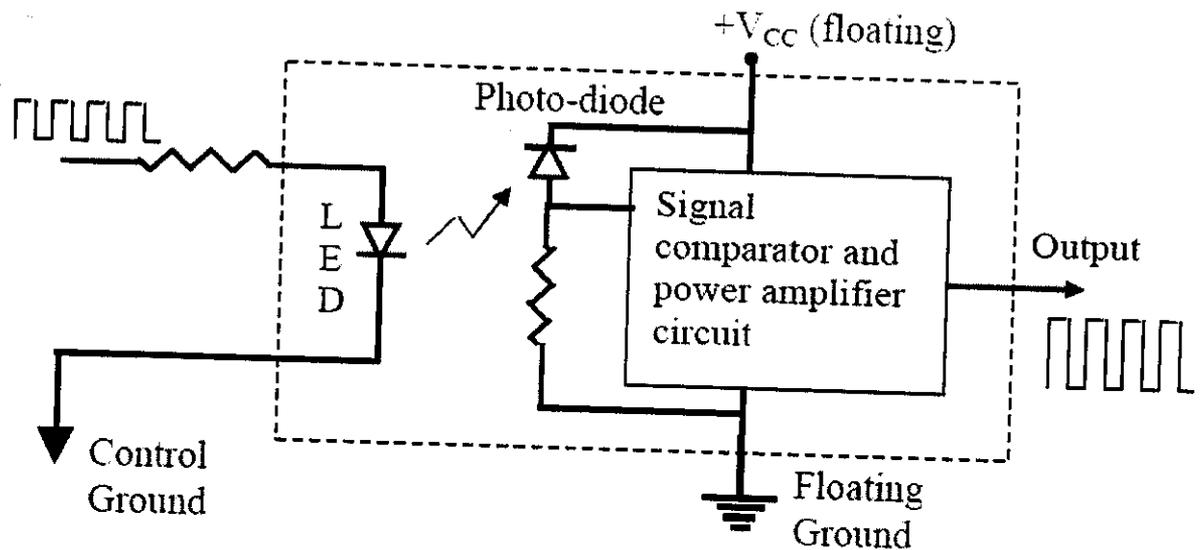


Figure. 5.4. A schematic opto – isolator circuit.

5.5. CLASSIFICATION OF VSI:

Voltage source inverters can be classified according to different criterions. They can be classified according to number of phases they output. Accordingly there are single-phase or three-phase inverters depending on whether they output single or three-phase voltages. It is also possible to have inverters with two or five or any other number of output phases. Inverters can also be classified according to their ability in controlling the magnitude of output parameters like, frequency, voltage, harmonic content etc. Some inverters can output only fixed magnitude (though variable frequency) voltages whereas some others are capable of both variable voltage, variable frequency (VVVF) output. Output of some voltage source inverters is corrupted by significant amount of many low order harmonics like 3rd, 5th, 7th, 11th, 13th order of the desired

(fundamental) frequency voltage. Some other inverters may be free from low order harmonics but may still be corrupted by some high order harmonics. Inverters used for ac motor drive applications are expected to have less of low order harmonics in the output voltage waveform, even if it is at the cost of increased high order harmonics. Higher order harmonic voltage distortions are, in most ac motor loads, filtered away by the inductive nature of the load itself. Inverters may also be classified according to their topologies.

Some inverter topologies are suitable for low and medium voltage ratings whereas some others are more suitable for higher voltage applications. The inverters shown in Figs. 5.2 and 5.3 are two level inverters as the pole voltages may acquire either positive dc bus or negative dc bus potential. For higher voltage applications it may not be uncommon to have three level or five level inverters.

CHAPTER 6

CHAPTER 6

METHODOLOGY OF THE PROJECT

6.1. BLOCK DIAGRAM :

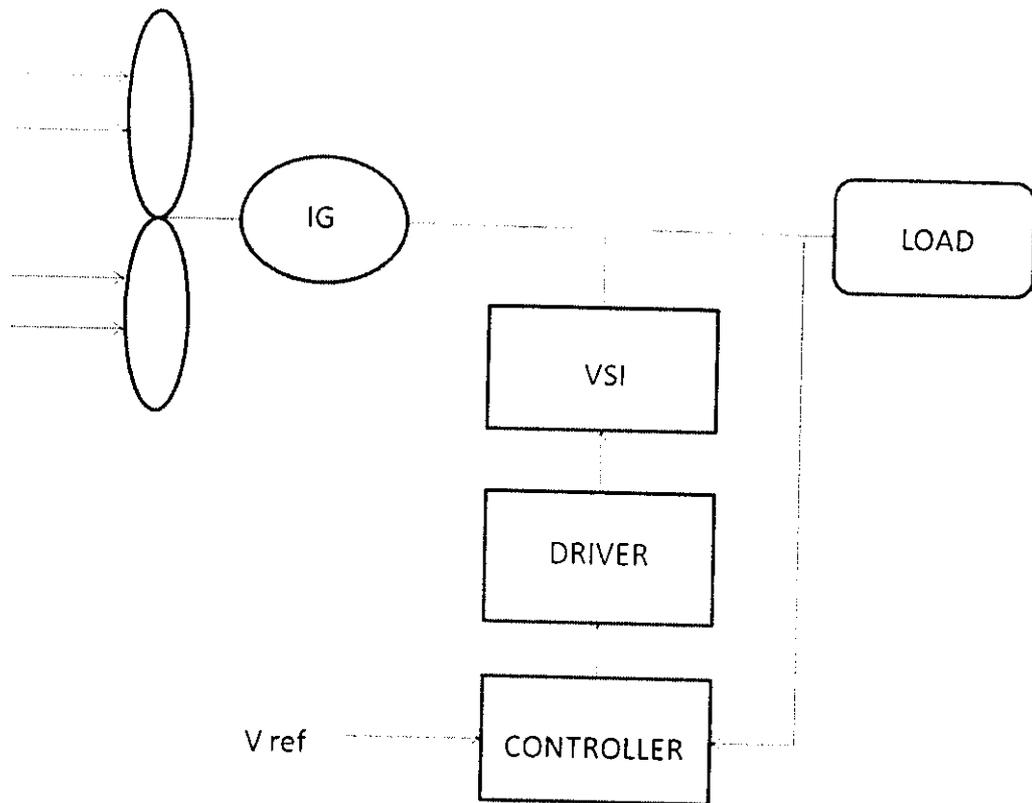


Figure 6.1. Block diagram of the proposed project.

The proposed voltage source inverter is used in a stand- alone wind energy conversion system. The self excited induction generator is used as the proposed generator in this project. Therefore, the controller is used to maintain the output voltage of the VSI as constant by using the modified MSPWM technique. Also the driver circuit is used to drive the voltage source inverter by giving suitable switching sequence to the devices in the VSI.

6.2. PRINCIPLE OF OPERATION OF THE CIRCUIT:

The proposed overall system block diagram is shown in Fig.6. 1. A battery on the dc side of inverter is provided for initial excitation. The reactive power required by the IG and load is provided by the voltage source inverter. Therefore the rating this inverter is chosen based on the excitation power of IG and reactive power requirements of the load. During startup, the controller sets the stator frequency lower than the rotor frequency so that the power produced by IG is used to charge the capacitor connected across the dc link to a set reference value. The error between the reference and actual capacitor voltages is processed by the PI controller. If the measured capacitor voltage is higher than the reference value, the stator frequency is increased by the controller, thereby decreasing the torque and power supplied by IG, and, if the measured capacitor voltage is lower than the reference value the stator frequency is decreased. The output of the PI regulator is fed to the harmonic oscillator to generate the sine and cosine waveforms. These waveforms are multiplied by the modulation index (ma) to get V_r , V_y and V_b as shown in Fig.6.2. These sinusoidal waveforms are compared with 1 kHz triangular carrier signal to generate the switching pulses to the IGBT inverter. Any variation in the output power of IG is directly indicated by the variation in the terminal voltage of the generator. A decrease in capacitor voltage below the reference value indicates that the active power drawn by the load is higher than the power generated by IG. This difference in power is supplied by the VSI and hence the dc link voltage falls. Due to step change in load, the input power to the induction generator decreases as speed of the prime mover decreases. To maintain a constant voltage at the IG terminal, the controller decreases the inverter frequency. An increase in capacitor voltage indicates that the active power required by the load is reduced due to the removal of load. Under this condition active power generated by the IG is higher than the power required by the load. In order to decrease the active power the controller increases the inverter frequency.

CHAPTER 7

CHAPTER 7

SIMULATION MODEL OF THE PROJECT

7.1. INTRODUCTION:

MATLAB:

The name MATLAB stands for matrix laboratory. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. In this project the modeling and simulation of the proposed system is done using MATLAB (using Simulink and power system block set tool boxes).

SIMULINK:

Simulink is a software package for modeling, simulating, and analyzing non linear dynamical systems. It is a graphical mouse-driven program that allows somebody to model a system by drawing a block diagram on the screen and manipulating it dynamically. Simulink is a platform for multi domain simulation and Model-Based Design for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications.

POWER SYSTEM BLOCK SET:

The Power System Block set allows scientists and engineers to build models that simulate power systems. The block set uses the Simulink environment, allowing a model to be built using click and drag procedures. Not only can the circuit topology be drawn rapidly, but also the analysis of the circuit can include its interactions with mechanical, thermal, control, and other

disciplines. SimPowerSystems extends Simulink with tools for modeling and simulating basic electrical circuits and detailed electrical power systems. These tools let you model the generation, transmission, distribution, and consumption of electrical power, as well as its conversion into mechanical power. SimPowerSystems is well suited to the development of complex, self-contained power systems, such as those in automobiles, aircraft, manufacturing plants, and power utility applications.

7.2. SIMULATION CIRCUIT:

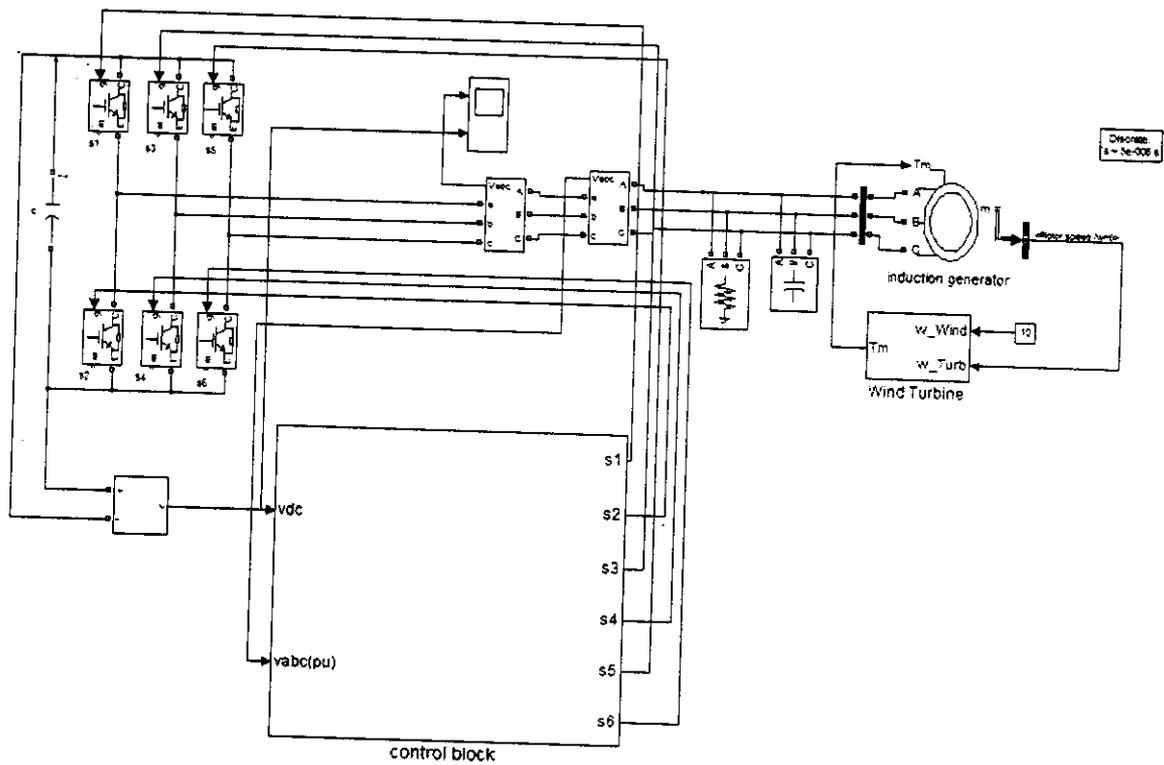


Fig 7.1 Overall simulation circuit.

The overall simulation circuit for the proposed topology is shown in the fig. 7.1. and the simulation model of the control circuit is shown in the figure 7.2.

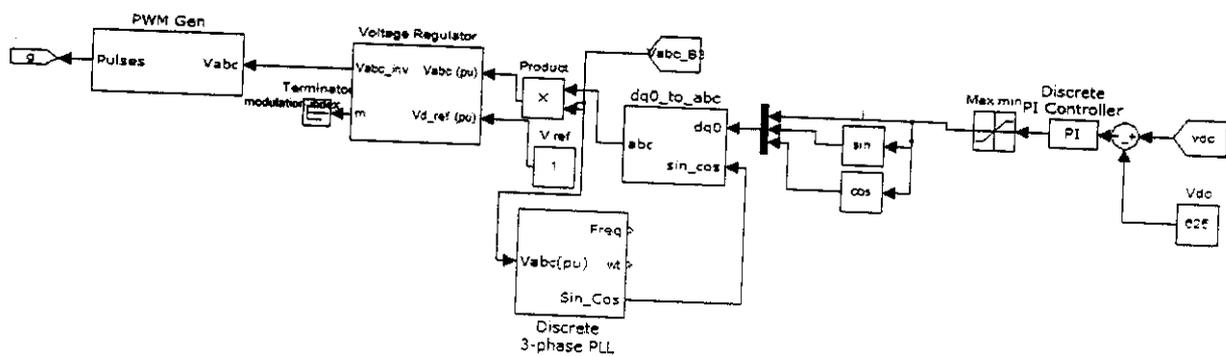


Figure 7.2. Simulation model of the controller circuit.

7.3. SWITCHING PATTERNS FOR THE PROPOSED INVERTER:

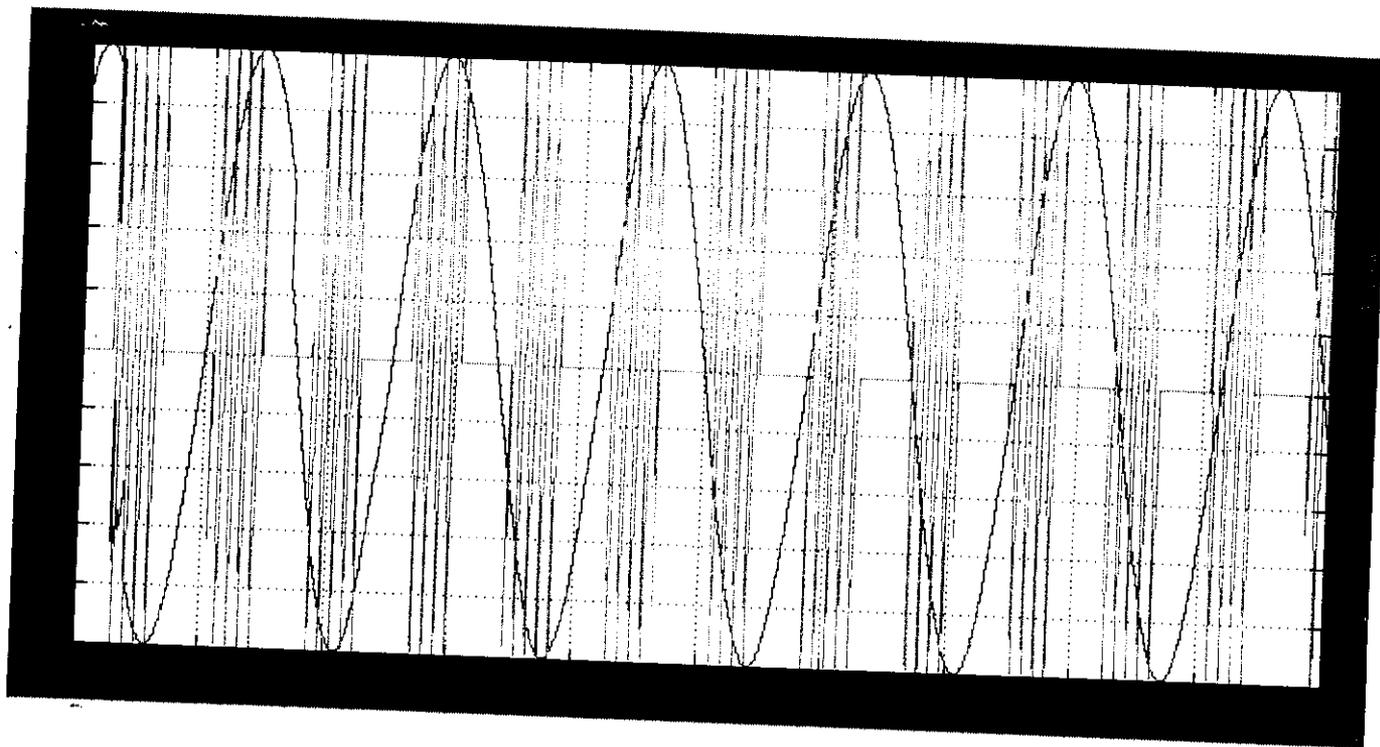
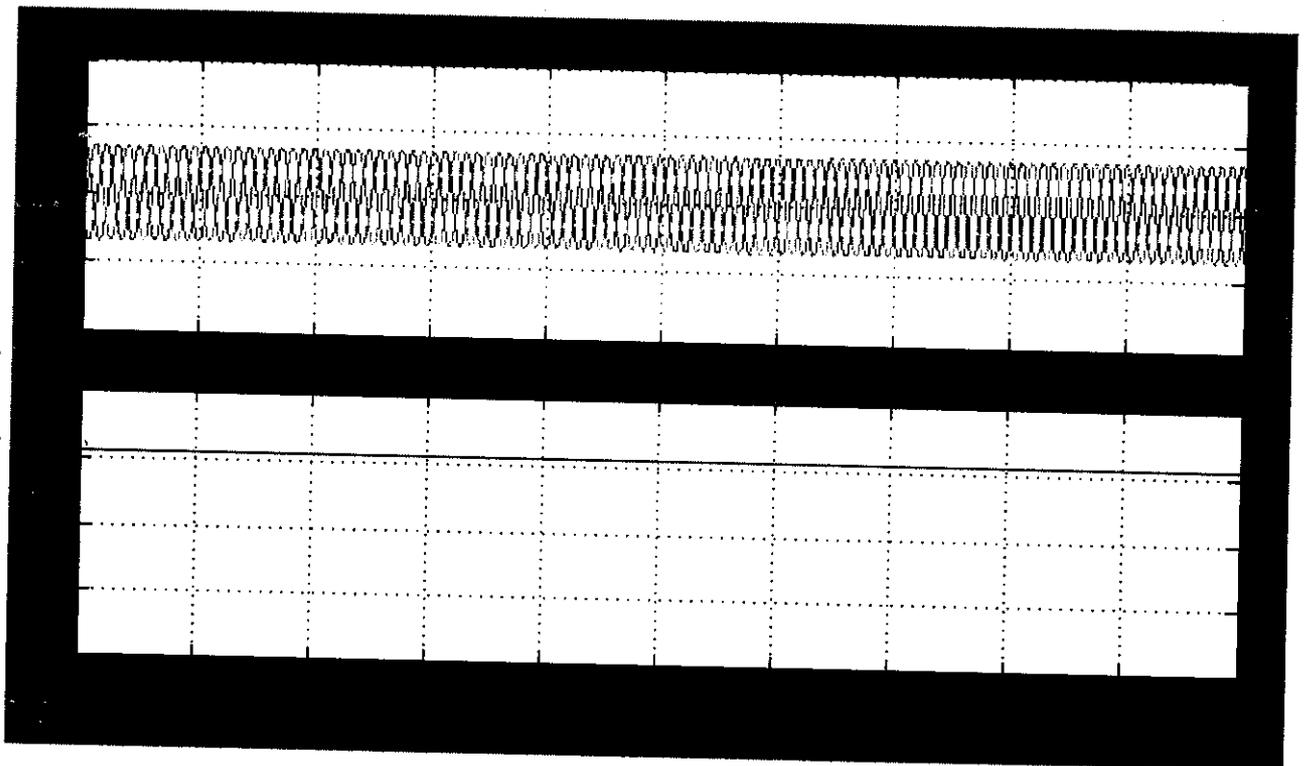


Figure. 7.3. Modified SPWM Switching pattern.

7.3. The modulation technique used here is the modified SPWM technique. The reference signal is the sinusoidal signal and the carrier signal is the 1kHz triangular signal. Here a 60 degree delay is introduced in a carrier triangular signal alternatively. The reference wave is compared with the carrier wave and by adjusting the amplitude of the modulation index suitably the switching patterns are produced.

7.4. SIMULATION RESULT OF THE OUTPUT VOLTAGE :

OUTPUT VOLTAGE at 10 m/sec:



7.4. Simulation result for the output voltage at 10 m/sec.

OUTPUT VOLTAGE at 12 m/sec:

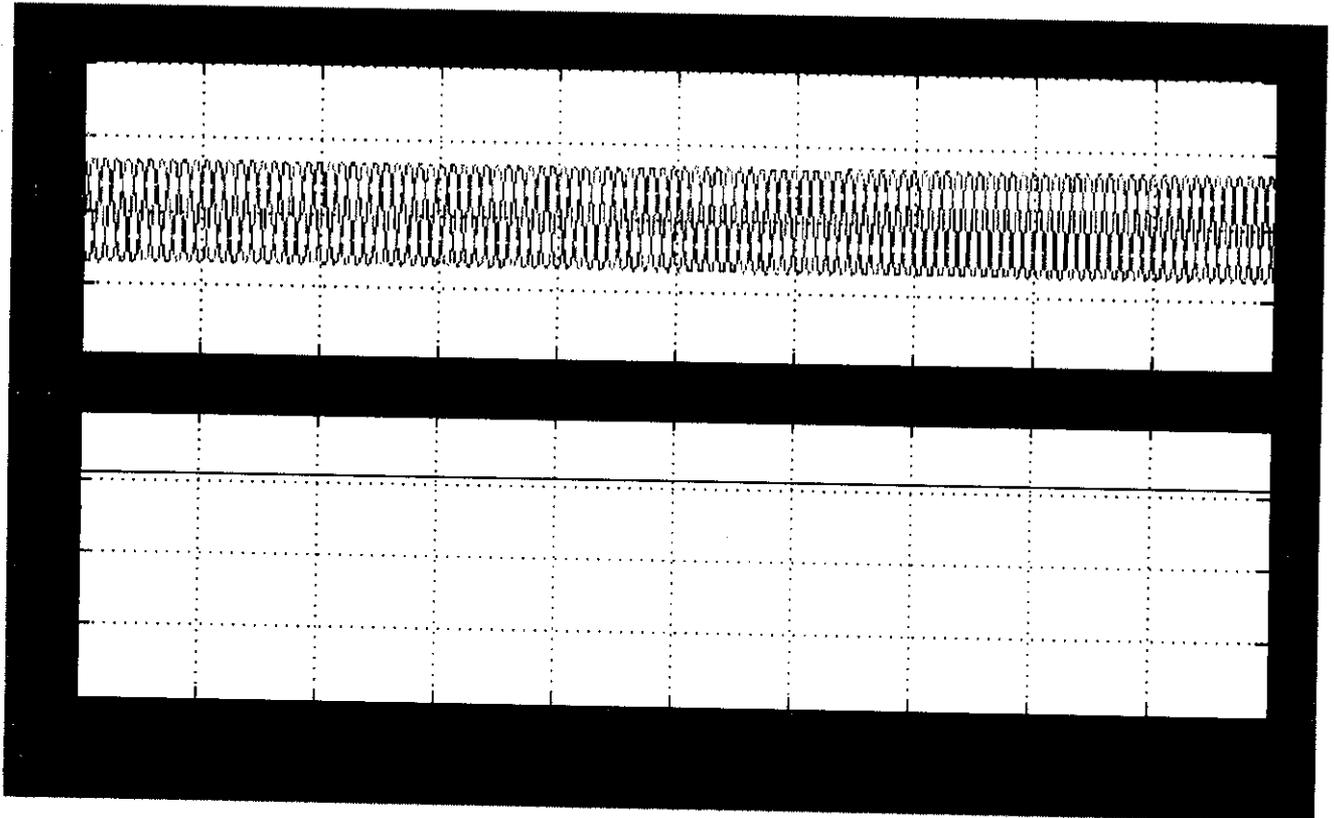


Figure 7.5. Simulation result for the output voltage at 12 m/sec.

The developed models of the sub-system are integrated and the resulting system is simulated using MATLAB/ SIMULINK. The terminal voltage of the induction generator is maintained constant at 420 V and the DC link voltage is also maintained constant at 625 V for various wind velocities. The closed loop controller adjusts the inverter frequency so that the terminal voltage is maintained at the reference value. The variation of the stator frequency and capacitor voltage during step change in load.

CHAPTER 8

CHAPTER 8

HARDWARE IMPLEMENTATION

8.1. BLOCK DIAGRAM:

In order to assess the performance of the proposed system, as shown in fig.8.1 is designed . In this prototype module, it consists of induction generator, voltage source converter, zero crossing detector and (MOSFET IRFZ44N), MOSFET Driver circuit and PIC microcontroller. Control algorithm is implemented in PIC Microcontroller, to maintain constant Inverter output voltage.

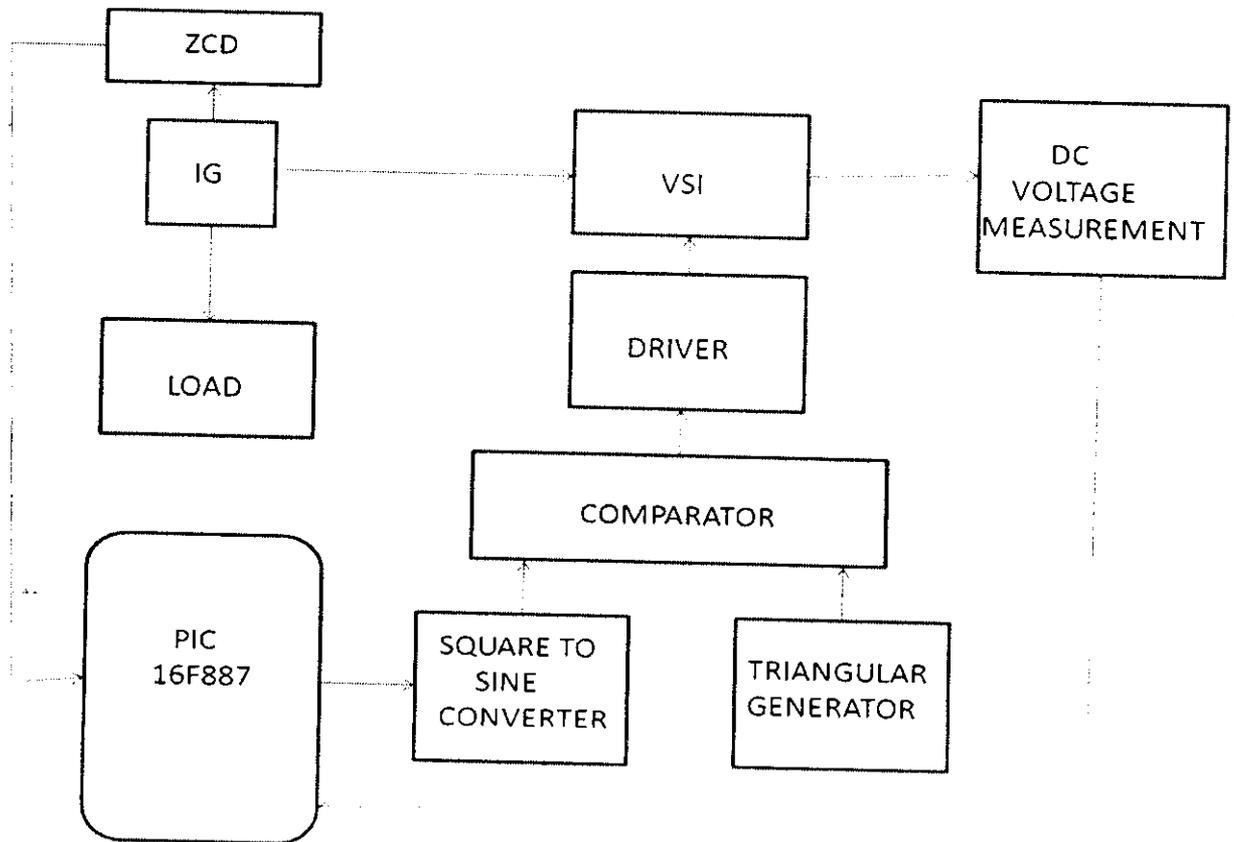


Figure. 8.1. Overall block diagram of the prototype.

8.2. SCHEMATIC DIAGRAM OF THE PROTOTYPE:

The prototype of converter and control circuit was implemented in PIC microcontroller (PIC 16F887) to provide the control signals for five-level inverter. C code of the incremental conductance and PWM scheme is built, debugged and run with the help of the microcontroller.

OVERALL SCHEMATIC OF THE SYSTEM:

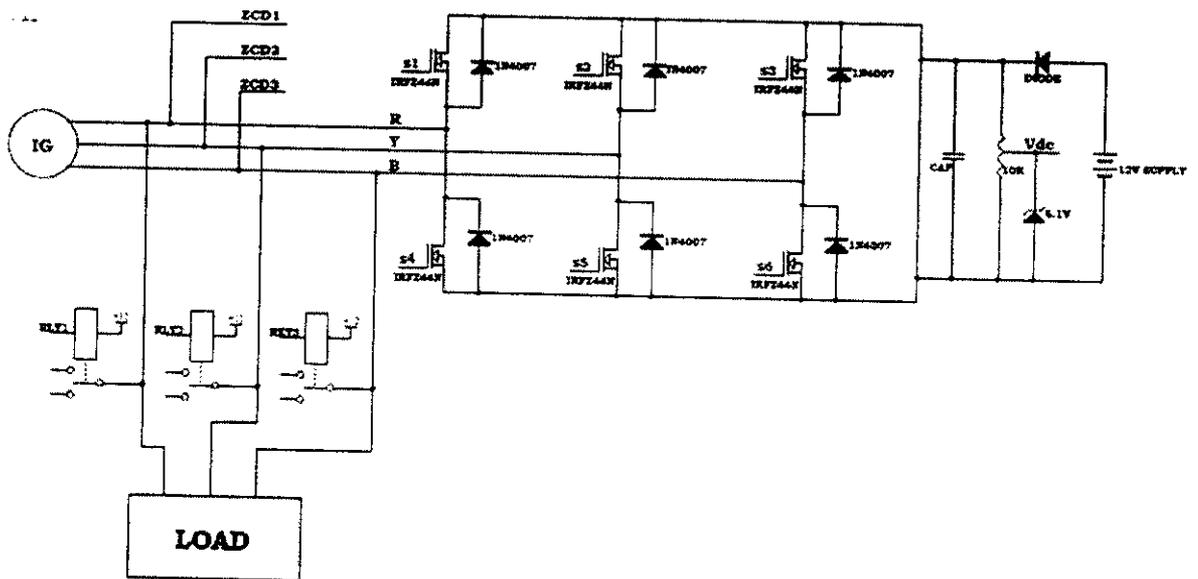


Figure 8.2. Overall circuit of the prototype.

ZERO CROSSING DETECTOR

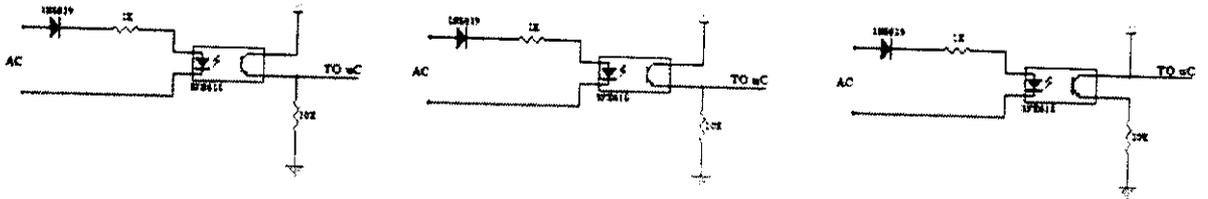


Figure.8.3. Circuit of the zero crossing detector.

CONTROLLER BLOCK

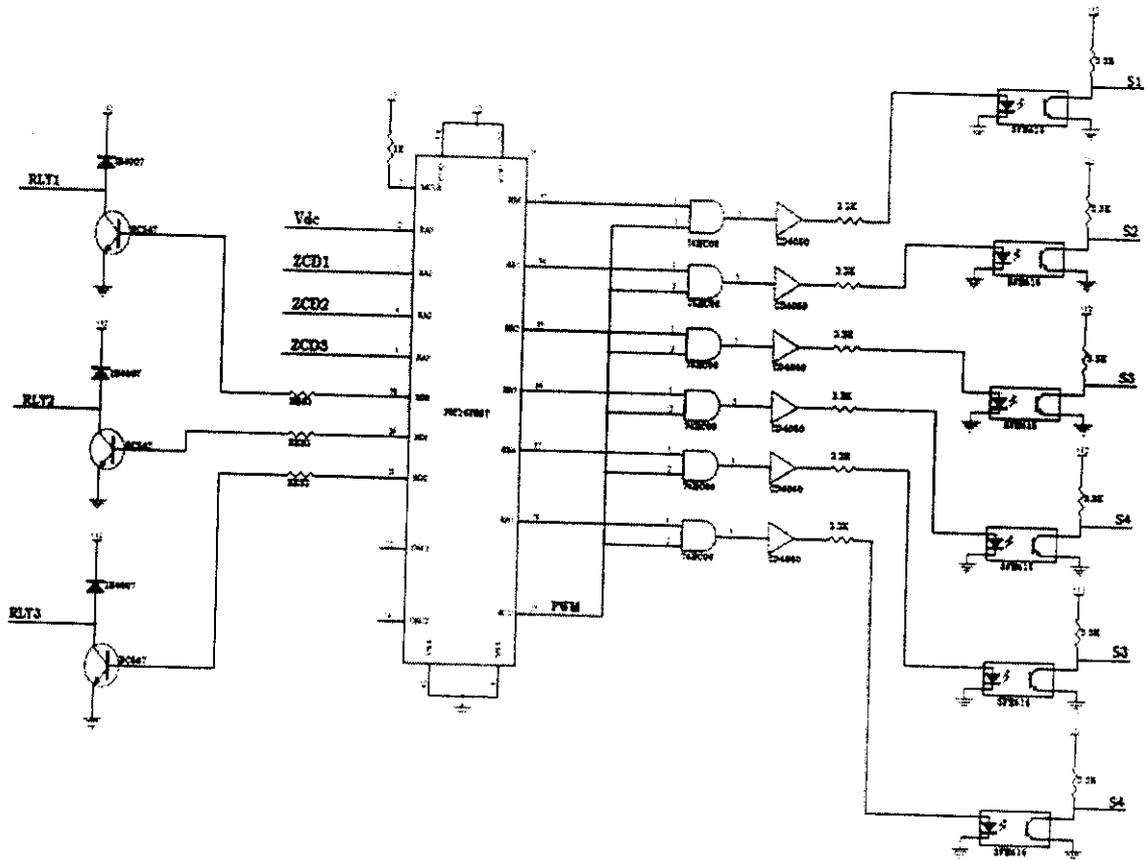


Figure 8.4. controller circuit of the prototype.

POWER CIRCUIT FOR THE PIC 16F887

The power circuit contains a step down transformer, which step downs the input voltage from 220V to 12V. In addition, the step downed voltage is rectified to DC. This is done by uncontrolled single phase diode rectifier. The output of this block is 12V DC. The schematic of rectifier is shown in the fig.8.5.

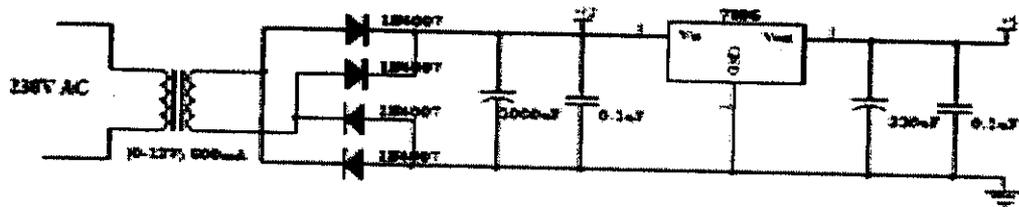


Figure 8.5. Power circuit for the controller.

8.3. ADVANTAGES OF MOSFET:

The main advantageous features of MOSFET are given as follows:

- MOSFETs provide much better system reliability.
- MOSFET are fast switching devices permit much higher switching frequencies and there by the efficiency is increased.
- MOSFETs have better temperature stability.
- Overload and peak current handling capacity is high.
- MOSFETS have low leakage current.
- MOSFETs are able to operate in hazardous radiation environments.

8.4. HARDWARE PROTOTYPE AND RESULTS:

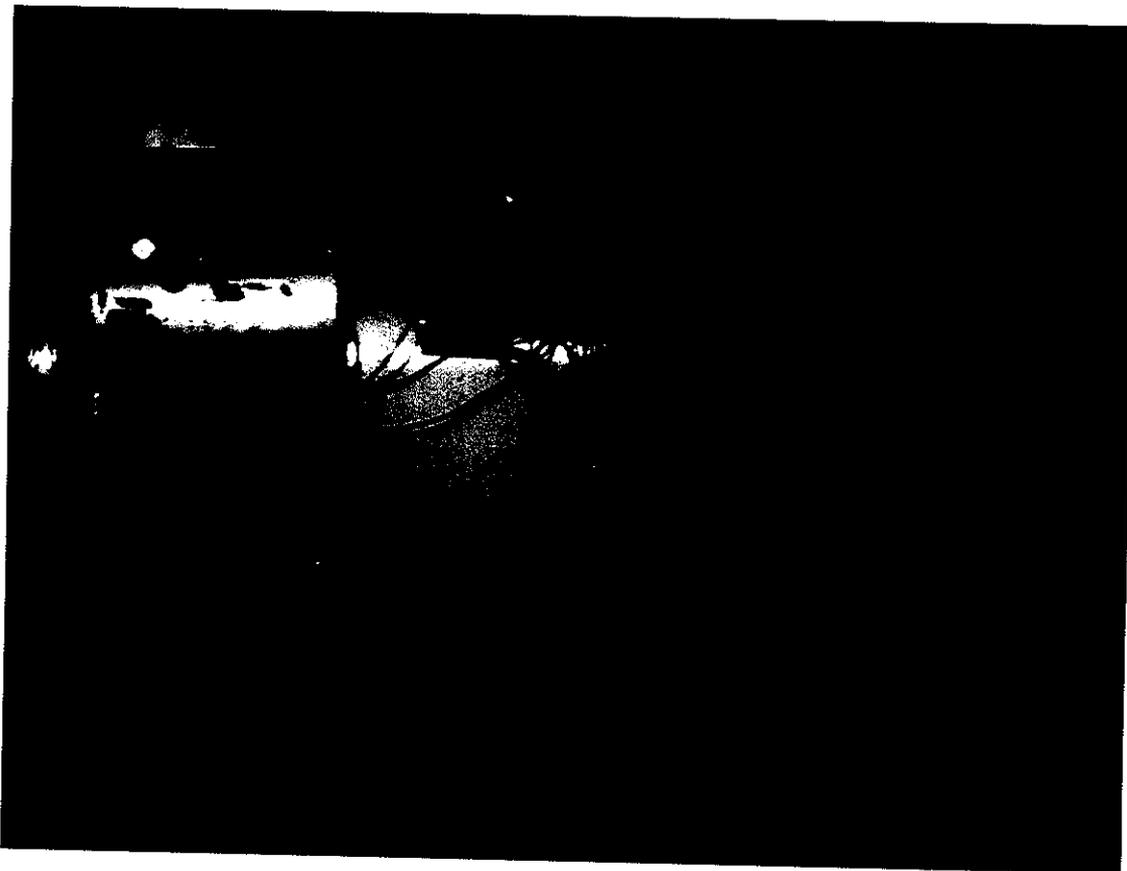


Figure 8.6. Photograph of the hardware

RESULTS:

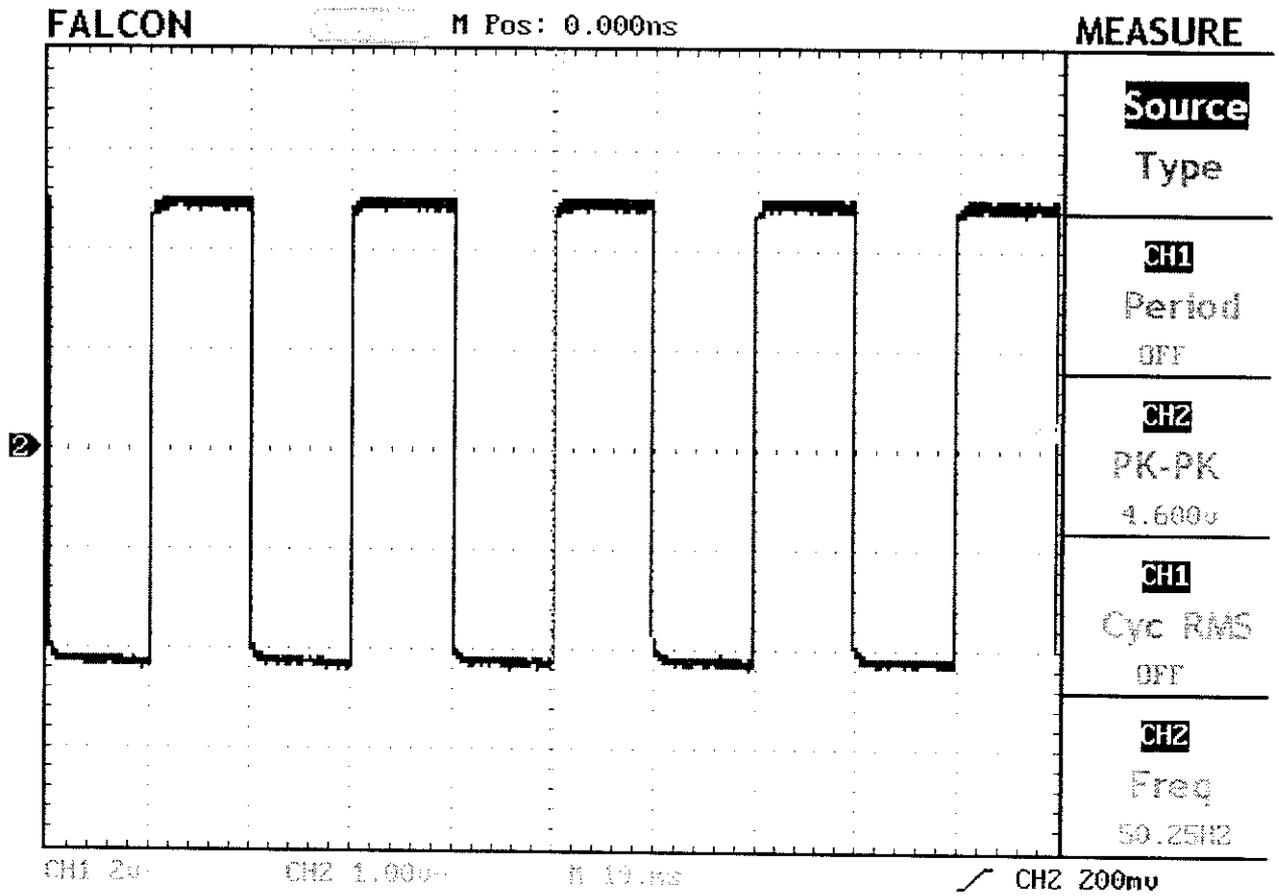


Figure 8.7 Waveform 1

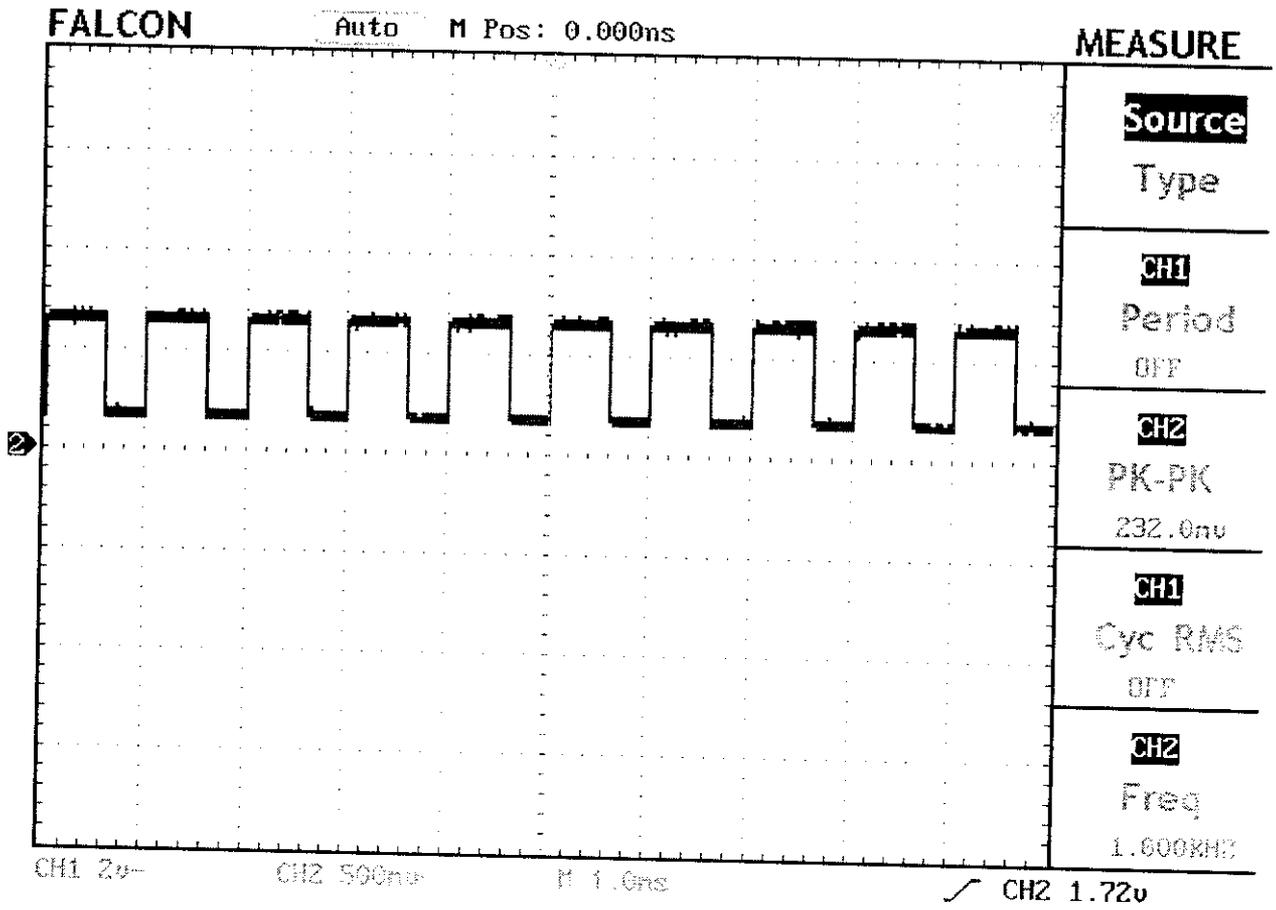


Figure 8.8 Waveform 2

CHAPTER 9

CHAPTER 9

CONCLUSION OF THE PROJECT

9.1. CONCLUSION:

A simple constant voltage controller for stand alone wind energy conversion system using induction generator is proposed. The controller is able to maintain a constant voltage at the terminals of IG during step change in load. The developed controller has a fast dynamic response, robust and reliable. The controller does not require any mechanical speed sensor thereby reducing the cost and complexity of the hardware. The simulation is done using MATLAB/ SIMULINK.

9.2. FUTURE SCOPE:

In the future scope of the work, the constant voltage controller using modified SPWM technique can be implemented for the doubly fed induction generator in wind energy conversion systems.

REFERENCES

- [1] E.D.Basset and F.M.Potter, "Capacitance excitation of Induction Generators", *Transaction on American Institute of Electrical Engineering*, vol. 54, no. 1, pp. 540–545, 1935.
- [2] D. W. Novotny and G. H. Studtmann, "Self-excitation in Inverter Driven Induction machine," *IEEE Transactions on Power Apparatus and Systems*, vol. 96, no. 4, pp. 1117–1125, July/Aug, 1977.
- [3] M.B.Brennan and A.Abbondanti, "Static Excitation for Induction Generator," *IEEE Transactions on Industry Applications*, vol. 13, no. 5, pp. 422–428, Sept/Oct, 1977.
- [4] H. C. Rai and A. K. Tandon, "Voltage Regulation of SEIG Using Passive Elements," *6th European Conference on Electrical Machines and Drives*, vol. 1, no. 1, pp. 240–245, 1983.
- [5] N. H. Malik and A. H. Al-Bahrani, "Influence of the Terminal Capacitor on the Performance Characteristics of SEIG," *IEE Proceedings of Instituteion of Electrical Engineering, Part C*, vol. 137, no. 2, pp. 168 – 173, March, 1990.
- [6] T.L.Maguire and A.M.Gole, "Apparatus for supplying an isolated dc load from a variable speed Self-Excited Induction Generator," *IEEE Transactions on Energy Conversion*, vol. 8, no. 3, pp. 468–475, 1993.
- [7] S. N. Bhadra, K. V. Ratnam, and A. Manjunath, "Study of voltage Build up in a Self-Excited, Variable Speed Induction Generator/Static Inverter System With D.C side Capacitor," *IEEE Conference on Power Electronics, Drives and Energy System*, vol. 2, no. 1, pp. 964–970, 1996.

[8] S. M. Alghuwainew, "Steady State Analysis of a Self-Excited Induction Generator by Shunt Saturable Reactor," *IEEE Conference on Electrical Machines and Drives*, vol. 1, no. 1, pp. 101–103, 1997.

APPENDIX I

PIC16F882/883/884/886/887

Device	Program Memory	Data Memory		I/O	10-bit A/D (ch)	ECCP/CCP	EUSART	MSSP	Comparators	Timers 8/16-bit
	Flash (words)	SRAM (bytes)	EEPROM (bytes)							
PIC16F882	2048	128	128	24	11	1/1	1	1	2	2/1
PIC16F883	4096	256	256	24	11	1/1	1	1	2	2/1
PIC16F884	4096	256	256	35	14	1/1	1	1	2	2/1
PIC16F886	8192	368	256	24	11	1/1	1	1	2	2/1
PIC16F887	8192	368	256	35	14	1/1	1	1	2	2/1

Pin Diagrams – PIC16F884/887, 40-Pin PDIP

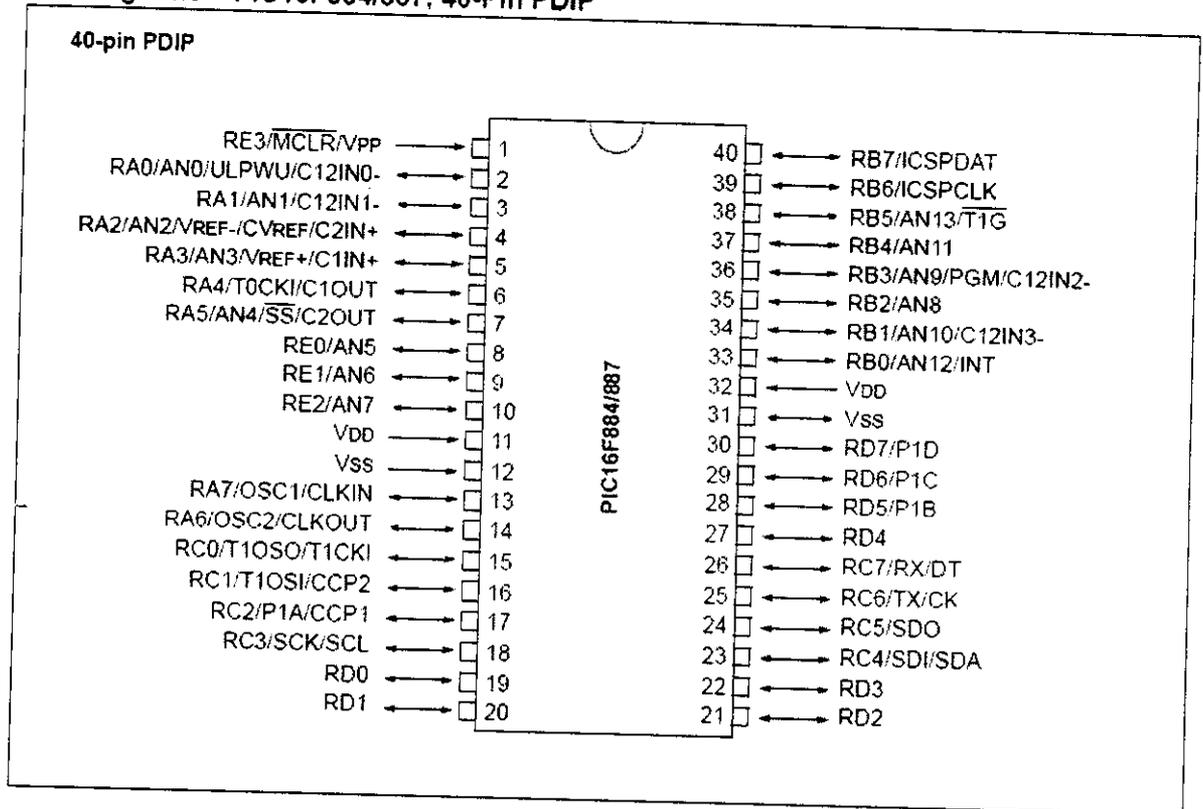


TABLE 3: PIC16F884/887 40-PIN SUMMARY (PDIP)

I/O	Pin	Analog	Comparators	Timers	ECCP	EUSART	MSSP	Interrupt	Pull-up	Basic
RA0	2	AN0/ULPWU	C12IN0-	—	—	—	—	—	—	—
RA1	3	AN1	C12IN1-	—	—	—	—	—	—	—
RA2	4	AN2	C2IN+	—	—	—	—	—	—	—
RA3	5	AN3	C1IN+	—	—	—	—	—	—	VREF-/CVREF
RA4	6	—	C1OUT	T0CKI	—	—	—	—	—	VREF+
RA5	7	AN4	C2OUT	—	—	—	SS	—	—	—
RA6	14	—	—	—	—	—	—	—	—	—
RA7	13	—	—	—	—	—	—	—	—	OSC2/CLKOUT
RB0	33	AN12	—	—	—	—	—	—	—	OSC1/CLKIN
RB1	34	AN10	C12IN3-	—	—	—	—	IOC/INT	Y	—
RB2	35	AN8	—	—	—	—	—	IOC	Y	—
RB3	36	AN9	C12IN2-	—	—	—	—	IOC	Y	—
RB4	37	AN11	—	—	—	—	—	IOC	Y	PGM
RB5	38	AN13	—	T1G	—	—	—	IOC	Y	—
RB6	39	—	—	—	—	—	—	IOC	Y	—
RB7	40	—	—	—	—	—	—	IOC	Y	ICSPCLK
RC0	15	—	—	T1OSO/T1CKI	—	—	—	—	Y	ICSPDAT
RC1	16	—	—	T1OSI	CCP2	—	—	—	—	—
RC2	17	—	—	—	CCP1/P1A	—	—	—	—	—
RC3	18	—	—	—	—	—	SCK/SCL	—	—	—
RC4	23	—	—	—	—	—	SDI/SDA	—	—	—
RC5	24	—	—	—	—	—	SDO	—	—	—
RC6	25	—	—	—	—	TX/CK	—	—	—	—
RC7	26	—	—	—	—	RX/DT	—	—	—	—
RD0	19	—	—	—	—	—	—	—	—	—
RD1	20	—	—	—	—	—	—	—	—	—
RD2	21	—	—	—	—	—	—	—	—	—
RD3	22	—	—	—	—	—	—	—	—	—
RD4	27	—	—	—	—	—	—	—	—	—
RD5	28	—	—	—	P1B	—	—	—	—	—
RD6	29	—	—	—	P1C	—	—	—	—	—
RD7	30	—	—	—	P1D	—	—	—	—	—
RE0	8	AN5	—	—	—	—	—	—	—	—
RE1	9	AN6	—	—	—	—	—	—	—	—
RE2	10	AN7	—	—	—	—	—	—	—	—
RE3	1	—	—	—	—	—	—	—	—	—
—	11	—	—	—	—	—	—	—	Y ⁽¹⁾	MCLR/VPP
—	32	—	—	—	—	—	—	—	—	VDD
—	12	—	—	—	—	—	—	—	—	VDD
—	31	—	—	—	—	—	—	—	—	VSS
—	—	—	—	—	—	—	—	—	—	VSS

Note 1: Pull-up activated only with external MCLR configuration

Pin Diagrams – PIC16F884/887, 44-Pin QFN

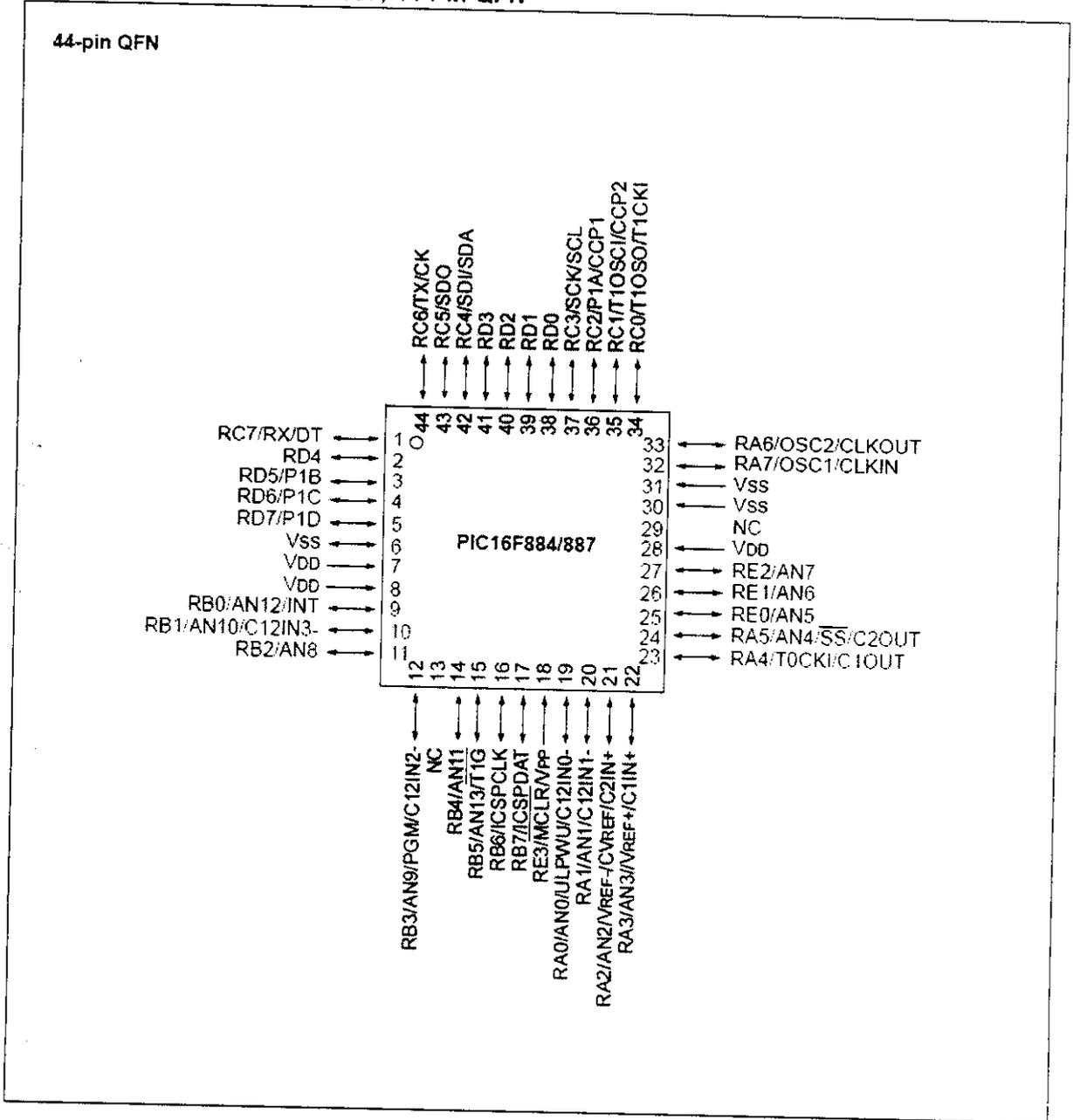


TABLE 4: PIC16F884/887 44-PIN SUMMARY (QFN)

I/O	Pin	Analog	Comparators	Timers	ECCP	EUSART	MSSP	Interrupt	Pull-up	Basic
RA0	19	AN0/ULPWU	C12IN0-	—	—	—	—	—	—	—
RA1	20	AN1	C12IN1-	—	—	—	—	—	—	—
RA2	21	AN2	C2IN+	—	—	—	—	—	—	—
RA3	22	AN3	C1IN+	—	—	—	—	—	—	VREF-/CVREF
RA4	23	—	C1OUT	T0CKI	—	—	—	—	—	VREF+
RA5	24	AN4	C2OUT	—	—	—	SS	—	—	—
RA6	33	—	—	—	—	—	—	—	—	—
RA7	32	—	—	—	—	—	—	—	—	OSC2/CLKOUT
RB0	9	AN12	—	—	—	—	—	—	—	OSC1/CLKIN
RB1	10	AN10	C12IN3-	—	—	—	—	IOC/INT	Y	—
RB2	11	AN8	—	—	—	—	—	IOC	Y	—
RB3	12	AN9	C12IN2-	—	—	—	—	IOC	Y	—
RB4	14	AN11	—	—	—	—	—	IOC	Y	PGM
RB5	15	AN13	—	T1G	—	—	—	IOC	Y	—
RB6	16	—	—	—	—	—	—	IOC	Y	—
RB7	17	—	—	—	—	—	—	IOC	Y	ICSPCLK
RC0	34	—	—	T1OSO/T1CKI	—	—	—	IOC	Y	ICSPDAT
RC1	35	—	—	T1OSI	CCP2	—	—	—	—	—
RC2	36	—	—	—	CCP1/P1A	—	—	—	—	—
RC3	37	—	—	—	—	—	—	—	—	—
RC4	42	—	—	—	—	—	SCK/SCL	—	—	—
RC5	43	—	—	—	—	—	SD/SDA	—	—	—
RC6	44	—	—	—	—	—	SDO	—	—	—
RC7	1	—	—	—	—	TX/CK	—	—	—	—
RD0	38	—	—	—	—	RX/DT	—	—	—	—
RD1	39	—	—	—	—	—	—	—	—	—
RD2	40	—	—	—	—	—	—	—	—	—
RD3	41	—	—	—	—	—	—	—	—	—
RD4	2	—	—	—	—	—	—	—	—	—
RD5	3	—	—	—	—	—	—	—	—	—
RD6	4	—	—	—	P1B	—	—	—	—	—
RD7	5	—	—	—	P1C	—	—	—	—	—
RE0	25	AN5	—	—	P1D	—	—	—	—	—
RE1	26	AN6	—	—	—	—	—	—	—	—
RE2	27	AN7	—	—	—	—	—	—	—	—
RE3	18	—	—	—	—	—	—	—	—	—
—	7	—	—	—	—	—	—	—	Y ⁽¹⁾	MCLR/VPP
—	8	—	—	—	—	—	—	—	—	VDD
—	28	—	—	—	—	—	—	—	—	VDD
—	6	—	—	—	—	—	—	—	—	VDD
—	30	—	—	—	—	—	—	—	—	VSS
—	31	—	—	—	—	—	—	—	—	VSS
—	13	—	—	—	—	—	—	—	—	VSS
—	29	—	—	—	—	—	—	—	—	NC (no connect)
—	—	—	—	—	—	—	—	—	—	NC (no connect)

Note 1: Pull-up activated only with external MCLR configuration.

FIGURE 1-2: PIC16F884/PIC16F887 BLOCK DIAGRAM

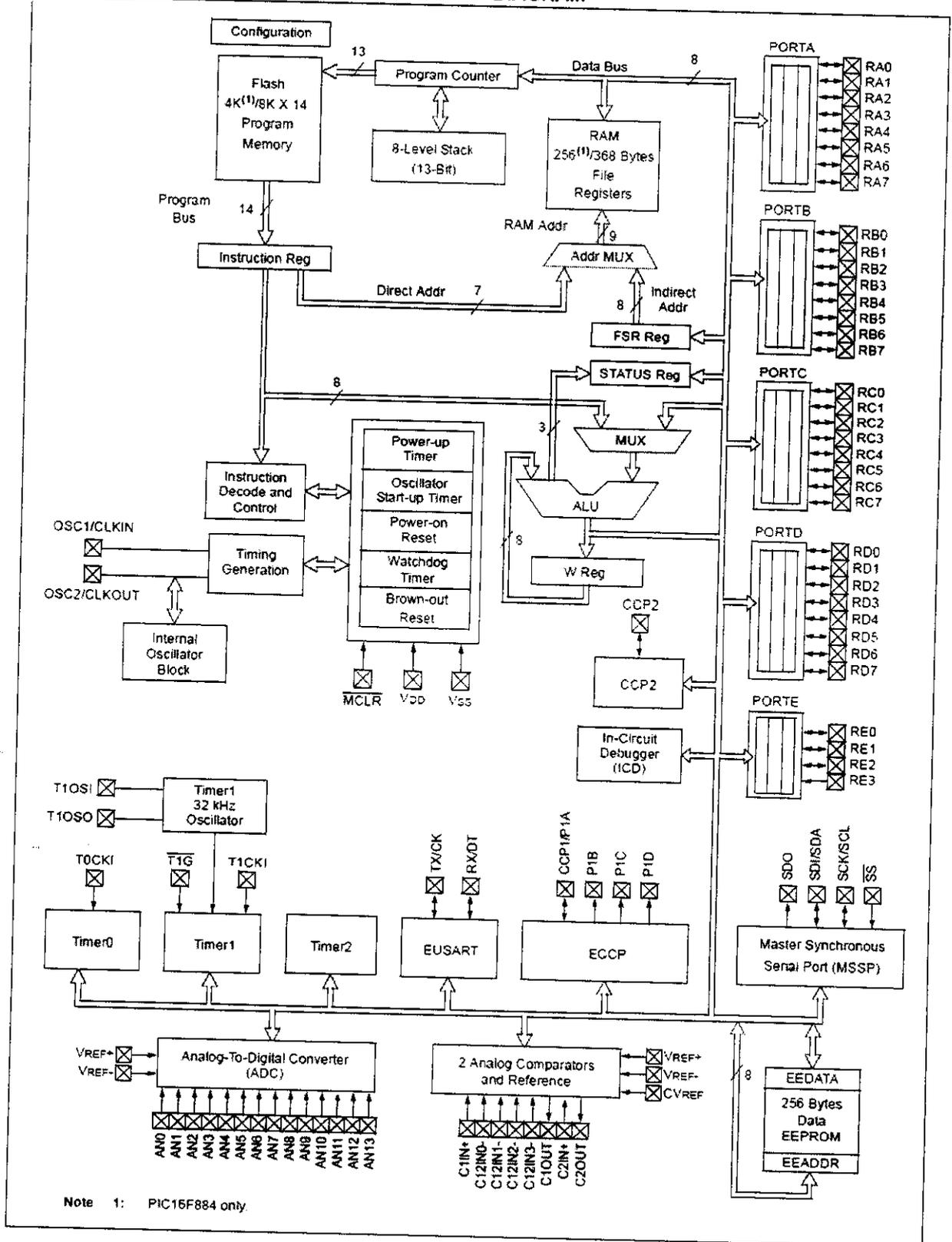


TABLE 1-2: PIC16F884/887 PINOUT DESCRIPTION

Name	Function	Input Type	Output Type	Description
RA0/AN0/ULPWU/C12IN0-	RA0	TTL	CMOS	General purpose I/O.
	AN0	AN	—	A/D Channel 0 input.
	ULPWU	AN	—	Ultra Low-Power Wake-up input.
	C12IN0-	AN	—	Comparator C1 or C2 negative input.
RA1/AN1/C12IN1-	RA1	TTL	CMOS	General purpose I/O.
	AN1	AN	—	A/D Channel 1 input.
	C12IN1-	AN	—	Comparator C1 or C2 negative input.
RA2/AN2/VREF-/CVREF/C2IN+	RA2	TTL	CMOS	General purpose I/O.
	AN2	AN	—	A/D Channel 2.
	VREF-	AN	—	A/D Negative Voltage Reference input.
	CVREF	—	AN	Comparator Voltage Reference output.
	C2IN+	AN	—	Comparator C2 positive input.
RA3/AN3/VREF+/C1IN+	RA3	TTL	CMOS	General purpose I/O.
	AN3	AN	—	A/D Channel 3.
	VREF+	AN	—	A/D Positive Voltage Reference input.
	C1IN+	AN	—	Comparator C1 positive input.
RA4/T0CKI/C1OUT	RA4	TTL	CMOS	General purpose I/O.
	T0CKI	ST	—	Timer0 clock input.
	C1OUT	—	CMOS	Comparator C1 output.
RA5/AN4/SS/C2OUT	RA5	TTL	CMOS	General purpose I/O.
	AN4	AN	—	A/D Channel 4.
	SS	ST	—	Slave Select input.
	C2OUT	—	CMOS	Comparator C2 output.
RA6/OSC2/CLKOUT	RA6	TTL	CMOS	General purpose I/O.
	OSC2	—	XTAL	Crystal/Resonator.
	CLKOUT	—	CMOS	Fosc/4 output.
RA7/OSC1/CLKIN	RA7	TTL	CMOS	General purpose I/O.
	OSC1	XTAL	—	Crystal/Resonator.
	CLKIN	ST	—	External clock input/RC oscillator connection.
RB0/AN12/INT	RB0	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN12	AN	—	A/D Channel 12.
	INT	ST	—	External interrupt.
RB1/AN10/C12IN3-	RB1	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN10	AN	—	A/D Channel 10.
	C12IN3-	AN	—	Comparator C1 or C2 negative input.
RB2/AN8	RB2	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN8	AN	—	A/D Channel 8.
RB3/AN9/PGM/C12IN2-	RB3	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN9	AN	—	A/D Channel 9.
	PGM	ST	—	Low-voltage ICSP™ Programming enable pin.
	C12IN2-	AN	—	Comparator C1 or C2 negative input.

Legend: AN = Analog input or output CMOS = CMOS compatible input or output OD = Open Drain
TTL = TTL compatible input ST = Schmitt Trigger input with CMOS levels
HV = High Voltage XTAL = Crystal



TABLE 1-2: PIC16F884/887 PINOUT DESCRIPTION (CONTINUED)

Name	Function	Input Type	Output Type	Description
RB4/AN11	RB4	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN11	AN	—	A/D Channel 11.
RB5/AN13/T1G	RB5	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN13	AN	—	A/D Channel 13.
	T1G	ST	—	Timer1 Gate input.
RB6/ICSPCLK	RB6	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	ICSPCLK	ST	—	Serial Programming Clock.
RB7/ICSPDAT	RB7	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	ICSPDAT	ST	TTL	ICSP™ Data I/O.
RC0/T1OSO/T1CKI	RC0	ST	CMOS	General purpose I/O.
	T1OSO	—	XTAL	Timer1 oscillator output.
	T1CKI	ST	—	Timer1 clock input.
RC1/T1OSI/CCP2	RC1	ST	CMOS	General purpose I/O.
	T1OSI	XTAL	—	Timer1 oscillator input.
	CCP2	ST	CMOS	Capture/Compare/PWM2.
RC2/P1A/CCP1	RC2	ST	CMOS	General purpose I/O.
	P1A	ST	CMOS	PWM output.
	CCP1	—	CMOS	Capture/Compare/PWM1.
RC3/SCK/SCL	RC3	ST	CMOS	General purpose I/O.
	SCK	ST	CMOS	SPI clock.
	SCL	ST	OD	I ² C™ clock.
RC4/SDI/SDA	RC4	ST	CMOS	General purpose I/O.
	SDI	ST	—	SPI data input.
	SDA	ST	OD	I ² C data input/output.
RC5/SDO	RC5	ST	CMOS	General purpose I/O.
	SDO	—	CMOS	SPI data output.
RC6/TX/CK	RC6	ST	CMOS	General purpose I/O.
	TX	—	CMOS	EUSART asynchronous transmit.
	CK	ST	CMOS	EUSART synchronous clock.
RC7/RX/DT	RC7	ST	CMOS	General purpose I/O.
	RX	ST	—	EUSART asynchronous input.
	DT	ST	CMOS	EUSART synchronous data.
RD0	RD0	TTL	CMOS	General purpose I/O.
RD1	RD1	TTL	CMOS	General purpose I/O.
RD2	RD2	TTL	CMOS	General purpose I/O.
RD3	RD3	TTL	CMOS	General purpose I/O.
RD4	RD4	TTL	CMOS	General purpose I/O.
RD5/P1B	RD5	TTL	CMOS	General purpose I/O.
	P1B	—	CMOS	PWM output.
RD6/P1C	RD6	TTL	CMOS	General purpose I/O.
	P1C	—	CMOS	PWM output.

Legend: AN = Analog input or output CMOS = CMOS compatible input or output OD = Open Drain
TTL = TTL compatible input ST = Schmitt Trigger input with CMOS levels
HV = High Voltage XTAL = Crystal

TABLE 1-2: PIC16F884/887 PINOUT DESCRIPTION (CONTINUED)

Name	Function	Input Type	Output Type	Description
RD7/P1D	RD7	TTL	CMOS	General purpose I/O.
	P1D	AN	—	PWM output.
RE0/AN5	RE0	TTL	CMOS	General purpose I/O.
	AN5	AN	—	A/D Channel 5.
RE1/AN6	RE1	TTL	CMOS	General purpose I/O.
	AN6	AN	—	A/D Channel 6.
RE2/AN7	RE2	TTL	CMOS	General purpose I/O.
	AN7	AN	—	A/D Channel 7.
RE3/MCLR/VPP	RE3	TTL	—	General purpose input.
	MCLR	ST	—	Master Clear with internal pull-up.
	VPP	HV	—	Programming voltage.
VSS	VSS	Power	—	Ground reference.
VDD	VDD	Power	—	Positive supply.

Legend: AN = Analog input or output CMOS = CMOS compatible input or output OD = Open Drain
TTL = TTL compatible input ST = Schmitt Trigger input with CMOS levels
HV = High Voltage XTAL = Crystal

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.



DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers (Glass Passivated)

Absolute Maximum Ratings*

$T_A = 25^\circ\text{C}$ unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	500	800	1000	V
I_{RAV}	Average Rectified Forward Current, 375 μ lead length @ $T_A = 75^\circ\text{C}$	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{STG}	Storage Temperature Range	-55 to +175							$^\circ\text{C}$
T_J	Operating Junction Temperature	-55 to +175							$^\circ\text{C}$

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	$^\circ\text{C/W}$

Electrical Characteristics

$T_A = 25^\circ\text{C}$ unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_R	Maximum Full Load Reverse Current, Full Cycle $T_A = 75^\circ\text{C}$	30							μA
I_{RS}	Reverse Current @ rated V_R $T_A = 25^\circ\text{C}$	5.0							μA
C_T	Total Capacitance $V_R = 4.0\text{ V}, f = 1.0\text{ MHz}$	500							μA
		15							pF

Typical Characteristics

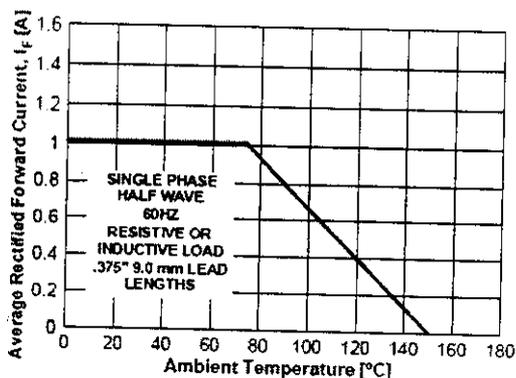


Figure 1. Forward Current Derating Curve

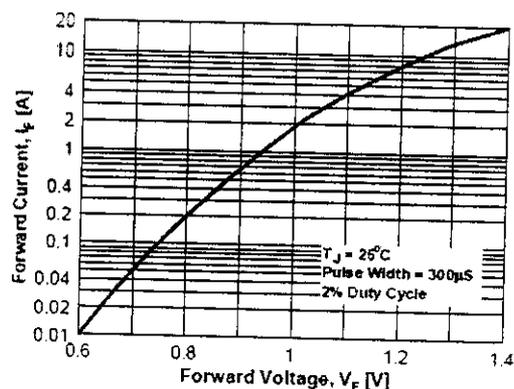


Figure 2. Forward Voltage Characteristics

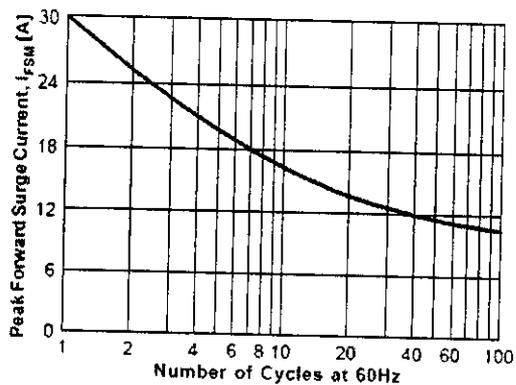


Figure 3. Non-Repetitive Surge Current

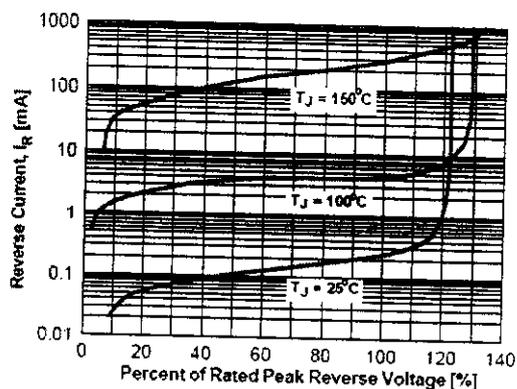


Figure 4. Reverse Current vs Reverse Voltage

APPENDIX III

PIC PROGRAM

```
#include<pic.h>
//__CONFIG(0x1F71);
__CONFIG(0x20A4);
__CONFIG(0x3FFF);
void main()
{
    ADCON1=0x06;
    ANSEL=0;
    ANSELH=0;

    PR2=99;
    CCP1L=50;
    CCP1CON=0X0C;
    T2CON=0X04;

    TRISD=0X0F;
    TRISC=0X80;
    TRISB=0;
    TRISA=0;
    PORTC=0;
    PORTB=0;

    OPTION=0x87;
    TMR0=0;

//    GIE=PEIE=INTE=TOIE=TMR1IE=1;
//
//    T1CON =0x01;
//    TMR1L = 0x00;
//    TMR1H = 0x00;

    while(1)
    {
//        while(RD0==0)
//        {
            PORTB=0x42;
            while(TMR0<4);
            PORTB=0x52;
            while(TMR0<22);

            PORTB=0x50;
            while(TMR0<26);
            PORTB=0x30;
            while(TMR0<30);
        }
    }
}
```

```

PORTB=0x38;
while(TMR0<48);
PORTB=0x28;
while(TMR0<52);

PORTB=0x0C;
while(TMR0<56);
PORTB=0x0E;
while(TMR0<74);

PORTB=0x06;
while(TMR0<78);
TMR0=0;
//      }
/*      while(RD0==1)
{
PORTB=0x42;
while(TMR0<8);
PORTB=0x52;
while(TMR0<44);

PORTB=0x50;
while(TMR0<52);
PORTB=0x30;
while(TMR0<60);

PORTB=0x38;
while(TMR0<96);
PORTB=0x28;
while(TMR0<104);

PORTB=0x0C;
while(TMR0<112);
PORTB=0x0E;
while(TMR0<148);

PORTB=0x06;
while(TMR0<156);
TMR0=0;
}
*/
}
while(1);
}

```