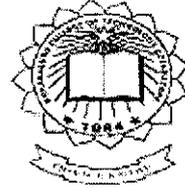
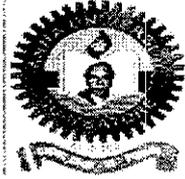


D-2538



**VOLTAGE AND FREQUENCY CONTROL OF INDEPENDENT
WIND POWER GENERATING SYSTEM**

By

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(An Autonomous Institution affiliated to Anna University Coimbatore)

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for the award of the degree

of

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IN

POWER ELECTRONICS AND DRIVES

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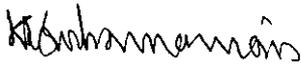
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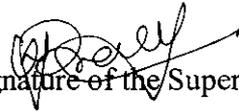
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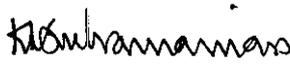
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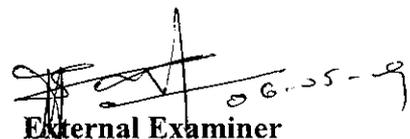
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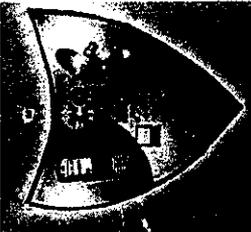
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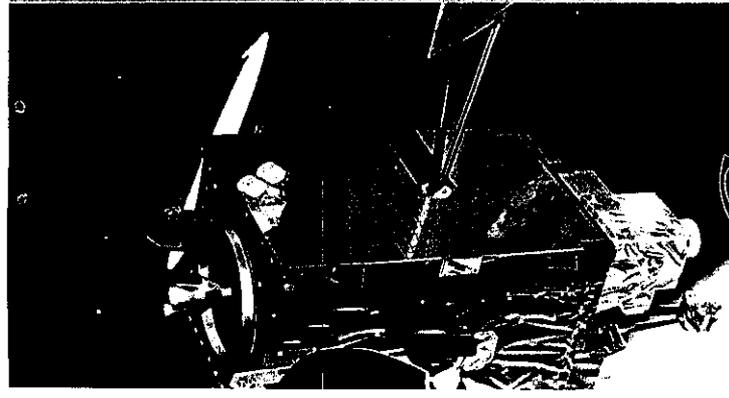
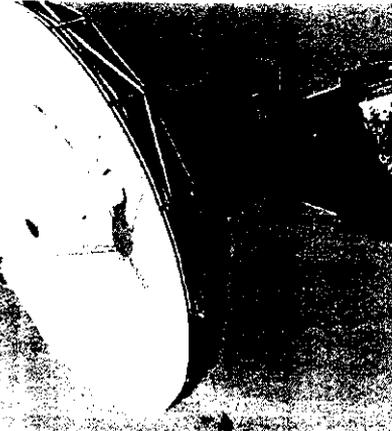
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ABSTRACT

This project aims to design an efficient voltage and frequency controller for a stand alone self excited induction generator wind energy conversion system where the control of magnitude and frequency of generated voltage have greater challenge . The designed voltage and frequency controller consist of IGBT based voltage source converter along-with battery energy storage system at its dc link. The proposed controller is having bidirectional active and reactive power flow capability by which it controls the system voltage and frequency with variation of consumer loads and the speed of the wind turbine. It is also having capability of harmonic elimination and load balancing. The electro-mechanical system along with its controller is modeled and simulated in MATLAB using Simulink and power system block-set toolboxes. Performance of the proposed controller is presented to demonstrate voltage and frequency control of a wind turbine driven isolated asynchronous generator along with harmonic elimination and load balancing. The proposed controller is implemented in hardware and tested. Micro controller PIC16F877A is used to generate the pulses for the switching devices of the VSC.

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ABBREVIATIONS

| | |
|-------|-------------------------------------|
| WECS- | Wind energy conversion system |
| AWEA- | American wind energy association |
| EWEA- | European wind energy association |
| HAWT- | Horizontal axis wind turbine |
| VAWT- | Vertical axis wind turbine |
| CVCF- | Constant voltage constant frequency |
| SEIG- | Self excited induction generator |
| THD- | Total harmonic distortion |
| EMI- | Electromagnetic Interference |
| PWM- | Pulse width modulation |
| AC- | Alternating current |
| DC- | Direct current |
| TMR0- | timer0 |
| TMR1- | timer1 |
| TMR2- | timer2 |
| CCP- | compares capture |
| PWRT- | power-up timer |

LIST OF SYMBOLS

| | |
|-------------|--------------------------------------|
| P - | Aerodynamic power of wind turbine, |
| R - | Turbine radius |
| ρ - | Air density |
| V - | Wind speed |
| C_p - | Power coefficient |
| λ - | Tip speed ratio |
| i_a - | Generator current in a phase |
| i_b - | Generator current in b phase |
| i_c - | Generator current in c phase |
| ω - | Rotational speed of the wind turbine |
| V_{ab} - | Voltage between phase a and phase b |
| V_{bc} - | Voltage between phase b and phase c |
| V_{ca} - | Voltage between phase c and phase a |
| R_f - | Interfacing resistance |
| L_f - | Interfacing inductance |
| C_{dc} - | Dc link capacitance |
| I_b - | Battery current |
| V_b - | Battery voltage |
| V_{ml} - | Maximum line voltage |
| α - | Firing angle of the switch |
| V_{tm} - | Terminal voltage |
| P_l - | Instantaneous active power. |
| f - | Frequency |

CHAPTER 1

1. INTRODUCTION

1.1 WIND ENERGY

Energy demand of the world is increasing year by year. With the increasing demand of energy, besides of the exploitation of the traditional sources, new energy sources are searched and used throughout the world depending upon their availability and their relative benefits. Within the new energy sources wind energy can play a significant role in solving the world energy problem. Wind energy is a form of solar energy, created by circulation patterns in the Earth's atmosphere that are driven by heat from the sun. Although people have made use of wind energy for thousands of years, in sailing and in mills to grind grain, extracting electrical energy from the wind appears to be a new application which gains increasing interest with the advances in the turbine and control technologies. Today the wind energy is the world's fastest growing energy source. Cumulative global wind energy generating capacity reached 74,223 MW and installed wind turbines reached 70,000 units at the end of 2006. 15,197 MW new capacity was installed worldwide during the year 2006, an increase of 32%, according to estimates by the American Wind Energy Association (AWEA) and the European Wind Energy Association (EWEA).

The countries with the highest total installed capacity are Germany (20,621 MW), Spain (11,615 MW), the USA (11,603 MW), India (6,270 MW) and Denmark (3,136). Thirteen countries around the world can now be counted among those with over 1000 MW of wind capacity, with France and Canada reaching this threshold in 2006. However, the upper limit for the utilization of the earth's wind supply is estimated 130,000 GW. A number of assessments confirm that the world's wind resources are extremely large and well distributed all regions. The total available resource that is technically recoverable is estimated to be 53,000 TWh/year

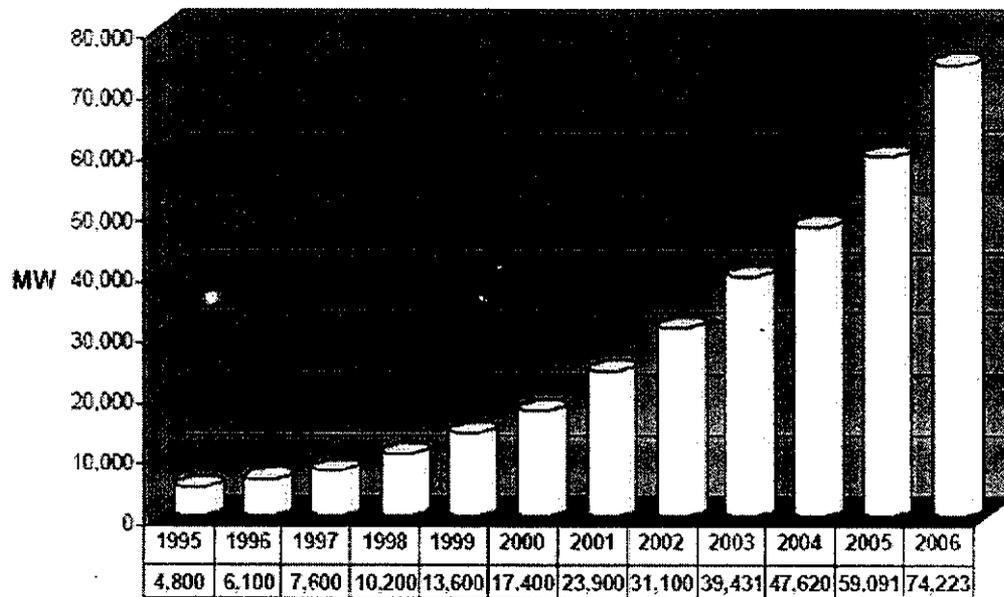


Fig1.1.Global Cumulative Installed Capacity

Wind energy conversion systems (WECS) consist of a wind turbine, which transforms the energy in the wind into mechanical energy and an electric generator coupled to the shaft of the turbine end, which converts the mechanical energy at the shaft into electrical energy. The types of the turbine and the generator used depend on different factors such as the wind characteristic, the size of the power plant and the nature of the application. According to the nature of the application, the electrical power generating systems can also be classified as grid-connected and stand-alone systems

1.2 SELF-EXCITED INDUCTION GENERATOR

Environmental concerns and international policies are supporting new interests and developments for small scale off grid power generation. In view of this, self excited asynchronous generators (AG) have regained importance for supplying electricity to the remote located communities (where grid supply is not applicable) using available renewable energy sources like wind, hydro and bio-mass.

The fundamental superiority of an IG is its ability to generate power at constant voltage constant frequency (CVCF) when driven by a variable speed source. Therefore, in the wind power applications, most of the generators are IGs, which are

grid connected. In stand-alone applications wind turbines can produce electricity or they can supply mechanical power directly to do work. There have been less examples for stand-alone (not grid connected) applications of IG due to some important drawbacks of this method. The main drawback of an induction generator is its reactive power demand for excitation. Therefore, capacitors should be connected across the generator terminals. Another drawback is that they have poor voltage and frequency regulations under varying load and wind speeds.

1.3 OBJECTIVE

To control the voltage and frequency of the power generated from an isolated asynchronous generator driven by a wind turbine, under different mechanical and electrical dynamic conditions.

1.4 LITERATURE SURVEY

It is well known that for maintaining constant voltage at the terminals of AG under the condition of varying loads and speed, a continuous demand of reactive power is needed. In case of constant speed prime mover like biogas, diesel, gasoline engines, and the speed of the isolated asynchronous generator (IAG) remains constant while voltage at the generator terminal varies under varying consumer loads because of increased reactive power requirement. Therefore in such application of IAG, reactive power compensators have been proposed such as SVC, STATCOM etc. In other applications of IAG where prime movers are constant power movers such as micro and Pico hydro uncontrolled turbines, frequency and voltage both are varying under varying load conditions. Therefore in such constant power prime mover applications of IAG, electronic load controllers have been proposed to maintain the constant output power at the generator terminal so that the frequency of the output voltage can be maintained constant at rated power while the voltage is maintained constant with fixed excitation. However, in applications such as wind power both input power and speed are varying which in turn varies the magnitude and frequency of the generated voltage of the IAG under the condition of varying wind speed and varying consumer loads. Substantial literature is available in remote located wind

power applications employing asynchronous generators. Some of them have used squirrel cage asynchronous generator and few have proposed slip ring asynchronous generator for regulating the voltage and frequency by applying electrical or mechanical controls.

This paper deals with an efficient voltage and frequency controller for a stand alone wind energy conversion system based on self excited squirrel cage asynchronous generator where the control of magnitude and frequency of the generated voltage have greater challenge because of unavailability of the grid. The proposed voltage and frequency controller is having additional capability of harmonic elimination and load balancing. This type of operation requires active and reactive power balances every time. Reactive power balance requires variable capacitance, which can be supplied with power semi-conductor circuits. Active power balance, on the other hand requires external elements to divert the excessive power from the system, when the source power exceeds the amount required by the load.

1.5. ORGANIZATION OF THESIS

This thesis deals with the operation of a wind turbine driven by a SEIG supplying power to an isolated load. An IG can satisfy constant voltage-constant frequency (CVCF) operation, if an appropriate control is applied to the control variables. The system can be thought of consisting of a VAWT-SEIG combination with two output variables - stator voltage V_s and frequency f - to be kept at pre-specified values, and two disturbances - wind speed v and load conductance G

Chapter 1 gives an introduction about the project.

Chapter 2 gives an overview about the windmill.

Chapter 3 describes the design of the proposed controller.

Chapter 4 explains the simulation of the controlled wind power generating system.

Chapter 5 details the hardware implementation of the simulated module.

Chapter 6 discusses the conclusion and future scope of the project.

CHAPTER 2

WINDMILL- AN OVERVIEW

2.1 COMPONENTS

The main components of a windmill are:

- 1) Wind Turbine
- 2) Transmission System
- 3) Braking System
- 4) Generator

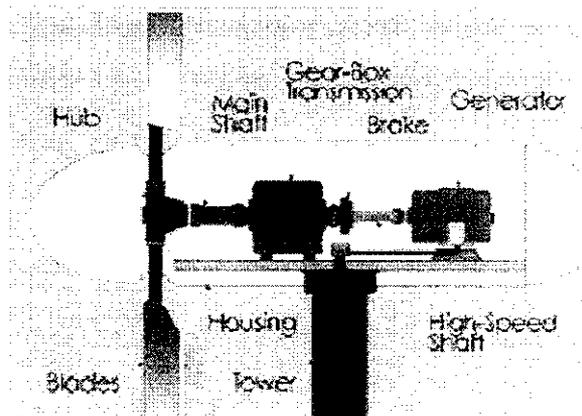


Fig 2.1 Schematic Diagram of the Windmill System

2.1.1 Wind Turbine

The wind turbine, converts the kinetic energy in the wind to rotational motion by the rotor-typically a three-bladed assembly at the front of the wind turbine. The rotor turns the main shaft, which transfers the motion into the nacelle (the large housing at the top of a wind turbine tower), which contains rotor brakes, gear box, generator, and electrical switch gear and control. Inside the nacelle, the slowly rotating shaft enters the gearbox that greatly increases the rotational shaft speed. The output (high speed) shaft is connected to the generator that converts the rotational movement into the electric power at medium voltages. The wind turbines can be classified according to the position of their axes as horizontal axis wind turbines

(HAWT) and vertical axis wind turbines (VAWT). For a horizontal axis turbine, the rotor axis is kept horizontal and aligned parallel in the direction of the wind stream. In a vertical wind turbine, the rotor axis is vertical and fixed and remains perpendicular to the wind stream. All grid-connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis

2.1.2 Transmission System

Hub- The central solid portion of the rotor wheel is known as hub. All blades are attached to the hub. Mechanism for pitch angle control is also provided inside the hub. The hub is casted in a special type of strong iron alloy called SG cast iron. The hub is of conical shape.

Main shaft- The main shaft of the wind turbine is usually forged from hardened and tempered steel. Hardening and tempering is result of forgoing the axle after it has been heated until it is white hot at about 1000 deg. Centigrade.

Gearbox- The Gear box is placed between the main shaft and the Generator. Its function is to increase the slow rotational speed of the rotor blades to the generator rotation speed of 1000 or 1500 rpm. The Gear box has a constant tip speed ratio.

2.1.3 Braking System

The Braking System works in the principle of centrifugal action that controls the rotor speed through governors. The rotor can be stopped under abrupt conditions by mechanical braking systems. In modern windmills electrical braking system is used instead of mechanical braking system because frequent use of mechanical braking system creates heat stress in the Generator.

2.1.4 Generator

The generator converts the mechanical power of the spinning wind turbine into electricity. Inside the generator, coils of wire are rotated in a magnetic field to produce electricity.. In the generator the armature is the coil of wire where the output voltage is generated and the current flows to the load. The portion of generator where the magnetic field is produced is the field .Relative motion between the two is obtained by either spinning the armature within the field or spinning the field with the

armature. The power produced by the generator depends on the size and the length of the wires used in the armature, the strength of the magnetic field and the rate of the motion between them. Main features of the various types of generators and their suitability in wind power generation are discussed below.

a) DC generator

Conventional dc generators are no more favored due to their high cost, weight, and maintenance problems due to commutator. However permanent magnet dc machines are considered in small rating isolated systems.

b) Synchronous generator

They produce high quality output and are universally used for power generation in conventional plants. However they have very rigid requirement of maintaining constant shaft speed and deviation from synchronous value immediately reflects in the generator frequency. Also precise rotor speed control is required for synchronization. Due to this reason a synchronous machine is not well suited to wind power generation.

c) Induction generator

The simplest form of AC generator and the type that has most often been used in wind turbines is the induction generator. Several reasons are there for using induction generators. They are:

Low cost

Ruggedness

Operates with slip (i.e., with some speed elasticity)

Readily available in the market in many sizes

Mature technology

Brushless construction

No need of separate dc field power

There are two kinds of induction generators used in wind turbines, Squirrel cage and wound rotor. Presently, about 90% of utility-grid-connected wind turbines use squirrel-cage induction generators. The rotor is made of soft iron with shorted rotor bars of copper or aluminum. They do not need slip rings like a

synchronous or wound rotor induction generator. The squirrel-cage induction machine has a shorted rotor; therefore, the rotor current is not accessible. Although physically there is no electrical connection between the rotor and stator; the electrical characteristics of the rotor are affected by the stator through magnetic coupling. With a wound rotor induction machine, the rotor is normally constructed as a three-phase winding with the same number of poles as the stator. Three-phase slip rings (and brushes) are used to allow control of the rotor current.

The induction generator requires ac excitation current, which is mainly reactive. In case of grid-connected system, the excitation current is drawn from the grid and there for, the network must be capable of supplying this reactive power. The voltage and frequency are determined by the grid. In a stand alone system the induction generator is self excited by shunt capacitors.

2.2 OPERATING CHARACTERISTICS OF WIND MILLS

The windmills have certain operating characteristics, such as cut-in, rated and cut-out wind speeds.

2.2.1 Cut-In- Speed

Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

2.2.2 Rated Speed

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases.

2.2.3 Cut-Out Speed

At very high wind speeds, typically between 72 and 128 kmph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed.

2.2.4 Betz Limit

It is the flow of air over the blades and through the rotor area that makes the wind turbine to function. The theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 59%. This value is known as the Betz limit.

2.3 WIND POWER CONVERSION

The function of a wind turbine is to convert the linear motion of the wind energy into rotational energy that can be used to drive a generator. Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it into rotating mechanical power. The aerodynamic power, P , of a wind turbine is given by

$$P = 1/2 \rho \Pi R^2 V^3 C_p$$

Where ρ is the air density. R is the turbine radius, V is the wind speed and C_p is the turbine power coefficient which represents the power conversion efficiency of a wind turbine. C_p is a function of the tip speed ratio (λ) as well as the blade pitch angle (β) in a pitch controlled wind turbine.

λ is defined as the ratio of the tip speed of the turbine blades to wind speed, and given by:

$$\lambda = \frac{R \cdot \omega}{V}$$

Where ω is the rotational speed of the wind turbine.

The Betz limit $C_{p,max}$, (theoretical) = $16/27=0.529$ the maximum theoretically possible rotor power Coefficient.

The wind turbine torque on the shaft can be calculated from the power

$$T_m = (1/2 \rho \Pi R^2 V^3 C_p) / \lambda .$$

CHAPTER 3

CONTROLLER DESIGN

3.1 SYSTEM CONFIGURATION

The complete off grid stand alone system with asynchronous generator, wind turbine, excitation capacitor, consumer loads and proposed controller is shown in Fig. 3.1.

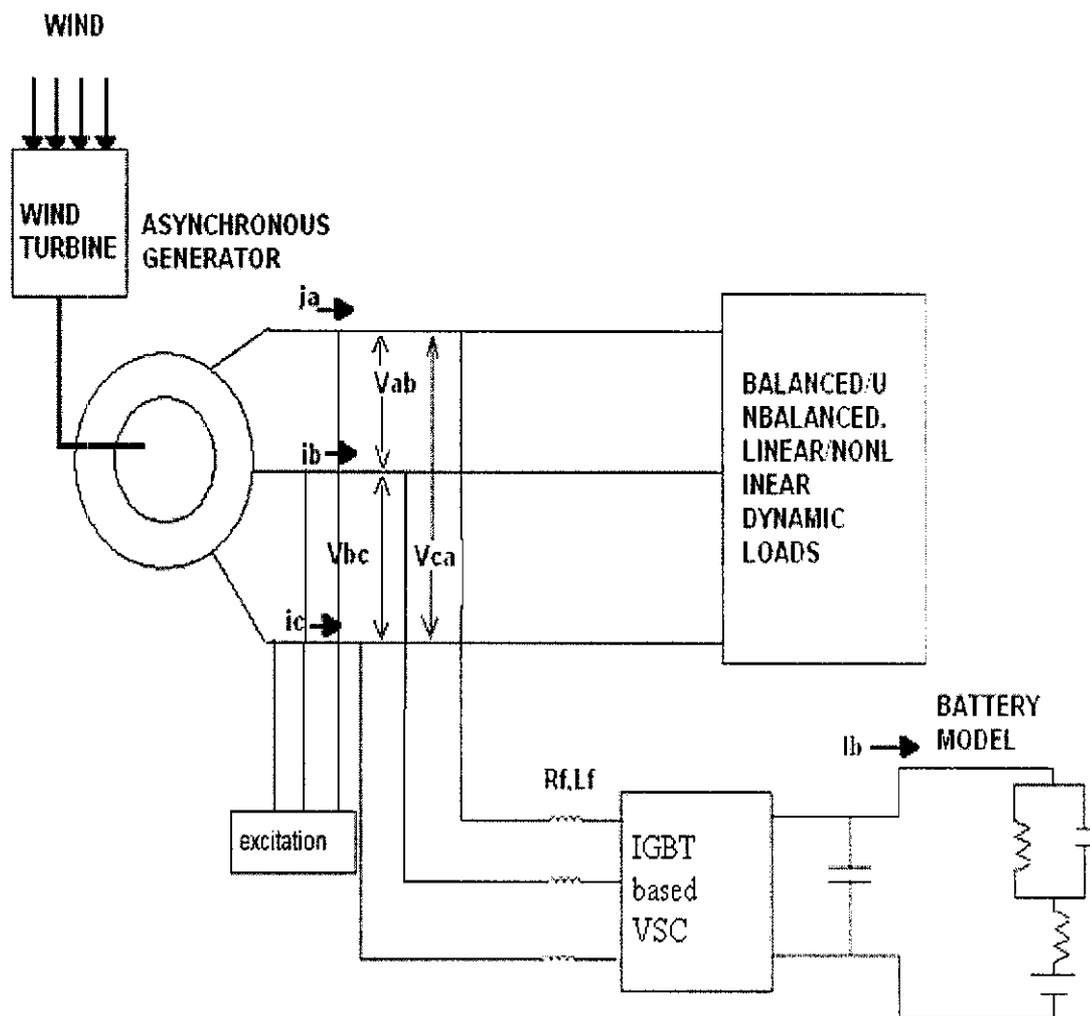


Fig 3.1 The Complete Off Grid Stand Alone System

The proposed controller includes three-phase voltage source converter (VSC) along with a battery at its dc link. The controller is connected at the point of common coupling (PCC) through the inter-facing inductor. The excitation capacitor is selected to generate the rated voltage at no-load while additional demand of reactive power is met by the controller. The proposed controller is having bidirectional flow capability of reactive and active powers because of which it can control the magnitude and frequency of the generated voltage under different electrical and mechanical dynamic conditions.

According to the principle of frequency regulation for generating constant frequency at fixed speed, the total generated power should be consumed by the applied load (consumer load + battery) otherwise additional generated power might be stored in the revolving component of the machine and it increases the machine speed which in turns increases the system frequency. On the other hand when there is variation in wind speeds and corresponding variation in the machine speed, the battery and consumer loads absorb such amount of power by which desired frequency of the generated voltage can be achieved.

In proposed control scheme, the frequency controller is used for extracting active component of the source current. When there is deficiency in the generated power, the battery supplies the additional required load demand through process of discharging and maintains the constant frequency along with providing the functions of load leveling. While there is an excess generated power it starts charging and consumes additional generated power which is not consumed by the consumer loads.

3.2 MODELING OF THE CONTROLLER



The proposed voltage and frequency controller consists of current controlled voltage source converter (CC-VSC) with the battery at its dc link. In Fig. 3.2, Thevenin's equivalent circuit of the battery based model is shown at dc link of the controller. The terminal voltage of the equivalent battery (V_b) is obtained as follows

$$V_b > (2\sqrt{2}/\sqrt{3})V_{LL}$$

Where V_{LL} is the line to line rms voltage of the generator.

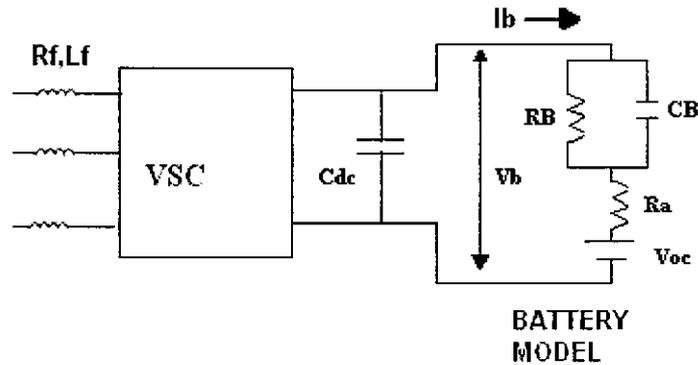


Fig 3.2 Controller

Since the battery is an energy storage unit, its energy is represented in KWh .when a capacitor is used to model the battery unit, the capacitance can be determined from

$$C_B = \frac{KWh * 3600 * 10^3}{0.5(V_{ocmax}^2 - V_{ocmin}^2)}$$

In the Thevenin's equivalent model of the battery, R_a is the equivalent resistance (external + internal) of parallel and series combination of a battery is usually a small value. The parallel circuit of R_B and C_B is used to describe the stored energy and voltage during charging or discharging . R_B in parallel with C_B , represents self discharging of the battery, since the self discharging current of a battery is small, the resistance is large. Here, the battery is considered of having 18 kW for 6 H peaking capacity, and with the variation in the voltage of order of 740–760 V.

A three phase Voltage source converter is used in the controller circuit. The VSC is connected to the wind power generating system at the point of common

the point of common coupling through the interfacing inductor. According to gate pulses, the voltage source converter operates and controls the charging and discharging of its dc link and thus battery. The output equation of a three phase voltage source converter is given by,

$$V_o = (3V_{ml}/\pi) \cos\alpha$$

Where V_{ml} is the maximum line voltage and α is the firing angle of the switch

3.3 CONTROL SCHEME

The control strategy of the proposed controller is based on the generation of reference source currents. Reference source currents are having two components one is reactive component for controlling the magnitude of the generated voltage and other one is the active component for regulating the frequency of the generated voltage. The amplitude of active power component of the source current (I_{dm}) is estimated by dividing the difference of filtered load power (P_{filter}) and output of PI frequency controller (PI) to the amplitude of the terminal voltage (V_{tm}). Multiplication of this with in-phase unit templates ($d_a, d_b,$ and d_c) yields the in-phase component of reference source currents. These templates are three-phase sinusoidal functions which are derived by dividing the ac voltages by their amplitude.

To generate the reactive component of reference source currents another set of unit templates is derived from in-phase unit template and which are 90 degree leading from the corresponding voltages. The multiplication of these templates and output of PI (Proportional-Integral) terminal voltage controller (V_{tm}) gives the reactive component of reference source currents. The sum of instantaneous reactive and active components of currents gives the total reference source currents and these are compared with the sensed source currents. The amplified current error signals are compared with fixed frequency (10 kHz) triangular carrier wave to generate the PWM switching signals for the devices of VSC.

3.3 MODELING OF THE CONTROL SCHEME

3.4.1 Computation of Active Component of Reference source currents.

Basic equations of the control scheme of the proposed controller are as follows.

Active component of reference source current is estimated by dividing the difference of filtered instantaneous load power (P_{filter}) and output of the PI frequency controller to the terminal voltage (V_{tm}). The load power (P_1) is estimated as by taking three-phase to two-phase transform .

$$v_{\alpha} = (\sqrt{2}/3)(v_{1a} - 0.5v_{1b} - 0.5v_{1c})$$

$$v_{\beta} = (\sqrt{2}/3)(0.866v_{1b} - 0.866v_{1c})$$

$$i_{\alpha} = (\sqrt{2}/3)(i_{1a} - 0.5i_{1b} - 0.5i_{1c})$$

$$i_{\beta} = (\sqrt{2}/3)(0.866i_{1b} - 0.866i_{1c})$$

Instantaneous active power is estimated as

$$P_1 = v_{\alpha}i_{\alpha} + v_{\beta}i_{\beta}$$

It is filtered to achieve its dc component (P_{filter}).

The frequency error is defined as

$$f_{\text{er}(n)} = f_{\text{ref}(n)} - f_{(n)}$$

where f_{ref} is reference frequency (50 Hz in present system) and f is the frequency of the voltage of an asynchronous generator. The instantaneous value of f is estimated using phase locked loop (PLL).

Then active component of reference source current (I_{dm}) is calculated as

Then active component of reference source current (I_{dm}) is calculated as

$$I_{dm} = \frac{2(P_{filter} - P_l)}{3V_{tm}}$$

The instantaneous line voltages at the terminals of an asynchronous generator (v_{la} , v_{lb} and v_{lc}) are considered sinusoidal and their amplitude is computed as

$$V_{tm} = \{(2/3)(v_{la}^2 + v_{lb}^2 + v_{lc}^2)\}^{1/2}$$

The unity amplitude templates are having instantaneous value in phase with instantaneous voltage (v_{la} , v_{lb} and v_{lc}) which are derived as

$$da = v_{la}/V_{tm}$$

$$db = v_{lb}/V_{tm}$$

$$dc = v_{lc}/V_{tm}$$

Instantaneous values of in-phase components of reference source currents are estimated as

$$i^f da = I_{dm} da$$

$$i^f db = I_{dm} db$$

$$i^f dc = I_{dm} dc$$

3.4.2 Computation of Active Component of Reference source currents.

The ac voltage error V_{er} at the n th sampling instant is

$$V_{er(n)} = V_{umref(n)} - V_{tm(n)}$$

where $V_{tmref(n)}$ is the amplitude of reference ac terminal voltage and is the amplitude of the sensed three-phase ac voltage at the terminals of an asynchronous generator at n th instant.

The instantaneous quadrature components of reference source currents are estimated as

$$i^r_{qa} = I_{qm} q_a$$

$$i^r_{qb} = I_{qm} q_b$$

$$i^r_{qc} = I_{qm} q_c$$

where q_a, q_b and q_c are another set of unit vectors having a phase shift of 90 degree leading the corresponding unit vectors, and which are computed as follows:

$$q_a = -d_b/\sqrt{3} + d_c/\sqrt{3}$$

$$q_b = \sqrt{3}d_a/2 + (d_b - d_c) / 2\sqrt{3}$$

$$q_c = -\sqrt{3}d_a/2 + (d_b - d_c) / 2\sqrt{3}$$

3.4.3 Computation of Reference Source Current and Generation of PWM pulses for the VSC

Total reference source currents are sum of in-phase and quadrature component of the reference source current as

$$i^r_{sa} = i^r_{qa} + i^r_{da}$$

$$i^r_{sb} = i^r_{qb} + i^r_{db}$$

$$i^r_{sc} = i^r_{qc} + i^r_{dc}$$

The current errors are computed by comparing reference source current (i^r_{sa} , i^r_{sb} and i^r_{sc}) with sensed source currents (i_{sa} , i_{sb} and i_{sc}). These current errors are amplified with a gain (K) and the amplified signals are compared with fixed frequency (10 kHz) triangular carrier wave of amplitude to generate gating signals for VSC of the controller.

CHAPTER 4

SIMULATION USING MATLAB 7.0.4

4.1 MATLAB

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 controller is done in matlab using simulink and power system block set tool boxes.

4.1.1 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.

4.1.2 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.

4.2 BLOCKS USED FOR SIMULATION

4.2.1 Windmill

The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation.

$$P_m = 1/2 \rho \Pi R^2 V^3 C_p$$

where

P_m Mechanical output power of the turbine (W)

C_p Performance coefficient of the turbine

ρ Air density (kg/m³)

R Turbine rotor radius (m)

V wind speed (m/s)

(b) Asynchronous Machine: Machines

Model the dynamics of a three-phase asynchronous machine, also known as an induction machine. The Asynchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque: If T_m is positive, the machine acts as a motor. If T_m is negative, the machine acts as a generator. The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator.

(c) Excitation capacitor.

The excitation for the asynchronous machine is given by the delta connected capacitor bank. This capacitor bank is modeled by using the three phase RLC parallel branch.

The simulation circuit of the windmill is shown below.

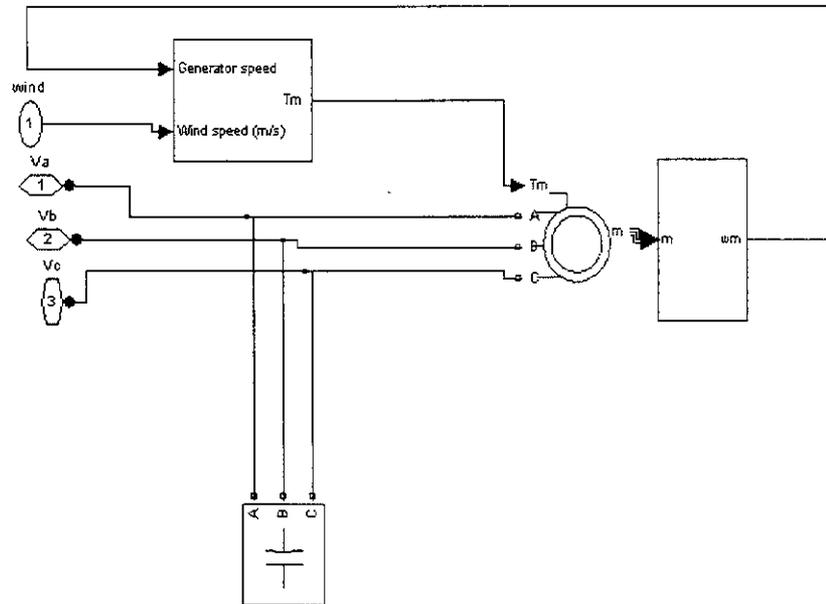


Fig 4.1 Windmill Model

4.2.2 Controller and Pulse Generating Block

(a) Controller: The controller for the windmill consists of an IGBT based current controlled voltage source converter and a battery in the dc link is shown in Fig 4.2.

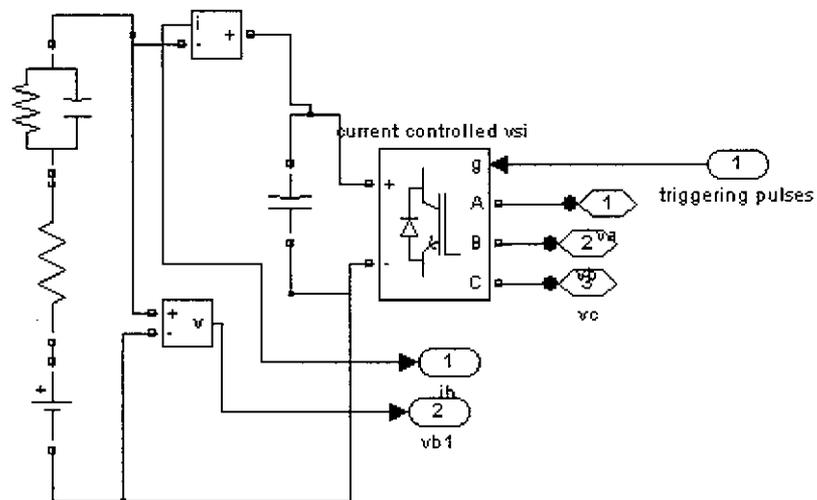


Fig 4.2 Controller Model

1. Universal Bridge : Power Electronics

The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The Universal Bridge block is the basic block for building two-level voltage-sourced converters (VSC).

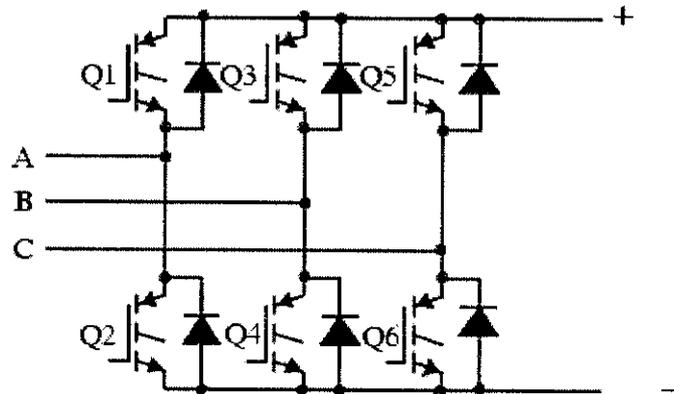


Fig4.3 IGBT-Diode Bridge

2. DC Voltage Source : Electrical Sources

The DC Voltage Source block implements an ideal DC voltage source.

(b) Pulse Generating Circuit

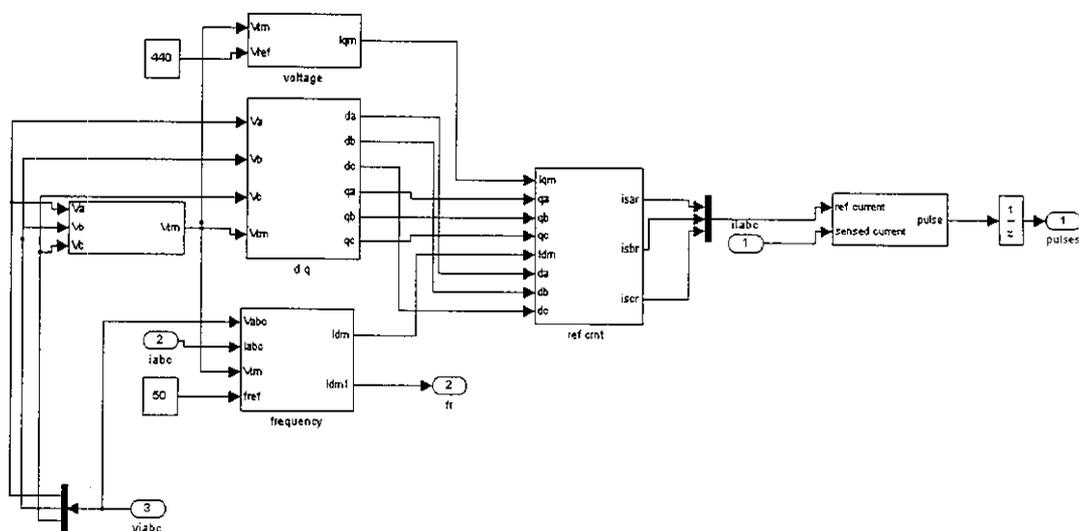


Fig.4.4 Pulse Generating Circuit

This pulse generator is designed according to the control techniques explained in the chapter 3. It consists of 6 subsystems.

4.2.3 Consumer Loads

Linear, non linear and dynamic consumer loads are designed from the simpower systems library. Linear load is modeled by an RLC load and non linear systems are shown by diode bridges with resistance. The dynamic load is modeled by an asynchronous machine with sudden load torque changes. The balanced and unbalanced conditions of load are also simulated.

4.3 SIMULATION RESULTS

The simulation results for a 22KW wind generating system with the following turbine power characteristics with the designed controller are shown below.

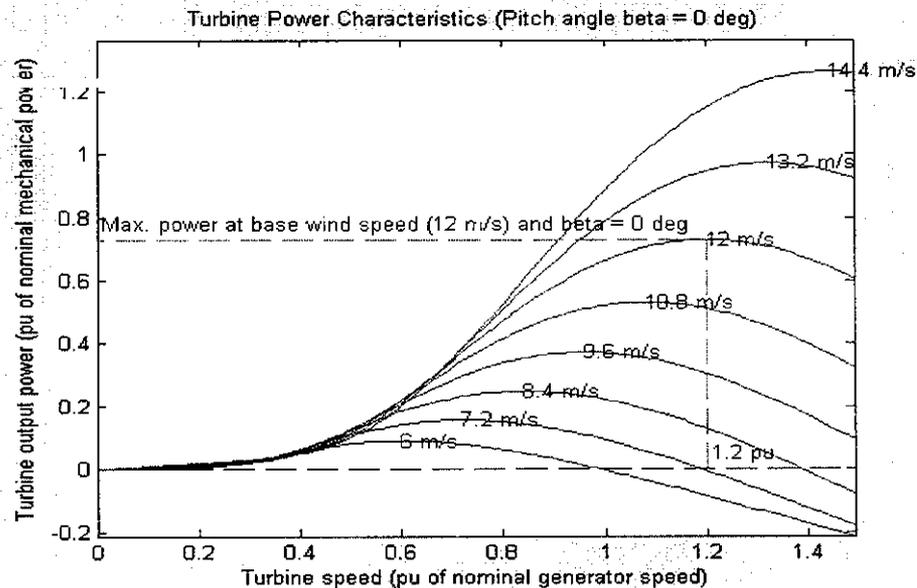


Fig4.5. Turbine Power Characteristics

4.3.1 Simulated Waveform of an Isolated Windmill without Any Controller

The waveforms shown below are the results obtained, when the wind velocity changed to 5m/s from 10m/s. When the wind velocity changes the voltage and frequency of generator terminal voltage also changes.

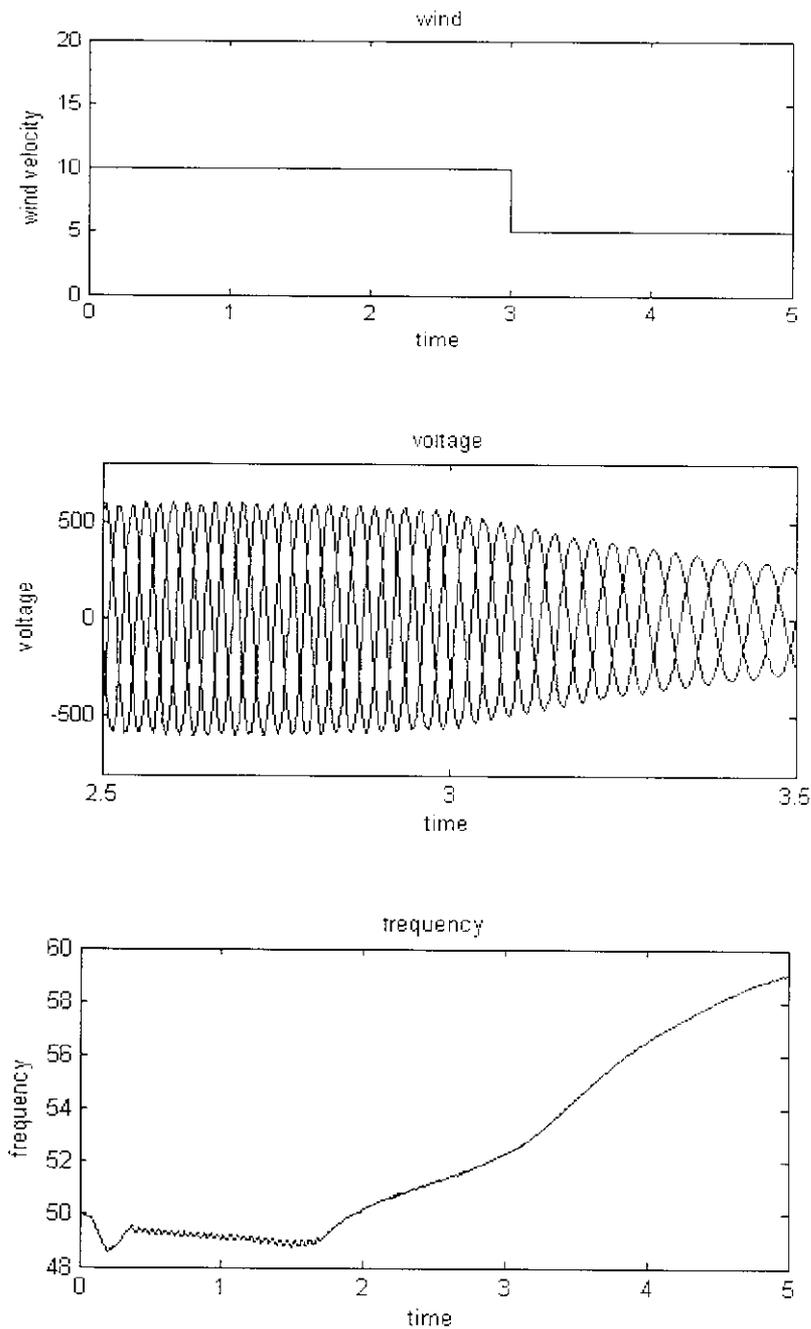
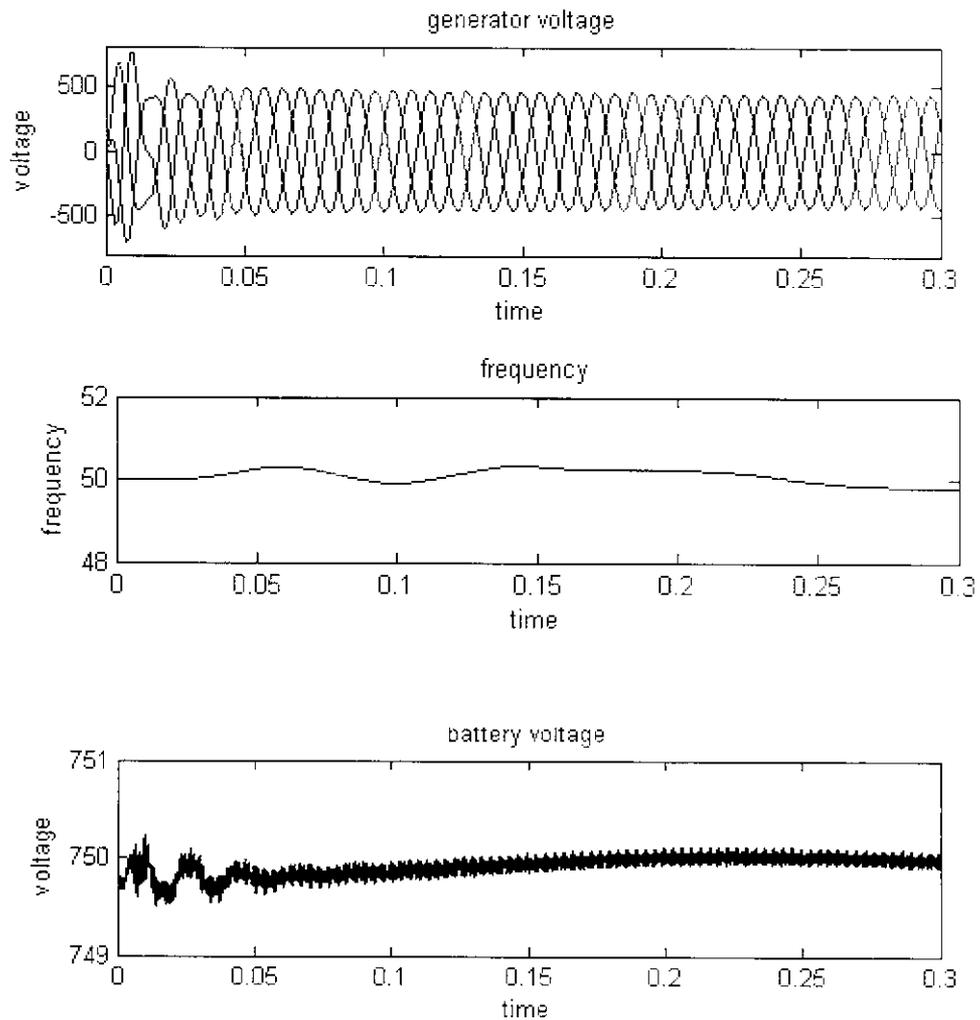


Fig.4.6 Simulated Waveform of an Isolated Windmill without Any Controller

4.3.2 Simulated Waveform of an Isolated Windmill with Controller

(a) Varying Wind

Fig 4.7 shows the performance of the controller with varying wind speeds at constant applied consumer load. At 0.19 sec the wind speed is changing from 10 m/s to 5 m/s. Here it is observed that due to insufficient power generation at low speed, an additional load power is supplied by battery to regulate the frequency.



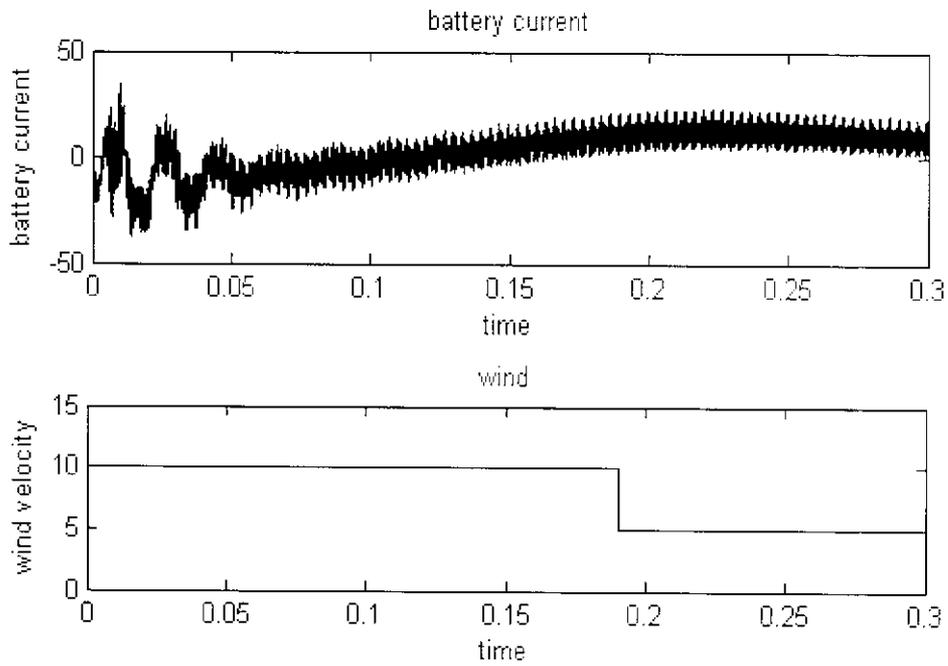
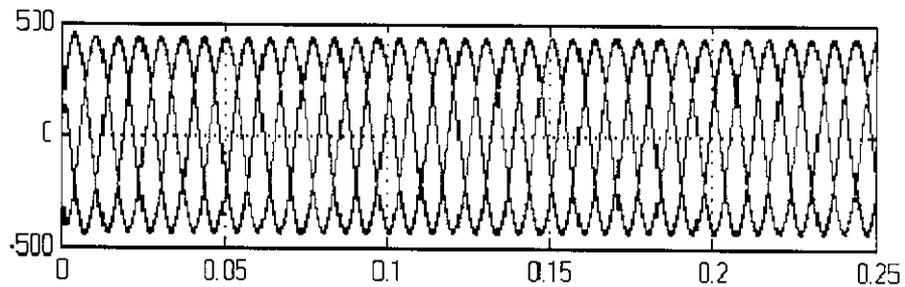


Fig 4.7. Simulated Waveform of an Isolated Windmill with Controller during Application of Consumer Load at Varying Wind Speed

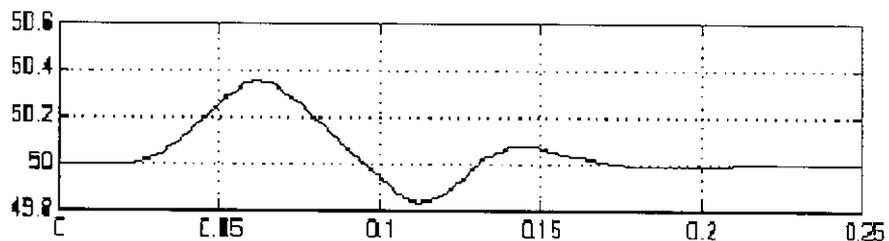
(b) Linear Balanced /Unbalanced Load

Fig 4.8 demonstrates the performance of the controller with 0.8 pf lagging reactive load at fixed wind speed. At 0.1 sec one phase and later at 0.2 sec another phase of the load are opened and thus the load becomes unbalanced, but voltage and frequency at the generator terminals remains balanced.

Generator voltage



Frequency



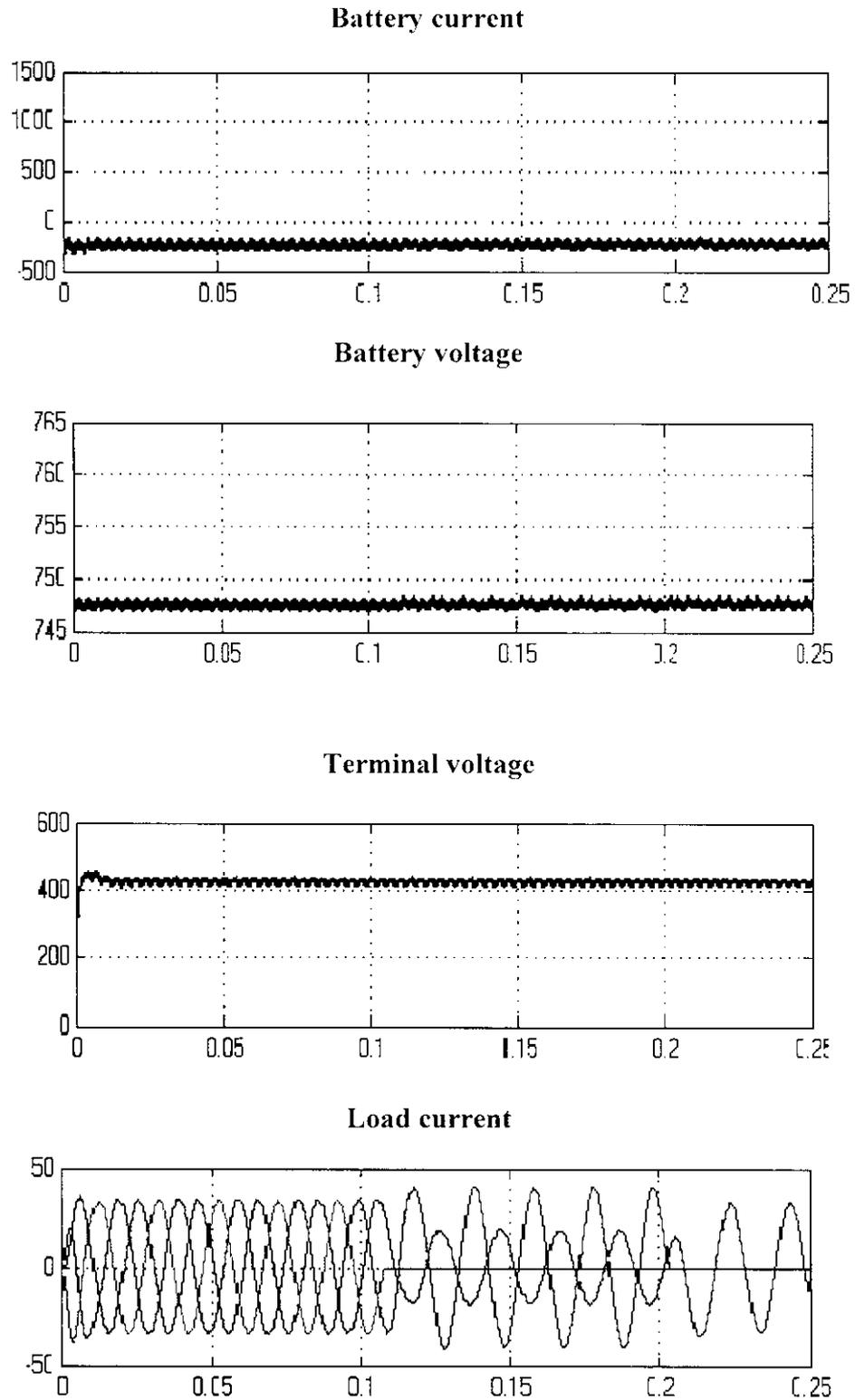
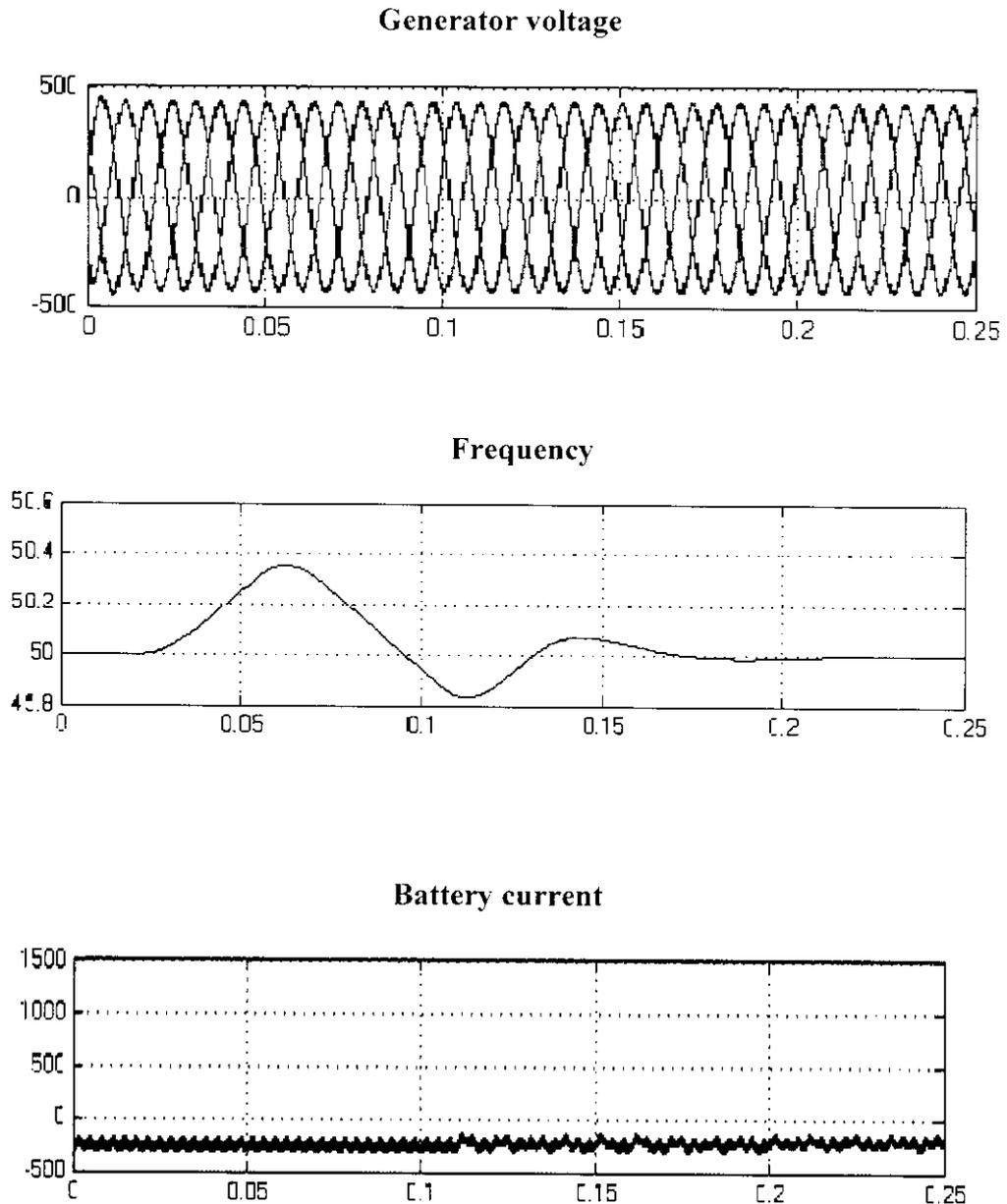


Fig4.8. Simulated Waveform of an Isolated Windmill with Controller during Application of Balanced/Unbalanced Linear Load at Fixed Wind Speed

(c) Non Linear Balanced /Unbalanced Load

Fig 4.9 demonstrates the performance of the controller with non-linear load at fixed wind speed. At 0.1 sec one phase and later at 0.2 sec another phase of the load are opened and the load becomes unbalanced but voltage and frequency at the generator terminals remain balanced.



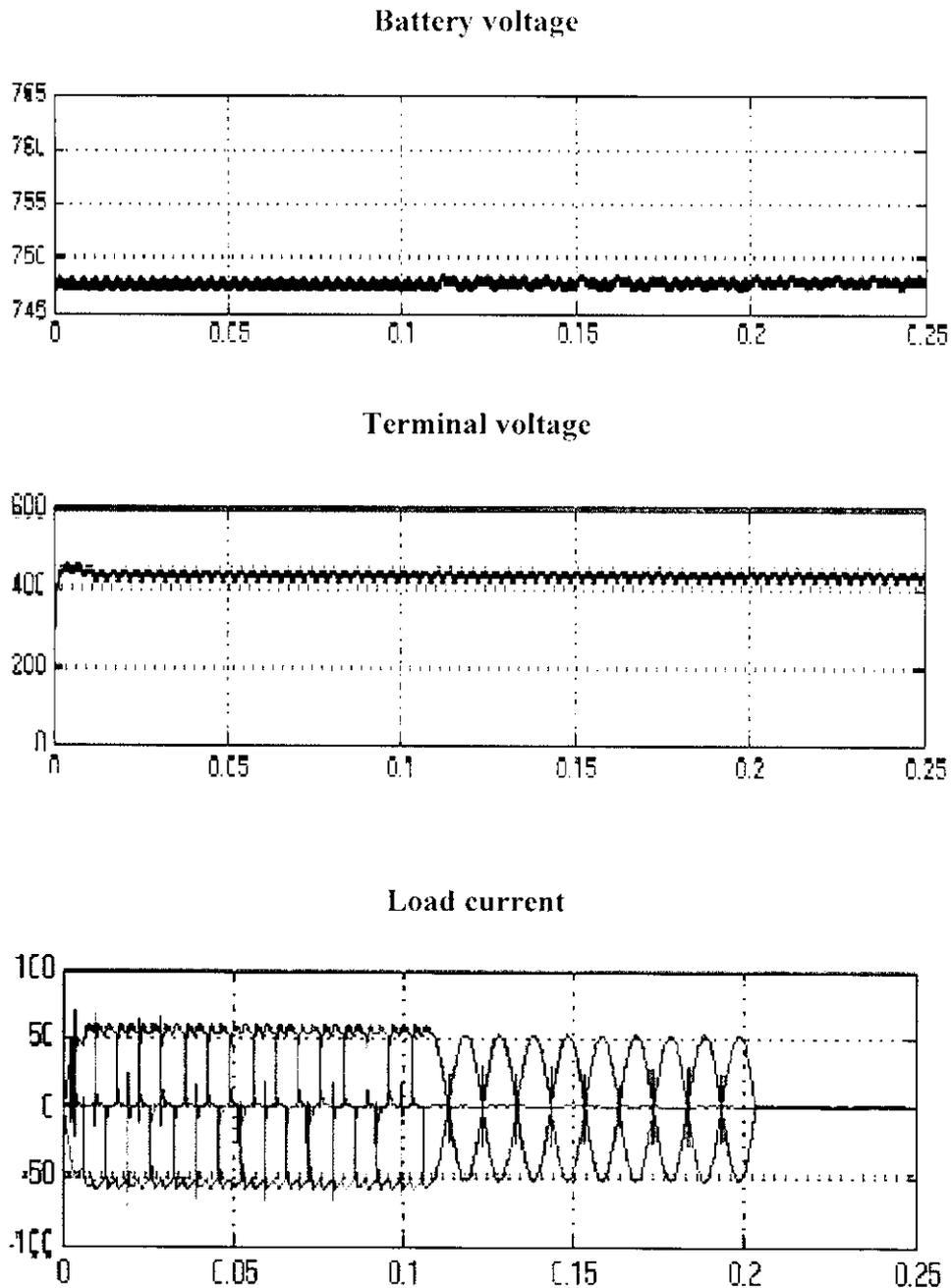
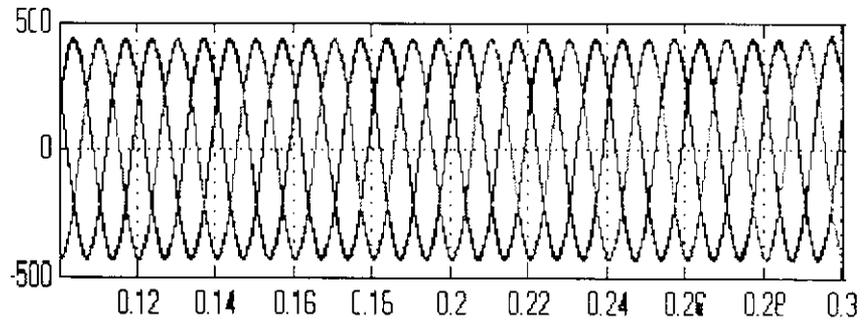


Fig 4.9. Simulated Waveform of an Isolated Windmill with Controller during Application of Balanced/Unbalanced Non-linear Load at Fixed Wind Speed

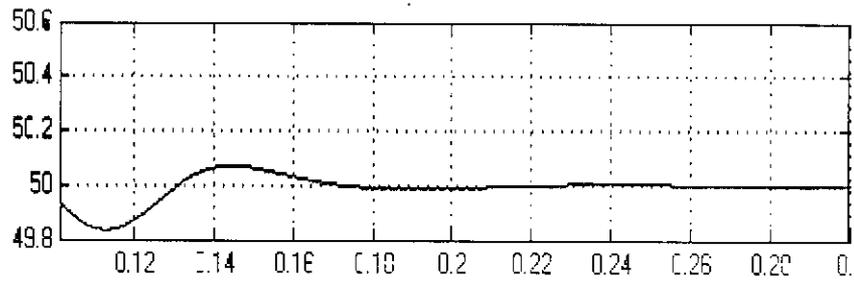
(d) Dynamic Load

Fig4.10 demonstrates the performance of the controller feeding an induction motor load at fixed wind speed. At 0.2 sec a load torque of 20 N is applied on the motor shaft then the motor load current is increased but the controller performs in desirable manner and it maintains the magnitude and frequency of the generated voltage constant.

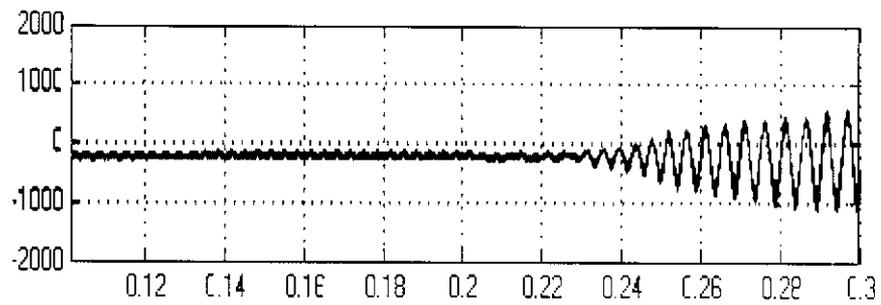
Generator voltage



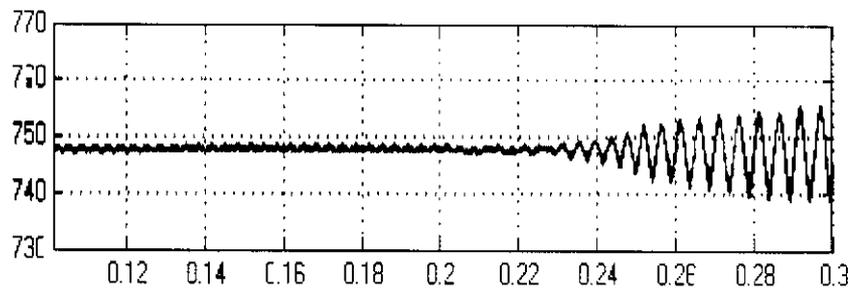
Frequency



Battery current



Battery voltage



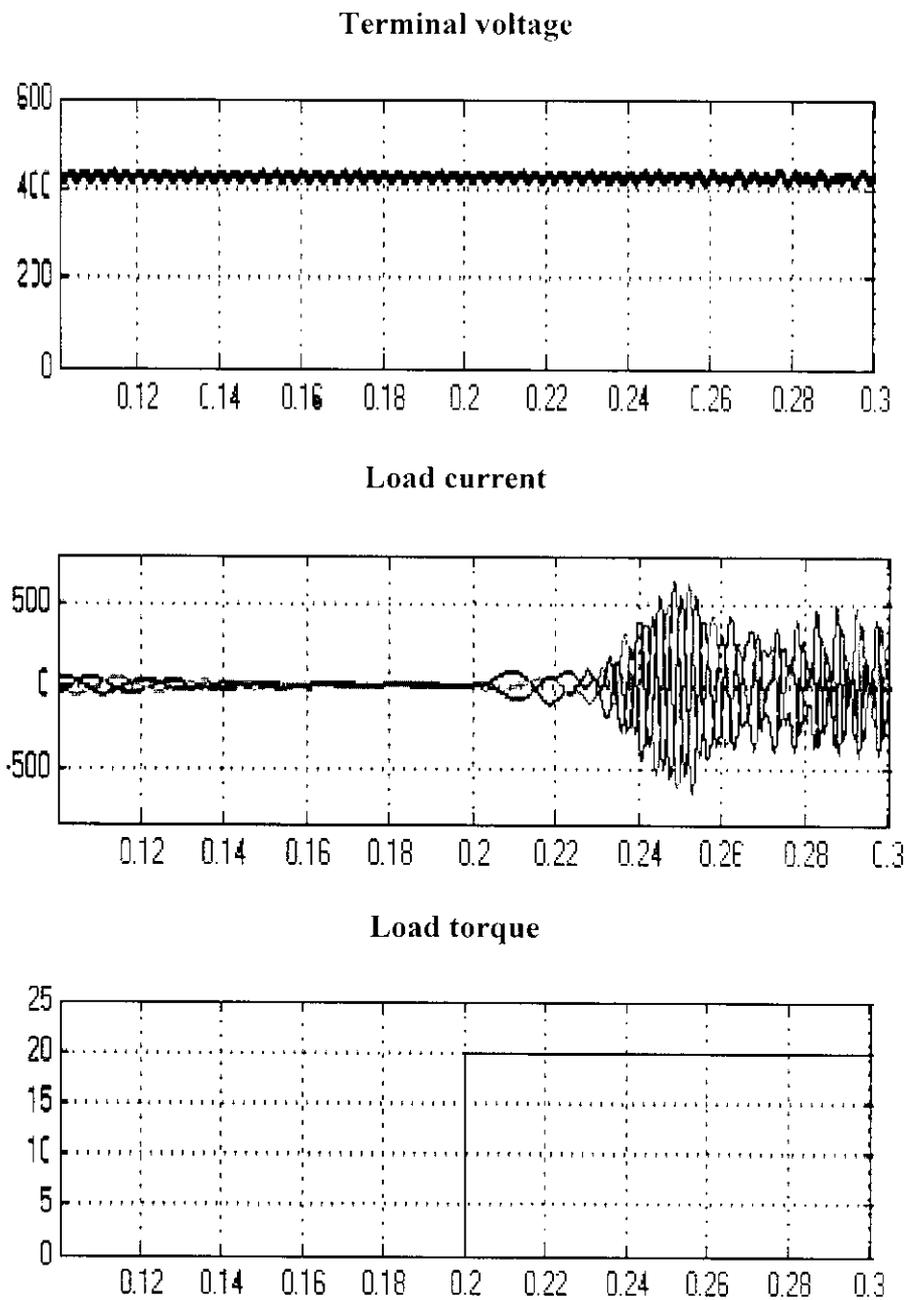


Fig 4.10. Simulated Waveform of an Isolated Windmill with Controller during Application of Motor Load Torque at Fixed Wind Speed

Figure below shows the total harmonic distortion of the generator voltage when the above controller is used to control the terminal voltage and frequency of the generated voltage. The THD is found to be very low. Thus it is clear that the proposed controller can be used as a harmonic compensator.

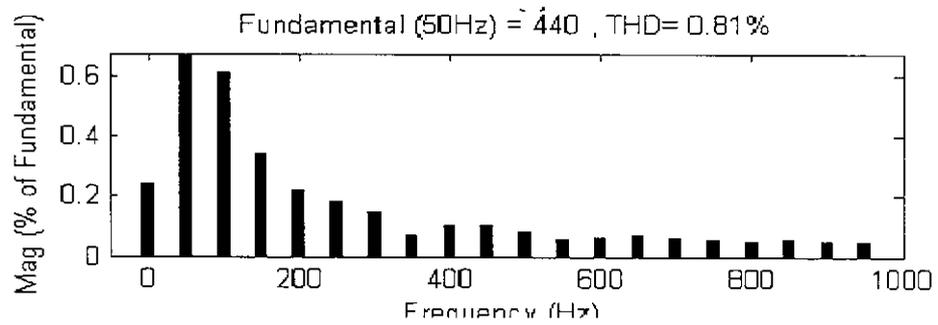


Fig4.11 The Total Harmonic Distortion of the Generator Voltage

CHAPTER 5

HARDWARE IMPLEMENTATION

5.1 BLOCK DIAGRAM OF THE PROPOSED HARDWARE

The proposed hardware for the Power Electronics control of windmill mainly consists of:

- 1) Voltage source Converter
- 2) Dc source
- 3) Loads

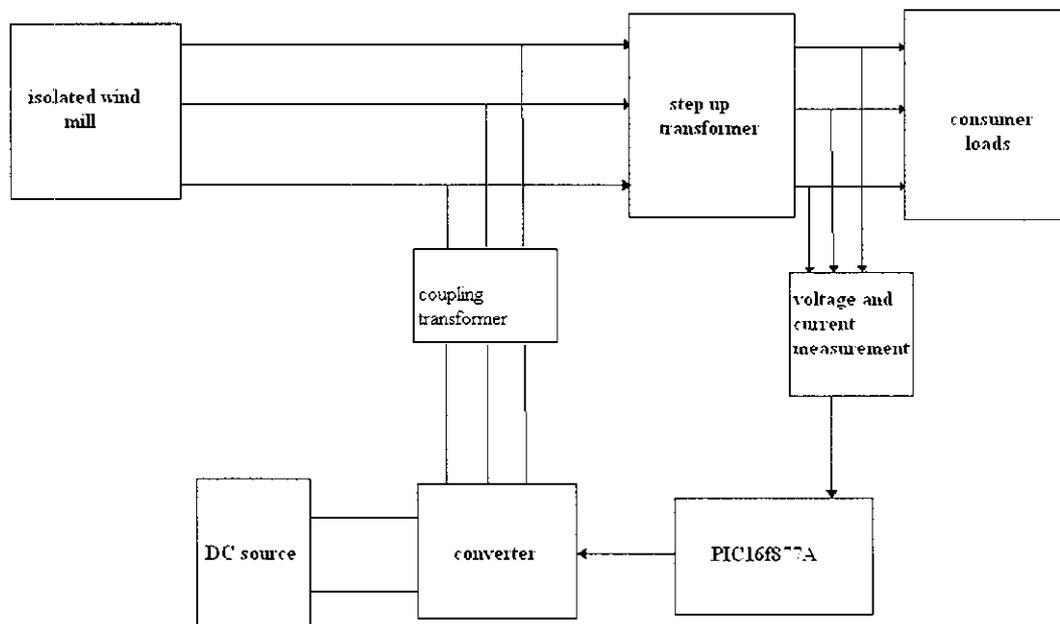


Fig. 5.1 Block Diagram of the Proposed System

5.2. DESIGN OF REGULATED POWER SUPPLY CIRCUIT

PIC motherboard is the core part. These units require a DC supply ranging from +5 V to +12 V. Thus a regulated power supply circuit is designed for +5 V and +12 V. The commonly available source of 230 V, 50 Hz AC is utilized and it is stepped down to the required maximum voltage, say 12 V AC. Then it is rectified, filtered and regulated to the required output voltage. +5 V power supply is shown in the fig 5.2. +12 V power supply is shown in the fig 5.3.

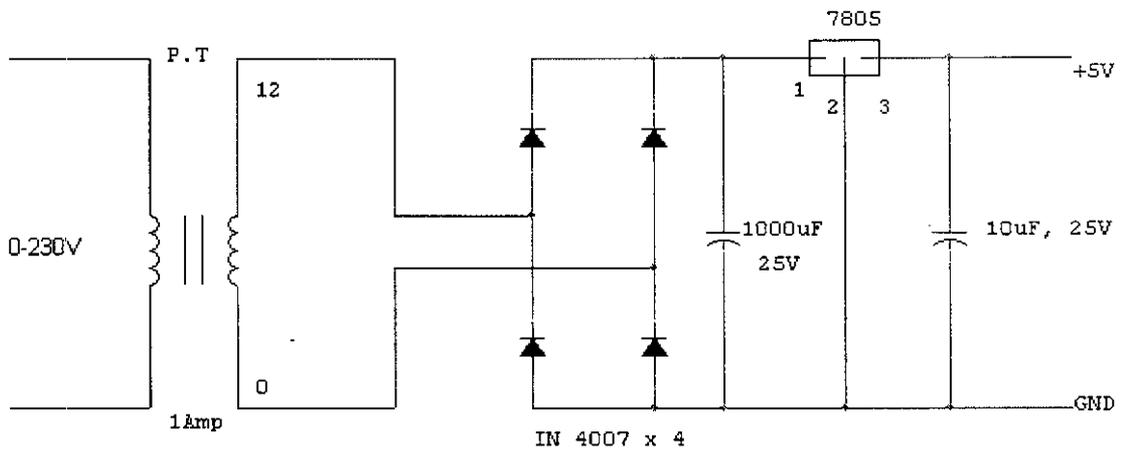


Fig. 5.2 +5 V Power supply

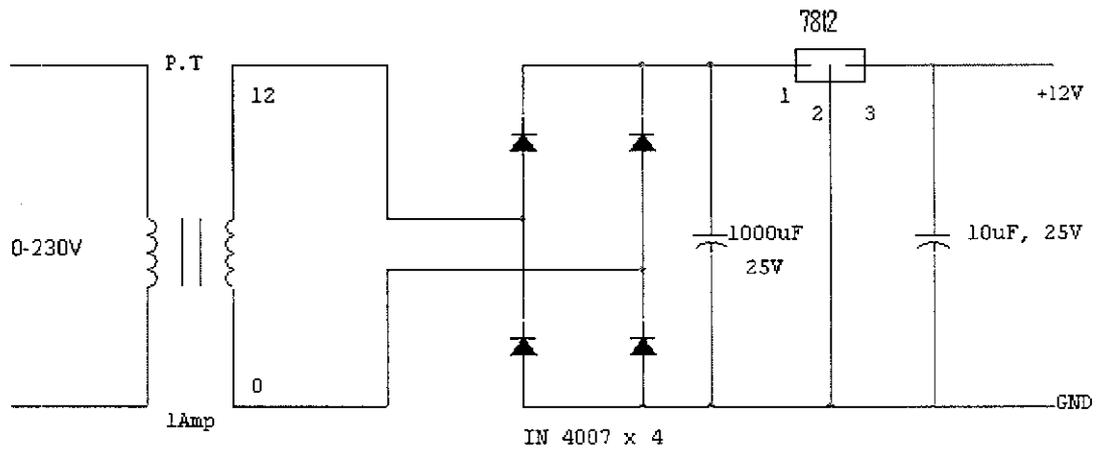


Fig. 5.3 +12 V Power supply

5.2.1. Step Down Transformer

Alternating current of 230V, 50 Hz supply is given to the primary side of the step down transformer of 230V/ 0-12V type to perform step down operation. The current rating of the transformer is 1A.

5.2.2. Rectifier Unit

Rectification is achieved using a full bridge rectifier circuit, which comprises of four 1N 4007 solid-state diodes. Two diodes will conduct during the positive cycle

and the other two will conduct during the negative half cycle. The output obtained is not a pure DC and therefore filtration has to be done.

5.2.3. Filtering Unit

Filter circuits usually consist of a capacitor, which smoothens the pulsating DC. It is helpful in reduction of the ripples from pulsating (1000 μ F/ 25V) and it maintains stability at the load side (10 μ F/ 25V).

5.2.4. Voltage Regulator

Voltage regulators play an important role in any power supply unit. The primary purpose of a regulator is to aid the rectifier and filter circuit in providing a constant DC voltage to the device. Power supplies without regulators have an inherent problem of changing DC voltage values due to variations in the load or due to fluctuations in the AC line voltage. MC 7805 and MC 7812 are used to provide +5V and +12V regulated DC supply respectively.

5.3 VOLTAGE SOURCE CONVERTERS

In this project a voltage source Converter is used to get a controlled AC voltage at the output by adjusting the ON and OFF period of the power MOSFET's by using PWM method.

5.3.1 Pulse Width Modulation

The PWM technique has the following advantages:

- The output voltage control in this method can be obtained without any additional components
- The lower order harmonic can be minimized along with the output voltage control.

The pulse width modulation techniques can be classified mainly as:

- (a) Single Pulse Width Modulation
- (b) Multiple Pulse Width Modulation

(a) Sinusoidal Pulse Width Modulation

5.3.1 (a) Single Pulse Width Modulation

The output voltage from the single phase PWM converter is shown below .It consists of a pulse of width $2d$ located symmetrically about $\pi / 2$ and the another pulse located symmetrically about $3 \pi / 2$.The range of pulse width varies from 0 to π ($0 < 2d < \pi$) .The output voltage is controlled by the pulse width of $2d$.The shape of the output voltage is a quasi-square wave.

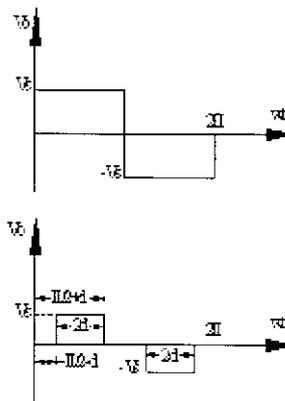


Fig 5.4 Single Phase PWM Output

5.3.1 (b) Multiple Pulse Width Modulation

The Multiple Pulse Width Modulation uses two symmetric pulses per half cycle. The symmetrical modulated wave form is shown below:

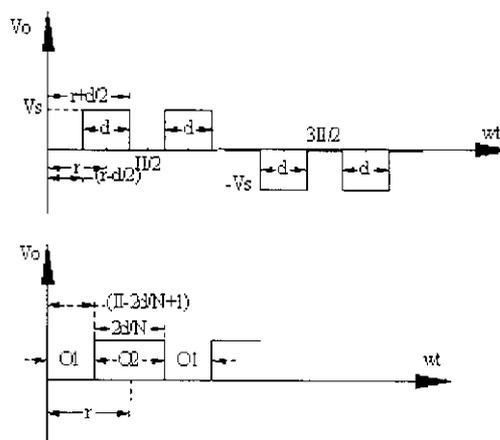


Fig 5.5 Symmetrical Modulated Wave for Multiple Pulse Width Modulation

This symmetric modulated wave can be generated by comparing an adjustable square voltage wave V_r of frequency f_c as shown in below:

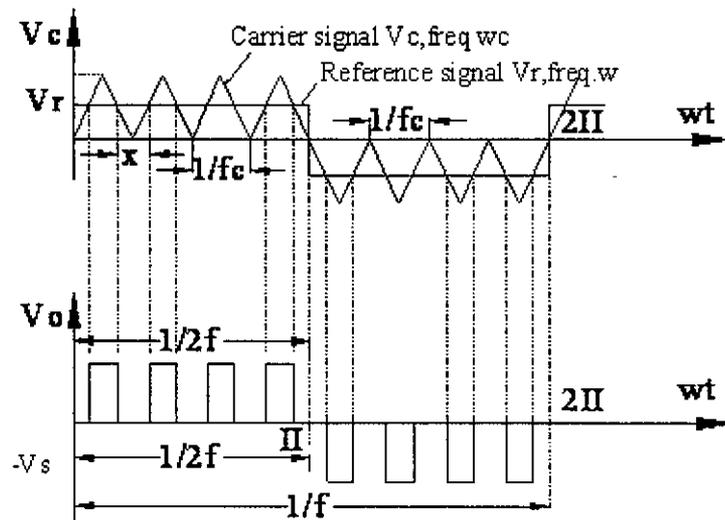


Fig 5.6 Output Voltage Waveform with Multiple Pulse Width Modulation

The firing pulse for the power MOSFET is given by the intersection of carrier and reference signal. The firing pulses so generated turn ON the MOSFET so that the output voltage is available during the interval triangular modulating wave exceeds the square modulating wave.

5.3.1 (c) Sinusoidal Pulse Width Modulation

In this modulation, several pulses per half cycle are used. In Multiple Pulse Width Modulation, the pulse width is equal for all pulses whereas in Sinusoidal PWM the pulse width is a sinusoidal function of the angular position of the pulse given in the cycle.

For releasing sine PWM, a higher frequency triangular wave is compared V_c is compared with the sinusoidal reference wave V_r of desired frequency. The value of V_r/V_c is called Modulation Index and it controls the harmonic content of the output waveform. The intersection of V_c and V_r determines the switching instant and

commutation of the modulated pulse. The below diagram shows the Sinusoidal PWM:

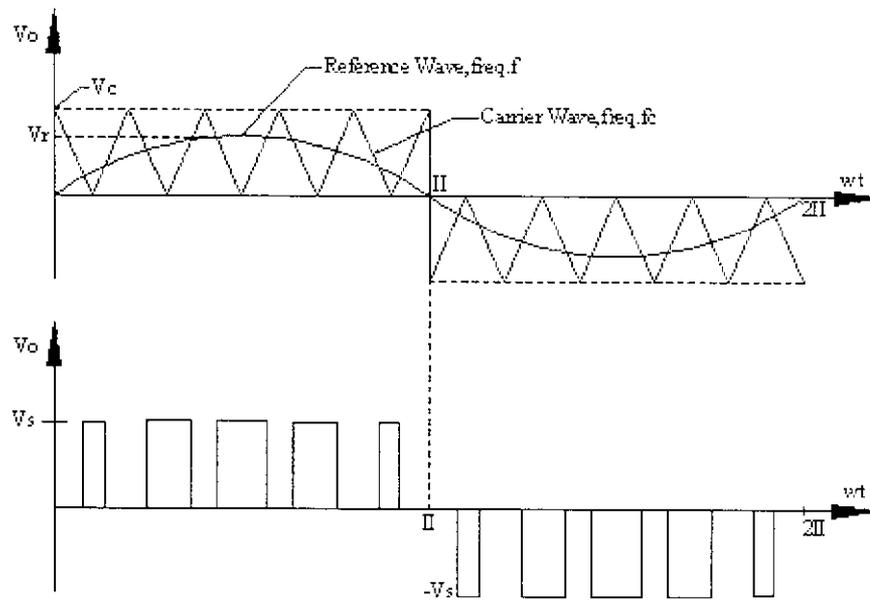


Fig 5.7 Output Voltage waveform with Sinusoidal Pulse Width Modulation

5.3.2 MOSFET (IRF9520)

MOSFETs provide much better system reliability.

- Typical $R_{ds(on)}=0.055$ ohm
- Exceptional dv/dt capability
- 100%avalanche tested
- Low gate charge
- Application oriented characterization
- Driver circuitry is simple and cheaper.
- MOSFET's fast switching speeds, permit much higher switching frequencies and there by the efficiency are increased.
- Overload and peak current handling capacity is high.
- MOSFETs have better temperature stability.
- MOSFET's leakage current is low.
- Drain-source conduction threshold voltage is absent which eliminates electrical noise.
- MOSFETs are able to operate in hazardous radiation environments.

5.4. OPTOCOUPLER (MCT2E)

An optocoupler is a combination of a light source and a photosensitive detector. In the optocoupler, or photon coupled pair, the coupling is achieved by light being generated on one side of a transparent insulating gap and being detected on the other side of the gap without an electrical connection between the two sides (except for minor amount of coupling capacitance). In the optocoupler, the light is generated by an infrared light emitting background, and the photo-detector is a silicon diode, which drives and amplifies, example transistor. The sensitivity of the silicon material peaks at the wavelength emitted by the LED, giving maximum signal coupling.

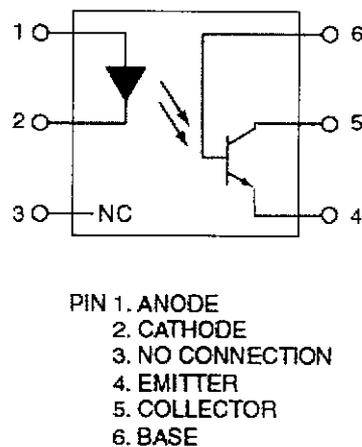


Fig. 5.8 Schematic Diagram of Optocoupler

5.5 PULSE GENERATING CIRCUIT

PIC16F877A microcontroller is used as the pulse generating circuit. PIC16F877A is a 40 pin; CMOS flash microcontroller with A/D controller.

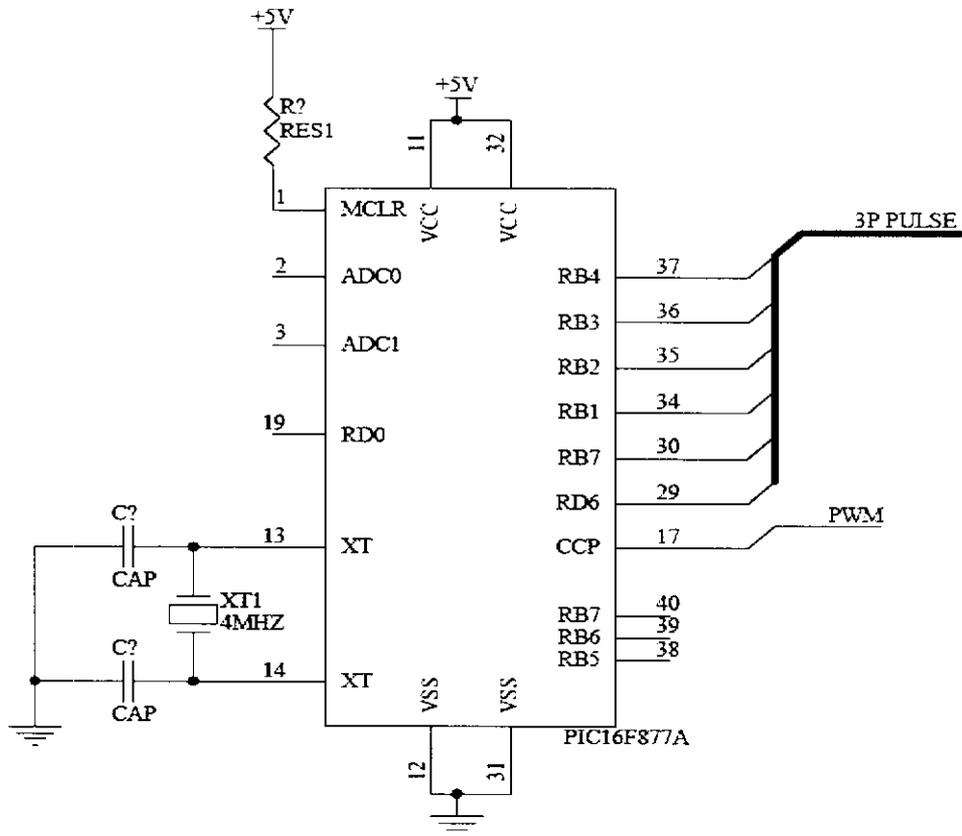


Fig. 5.9 Pin configuration of PIC16F877A

5.5.2 Features of PIC16F877A

High-Performance RISC CPU:

- Only 35 single word instructions to learn
- All instructions are $1\mu\text{s}$ (@4MHz) except for program branches which are 2 cycles.
- Operating speed: DC - 20MHz clock input.

Peripheral Features:

- Two 8-bit timer/counter (TMR0, TMR2) with 8-bit programmable prescaler.
- One 16-bit timer/counter (TMR1)
- High source/sink current: 25mA
- 12.5 ns resolution for PWM mode.
- Two Capture/Compare PWM (CCP) Module.
- Brown-out detection circuitry for brown-out Reset (BOR).

- Synchronous serial port (SSP) with SPI (Master mode) and I2C (Master/slave mode).
- Universal synchronous asynchronous receiver/transmitter (USART/SCI) with 9-bit address detection.

Special Micro controller Features

- Power-On Reset
- Power-up Timer (PWRT) and Oscillator Start-Up Timer (OST)
- Selectable oscillator options.
- Watchdog timer (WDT) with its own on-chip RC oscillator for reliable operation.
- Self-reprogrammable under software control.
- Power saving Sleep mode.

CMOS Technology

- Fully static design
- Low power, high speed CMOS FLASH technology
- Wide operating voltage range: 2.0V to 5.5V
- < 0.6 mA typical @ 3V, 4MHz.

5.5.3 Timers

The PIC 16F877 also has three timers namely:

- Timer 0 Module
- Timer 1 Module
- Timer 2 Module

5.5.3(a) Timer 0 Mode

Timer mode is selected by clearing bit T0CS (OPTION_REG 5). In timer mode, the Timer0 module will increment every instruction cycle (without prescaler). Counter mode is selected by setting bit T0CS (OPTION_REG 5). In counter mode, Timer0 will increment either on every rising or falling edge of pin RA4/T0CKI. The incrementing edge is determined by the Timer0 Source Edge Select bit T0SE of (OPTION_REG 4). Clearing bit T0SE selects the rising edge. The prescaler is mutually exclusively shared between the Timer0 module and the watchdog timer.

5.5.3(b) Timer 1 Mode

The Timer1 module is a 16-bit timer/counter consisting of two 8-bit registers (TMR1H and TMR1L), which are readable and writable. The TMR1 Register pair (TMR1H:TMR1L) increments from 0000h to FFFFh and rolls over to 0000h.

Timer1 can operate in one of two modes:

- As a timer
- As a counter

The operating mode is determined by the clock select bit, TMR1CS (T1CON 1).

In timer mode, Timer1 increments every instruction cycle. In counter mode, it increments on every rising edge of the external clock input. Timer1 can be enabled/disabled by setting/clearing control bit TMR1ON (T1CON 0).

5.5.3(c) Timer 2 Mode

Timer 2 is an 8-bit timer with a prescaler and a postscaler. It can be used as the PWM time-base for the PWM mode of the CCP module(s). The TMR2 register is readable and writable, and is cleared on any device reset. The Timer2 module has an 8-bit period register PR2. Timer2 increments from 00h until it matches PR2 and then resets to 00h on the next increment cycle. PR2 is a readable and writable register. The PR2 register is initialized to FFh upon reset.

5.5.4 Capture/Compare/Pwm Mode

Each Capture/Compare/PWM (CCP) mode contains a 16-bit register which can operate as a:

- 16-bit Capture register
- 16-bit Compare register
- PWM master/slave Duty Cycle register

Both the CCP1 and CCP2 modules are identical in operation, with the exception being the operation of the special event trigger.

5.5.4 (a) CCP1 Mode

Capture/Compare/PWM Register1 (CCPR1) is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). The CCP1CON register

controls the operation of CCP1. The special event trigger is generated by a compare match and will reset Timer1.

5.5.4 (b) CCP 2 Mode

Capture/Compare/PWM Register 2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2. The special event trigger is generated by a compare match and will reset Timer 2 and start an A/D conversion.

5.5.4 (c) PWM Mode

In pulse width modulation mode, the CCPx pin produces up to a 10-bit resolution PWM output. Since the CCP1 pin is multiplexed with the PORT C data latch, the TRISC 2 bit must be cleared to make the CCP1 pin an output. The Block Diagram of the PWM Mode and the PWM output is given below

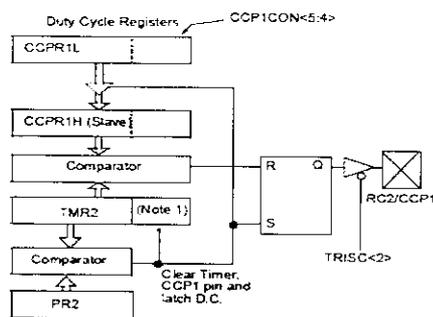


Fig 5.10 Functional Block Diagram of PWM Operation

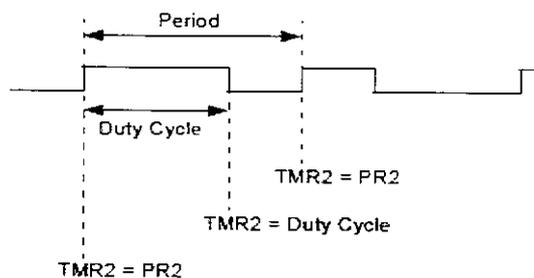


Fig 5.11 PWM Output

A PWM output has a time-base (period) and a time that the output has high (duty cycle). The frequency of the PWM is the inverse of the period (1/period). The PWM period is specified by writing to the PR2 register. The PWM period is calculated using the following formula

$$\text{PWM period} = [(\text{PR2}) + 1] * 4 * \text{TOSC}$$

5.5.4 (d) PWM Duty Cycle

The PWM duty cycle is specified by writing to the CCPR1L register and to the CCP1CON 5, 4 bits. Up to 10-bit resolution is available. The CCPR1L contains the eight MSBs and the CCP1CON5, 4 contains the two LSBs. This 10-bit value is represented by CCPR1L:CCP1CON 5, 4. The following equation is used to calculate the PWM duty cycle in time

$$\text{PWM duty cycle} = (\text{CCPR1L:CCP1CON 5, 4}) * \text{Tosc} * (\text{TMR2 prescale value})$$

CCPR1L and CCP1CON 5,4 can be written to at any time, but the duty cycle value is not latched into CCPR1H until after a match between PR2 and TMR2 occurs (i.e., the period is complete). In PWM mode, CCPR1H is a read-only register.

The following steps should be taken when configuring the CCP module for PWM operation:

1. Set the PWM period by writing to the PR2 register.
2. Set the PWM duty cycle by writing to the CCPR1L register and CCP1CON 5, 4 bits.
3. Make the CCP1 pin an output by clearing the TRISC 2 bit.
4. Set the TMR2 prescale value and enable Timer2 by writing to T2CON.
5. Configure the CCP1 module for PWM operation

5.6 HARDWARE PHOTOGRAPH

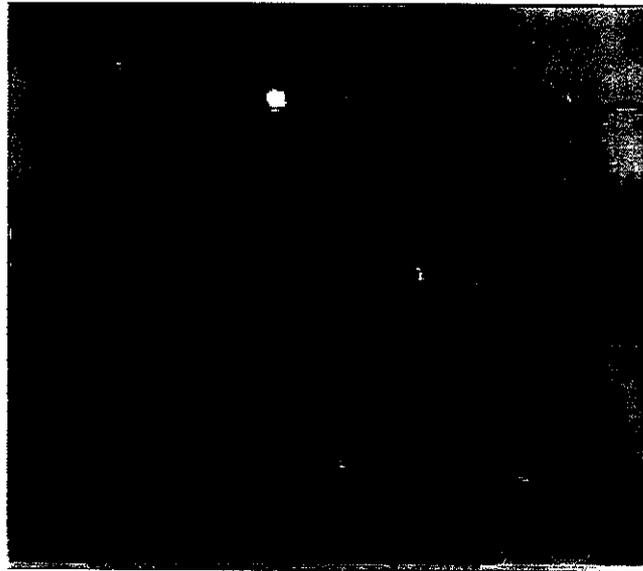


Fig 5.12 Voltage Source Converter Hardware Setup

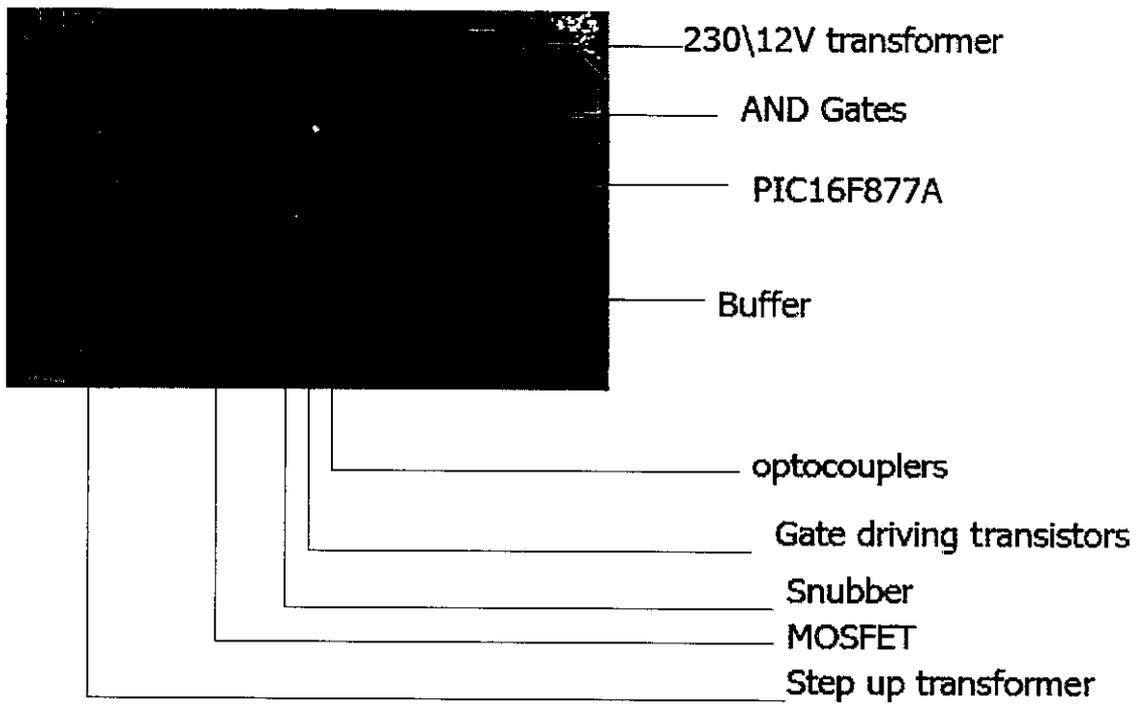


Fig 5.13 PIC Microcontroller Interfaced with Converter Hardware Setup



Fig 5.14 Complete Circuit Hardware Setup

5.7 HARDWARE RESULT

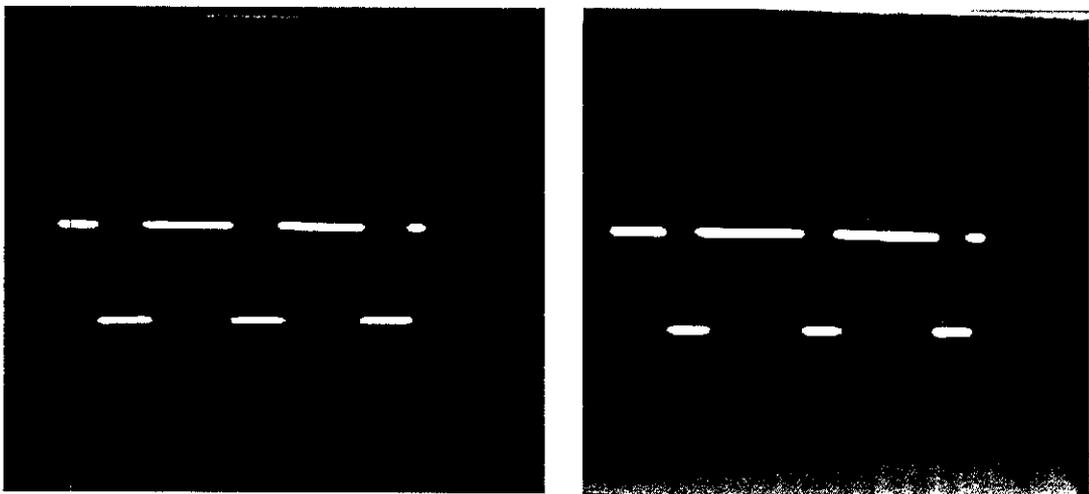


Fig 5.15 PWM Pulses

5.8 PROGRAM CODING

```
#include<pic.h>
unsigned char count=0,d_cycle,set_f[5]={0};
unsigned int ADRES=0;

#define S1 RB1
#define S2 RD7
#define S3 RB2
#define S4 RB4
#define S5 RD6
#define S6 RB3
__CONFIG(WDTDIS & XT & PWRTEN & BOREN & LVPDIS);
void main()
{
    ADCON1=0X8E;
    TRISA=0x01;
    TRISB=0;
    TRISD=0;
    TRISA=0X01;
    TRISC=0;

    PORTB=0;
    PORTD=0;
    PORTA=0;
    PORTC=0;

    T1CON=0X01;
```

```

TMR1H=0XF2;
TMR1L=0XFB;

// TMR1H=0XFF;
// TMR1L=0XC8;

T2CON=0X04;
PR2=99;
CCP1CON=0X0C;
CCPR1L=d_cycle=65;

S1=0;
S6=1;

GIE=PEIE=TMR1IE=1;

while(1)
{
    ADCON0=0X81;
    delay();
    ADGO=1;
    delay();
    while(ADGO);
    ADRES=ADRESH*256+ADRESL;

    ADRES=ADRES/2;

/*    if(ADRES<150)
        d_cycle=0;

```

```

else if(ADRES<160)
{
    if(set_f[1]==0)
    {
        set_f[1]=1;
        d_cycle=d_cycle-10;
        if(d_cycle<70)
            d_cycle=70;
    }
}
else if(ADRES<170)
{
    if(set_f[2]==0)
    {
        set_f[2]=1;
        d_cycle=d_cycle-5;
        if(d_cycle<75)
            d_cycle=75;
    }
}
else if(ADRES<190)
    d_cycle=80;
else if(ADRES<200)
{
    if(set_f[3]==0)
    {
        set_f[3]=1;
        d_cycle=d_cycle+5;
        if(d_cycle>85)

```

```

        d_cycle=85;
    }
}
else if(ADRES<210)
{
    if(set_f[4]==0)
    {
        set_f[4]=1;
        d_cycle=d_cycle+10;
        if(d_cycle>90)
            d_cycle=90;
    }
}
else
    d_cycle=90;

if(d_cycle<80)
    d_cycle++;
else if(d_cycle>80)
    d_cycle--;
else
{
    set_f[1]=0;
    set_f[2]=0;
    set_f[3]=0;
    set_f[4]=0;
}

```

*/

```

        if(ADRES<200)
        {

                d_cycle++;
                if(d_cycle>80)
                        d_cycle=80;

        }
        if(ADRES>210)
        {

                d_cycle--;
                if(d_cycle<50)
                        d_cycle=50;

        }
        CCPR1L=d_cycle;

        delay1();
}

}
delay()
{
        unsigned char i;
        for(i=0;i<=100;i++);
}
delay1()
{

```

```
    unsigned int i;
    for(i=0;i<50000;i++);
}
```

```
void interrupt isr()
{
    if(TMR1IF==1)
    {
        TMR1IF=0;
        TMR1H=0XF2;
        TMR1L=0XFB;
//        TMR1H=0XFF;
//        TMR1L=0XC8;

        count++;
        if(count==1)
        {
            S2=1;
            S6=0;
        }
        if(count==2)
        {
            S1=1;
            S3=0;
        }
        if(count==3)
        {
            S2=0;

```

```
        S4=1;
    }
    if(count==4)
    {
        S3=1;
        S5=0;
    }
    if(count==5)
    {
        S6=1;
        S4=0;
    }
    if(count==6)
    {
        count=0;
        S5=1;
        S1=0;
    }
}
}
```

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

In this project the power electronics control mechanism for the control of windmill is carried out. Here the concept of voltage source converter and battery storage system is implemented. Both the hardware and simulation results are found to be comparable. The output is connected to various loads as a part of consumer requirement. The simulation results show that the proposed controller is capable to function as a harmonic compensator, a load balancer and a load leveler.

6.2 FUTURE SCOPE

In the future scope of the work the concept of Pitch Angle Control of the windmill can be implemented.

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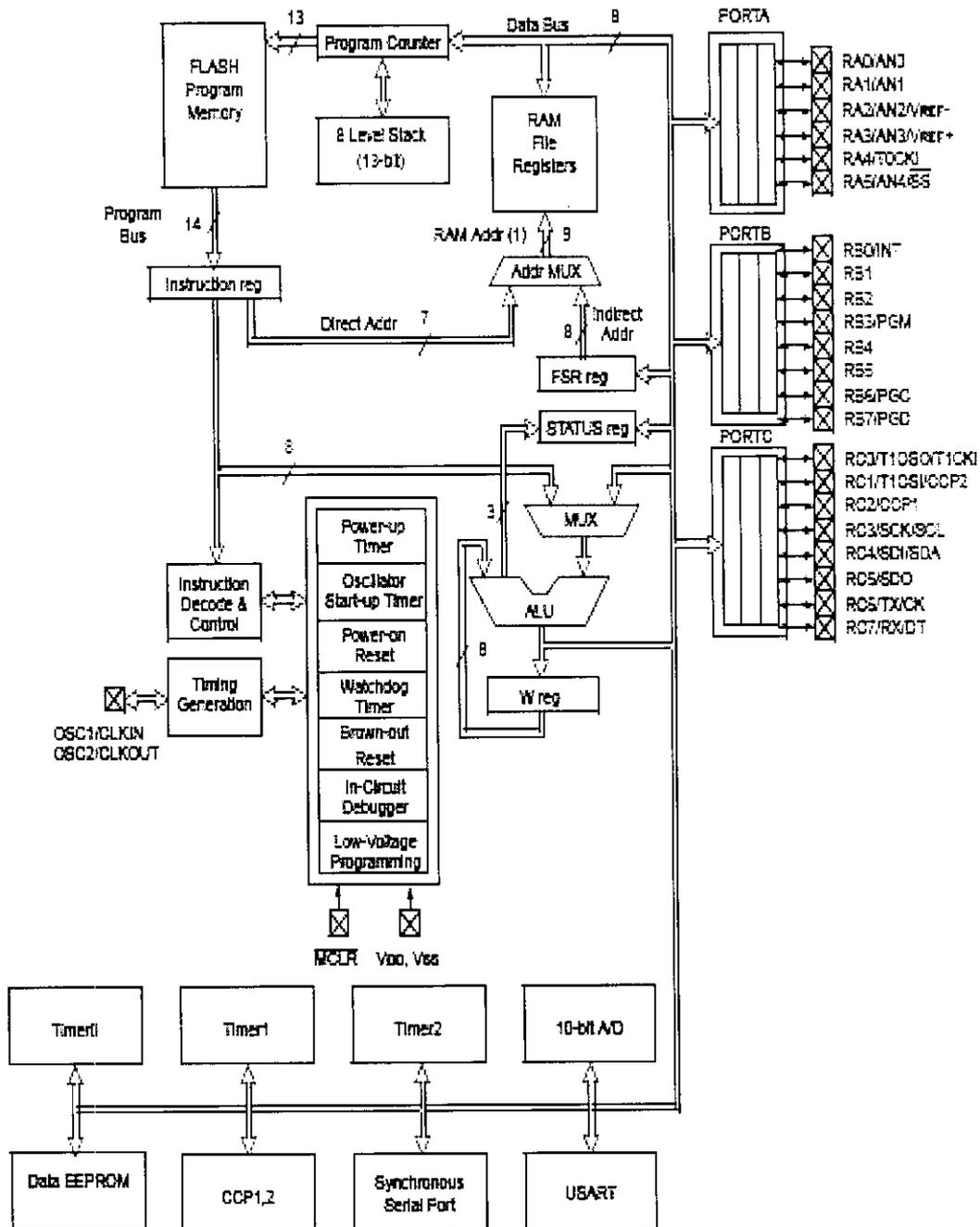
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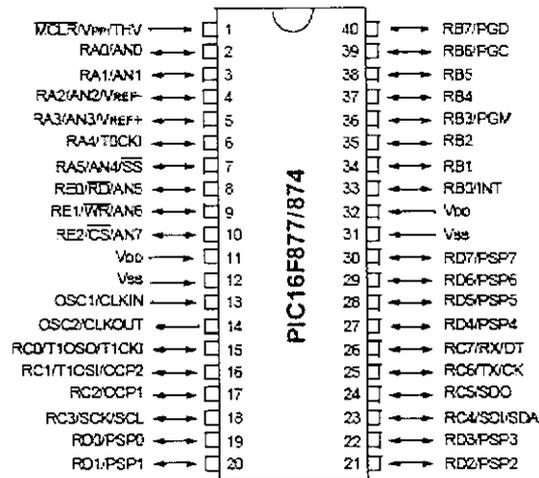
APPENDIX I

ARCHITECTURE OF PIC 16F877

| Device | Program FLASH | Data Memory | Data EEPROM |
|-----------|---------------|-------------|-------------|
| PIC16F873 | 4K | 192 Bytes | 128 Bytes |
| PIC16F876 | 8K | 368 Bytes | 256 Bytes |



Pin Configuration Of PIC16F877A



TIMER 0 CONTROL REGISTER:

| | | | | | | | |
|-------|--------|-------|-------|-------|-------|-------|-------|
| R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
| RBP0 | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 |
| bit 7 | | | | | | | bit 0 |

bit 7: **RBP0**

bit 6: **INTEDG**

bit 5: **T0CS**: TMR0 Clock Source Select bit

1 = Transition on T0CKI pin

0 = Internal instruction cycle clock (CLKOUT)

bit 4: **T0SE**: TMR0 Source Edge Select bit

1 = Increment on high-to-low transition on T0CKI pin

0 = Increment on low-to-high transition on T0CKI pin

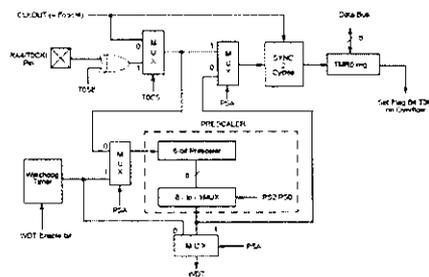
bit 3: **PSA**: Prescaler Assignment bit

1 = Prescaler is assigned to the WDT

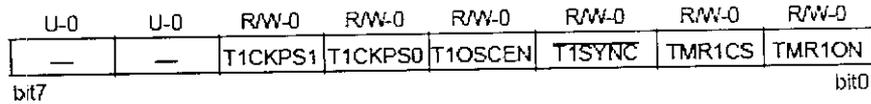
0 = Prescaler is assigned to the Timer0 module

bit 2-0: **PS2 PS1 PS0**: Prescaler Rate Select bits

TIMER 0 BLOCK DIAGRAM:



TIMER 1 CONTROL REGISTER:



bit 7-6: **Unimplemented:** Read as '0'

bit 5-4: **T1CKPS1:T1CKPS0:** Timer1 Input Clock Prescale Select bits

- 11 = 1:8 Prescale value
- 10 = 1:4 Prescale value
- 01 = 1:2 Prescale value
- 00 = 1:1 Prescale value

bit 3: **T1OSCEN:** Timer1 Oscillator Enable Control bit

- 1 = Oscillator is enabled
- 0 = Oscillator is shut off (The oscillator inverter is turned off to eliminate power drain)

bit 2: **T1SYNC:** Timer1 External Clock Input Synchronization Control bit

TMR1CS = 1

- 1 = Do not synchronize external clock input
- 0 = Synchronize external clock input

TMR1CS = 0

This bit is ignored. Timer1 uses the internal clock when TMR1CS = 0.

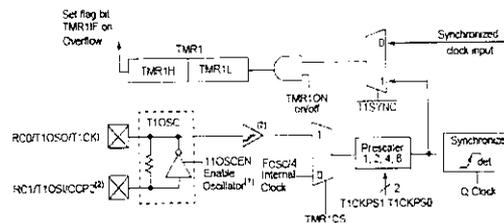
bit 1: **TMR1CS:** Timer1 Clock Source Select bit

- 1 = External clock from pin RC0/T1OSO/T1CKI (on the rising edge)
- 0 = Internal clock (FOSC/4)

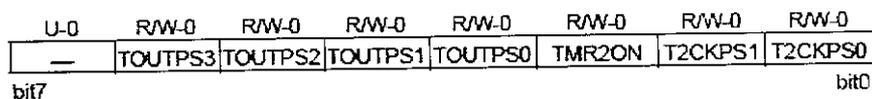
bit 0: **TMR1ON:** Timer1 On bit

- 1 = Enables Timer1
- 0 = Stops Timer1

TIMER 1 BLOCK DIAGRAM:



TIMER 2 CONTROL REGISTER:



bit 7: **Unimplemented:** Read as '0'

bit 6-3: **TOUTPS3:TOUTPS0:** Timer2 Output Postscale Select bits

- 0000 = 1:1 Postscale
- 0001 = 1:2 Postscale
- 0010 = 1:3 Postscale
- 1111 = 1:16 Postscale

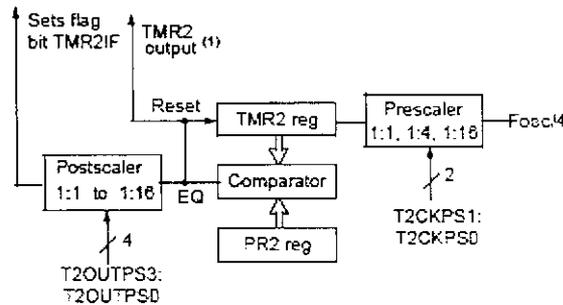
bit 2: **TMR2ON**: Timer2 On bit

- 1 = Timer2 is on
- 0 = Timer2 is off

bit 1-0: **T2CKPS1:T2CKPS0**: Timer2 Clock Prescale Select bits

- 00 = Prescaler is 1
- 01 = Prescaler is 4
- 1x = Prescaler is 16

TIMER2 BLOCK DIAGRAM:



CCP1CON REGISTER/CCP2CON REGISTER:

| | | | | | | | |
|------|-----|-------|-------|--------|--------|--------|--------|
| U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | — | CCPxX | CCPxY | CCPxM3 | CCPxM2 | CCPxM1 | CCPxM0 |
| bit7 | | | | | | bit0 | |

bit 7-6: **Unimplemented**: Read as '0'

bit 5-4: **CCPxX :CCPxY**: PWM Least Significant bits

Capture Mode: Unused

Compare Mode: Unused

PWM Mode: These bits are the two LSB s of the PWM duty cycle. The eight MSB s are found in CCPRxL.

bit 3-0: **CCPxM3:CCPxM0**: CCPx Mode Select bits

0000 = Capture/Compare/PWM off (resets CCPx module)

0100 = Capture mode, every falling edge

0101 = Capture mode, every rising edge

0110 = Capture mode, every 4th rising edge

0111 = Capture mode, every 16th rising edge

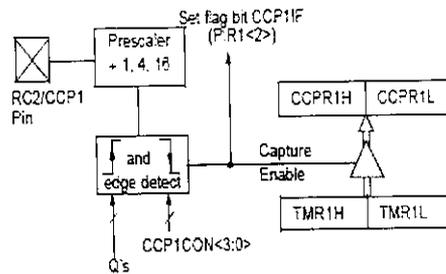
1000 = Compare mode, set output on match (CCPxIF bit is set)

1001 = Compare mode, clear output on match (CCPxIF bit is set)

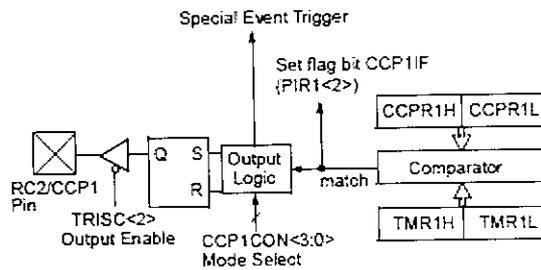
1010 = Compare mode, generate software interrupt on match (CCPxIF bit is set, CCPx pin is unaffected)

1011 = Compare mode, trigger special event (CCPxIF bit is set, CCPx pin is unaffected); CCP1 resets TMR1; CCP2 resets TMR1 and starts an A/D conversion (if A/D module is enabled)
 11xx = PWM mode

CAPTURE MODE OPERATION BLOCK DIAGRAM:

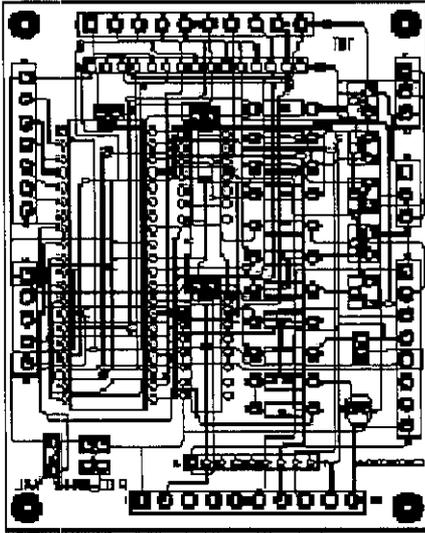


COMPARE MODE OPERATION BLOCK DIAGRAM:

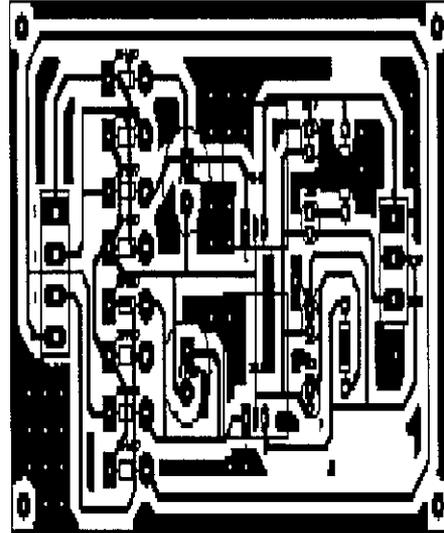


APPENDIX II PCB DESIGNS

Microcontroller Design



12 V Power Supply



PWM CONVERTER

