DESIGN OF AN EFFICIENT DIGITAL CONTROL PANEL FOR SMALL WIND TURBINE

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report entitled "**DESIGN OF AN EFFICIENT DIGITAL CONTROL PANEL – FOR A SMALL WIND TURBINE**" is the bonafide work of

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INTERNAL EXAMINER 25/4/07	**EXTERNAL EXAMINER**

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ABSTRACT

The production of electricity by a wind turbine at a specific site depends on many factors. These factors include the wind speed conditions at the site and the characteristics of the wind turbine generator itself, particularly the rated cut in and cut out wind speed parameters; it is desirable to select a wind turbine which is best suited for a particular site in order to obtain the maximum power benefit at the available low wind velocity. This project proposes the design of a horizontal axis, three-blade wind turbine system, which can produce approximately 500 watts at a wind speed of 1.5m/s. According to the wind velocity analysis, the parameter specifications are determined for rotor blade design to extract the maximum output from low wind velocity and generator is designed to utilize the rotor power to generate low electric power to meet the requirements in rural areas. The control system is designed to monitor and control the variation in the generator output. It used to charge battery for utility purposes. The main objective is to obtain constant power output for variable wind speed. Distributed small wind energy systems enhance the reliability and power quality of the power grid, reduce peak power demands, increase in-state electricity generation, diversity the state's energy supply portfolio, and make the electricity supply market more competitive by promoting consumer.

ACKNOWLEDGEMENT

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LIST OF SYMBOLS AND ABBREVIATIONS

NO	SYMBOLS	ABBREVIATIONS
1	AC	Alternating Current
2	DC	Direct Current
3	PWM	Pulse Width Modulation
4	v	Wind speed (m/sec)
5	ρ	Air density (kg/m^2)
6	A	Swept area of wind turbine (m^2)
7	η_m	Efficiency of wind turbine
8	η_g	Efficiency of generator
9	ω	Rotational speed of the wind turbine (rad/sec)
10	λ	Tip speed ratio
11	PMSG	Permanent magnet synchronous generator
12	V_R	Dc voltage at rectifier output
13	V_I	Dc voltage at inverter input
14	M	Modulation index of PWM inverter
15	Po	Rectifier output power.
16	δ	Duty Ratio

CHAPTER-1

INTRODUCTION

INTRODUCTION

According to our president **Dr. A.P.J. Abdul Kalam's** speech " by **2030** India should achieve **energy independence** although unseen, **WIND** is the **most powerful natural force** and Wind energy is one of the best forms of non-conventional energy source...". His inspirational speech motivated us to do a project in the area of wind energy.

Since the wind power generation has been established based on electric motor technology, it is expected as natural energy power generating system of which the practical application is most regarded promising. Besides the conventional renewable power generation such as hydro and pumping storage, wind power generation has been considered as the most cost effective with developing potential. For wind speed exceeding1.5m/s, the wind turbine can generate power and the rated output power is obtained for wind speed above 8m/s. The increase of unit size and enhancement of performance it higher loading factor and reliability have made wind power generation more attractive and its unit generation cost becomes very competitive as compared to traditional fossil generation.

The main aim of the project is to design and fabricate an efficient control panel for low power wind turbine and to obtain a constant voltage with constant frequency at the output. The wind turbine converts the kinetic energy presented in the wind into mechanical energy, which drives the permanent magnet synchronous generator through gearbox. The PMSG input AC voltage is rectified using diode bridge rectifier and the voltage is boosted up by a Boost chopper. Then this voltage is inverted by a PWM inverter. To obtain the required output, the control circuit is designed, simulated using MATLAB, and implemented in the Hardware.

CHAPTER-2

WIND POWER GENERATION

2.1 INTRODUCTION

Wind power is converted into electricity by a wind turbine. In a typical, modern, large-scale wind turbine, the kinetic energy in the wind (the energy of moving air molecules) is converted to rotational motion by the rotor – typically a three-bladed assembly at the front of the wind turbine. The rotor turns a shaft, which transfers the motion into the nacelle (the large housing at the top of a wind turbine tower).Inside the nacelle; the slowly rotating shaft enters a gearbox that greatly increases the rotational shaft speed. The output (high-speed) shaft is connected to a generator that converts the rotational movement into electricity at medium voltage (a few hundred volts).

The electricity flows down heavy electric cables inside the tower to a transformer, which increases the voltage of the electric power to the distribution voltage (a few thousand volts). (Higher voltage electricity flows more easily through electric lines, generating less heat and fewer power losses.) The distribution-voltage power flows through underground lines to a collection point where the power may be combined with other turbines.

In many cases, the electricity is sent to nearby farms, residences and towns where it is used. Otherwise, the distribution-voltage power is sent to a substation where the voltage is increased dramatically to transmission-voltage power (a few hundred thousand volts) and sent through very tall transmission lines many miles to distant cities and factories.

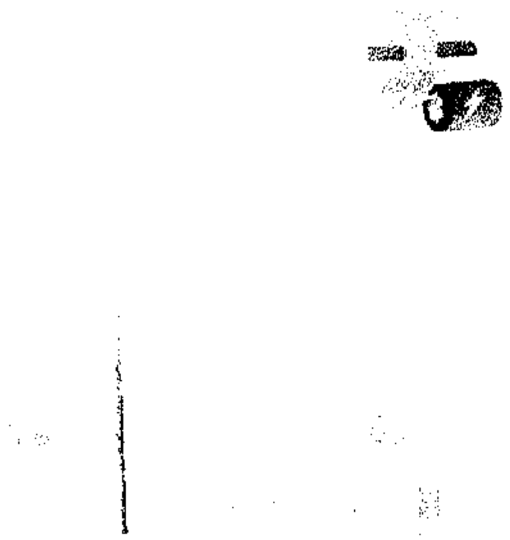


Fig. 1.1 Wind Power Generation Setup

The wind generator consists of the following parts,

1. Tower
2. Shaft inside the Nacelle
3. Gear Box
4. Generator
5. Voltage Regulation
6. Distribution System

2.2 SMALL WIND TURBINE

Improved airfoil designs for maximum efficiency at low wind speed, high efficiency direct drive permanent magnet alternators, improved governing methods and highly sophisticated controls and inverters now allow homeowners to interface directly with utility companies or design off-grid systems. These systems are increasing energy independence, competing with current energy prices and reducing environmental impacts. Small (or residential) wind energy systems typically generate just enough power to meet the demands of a home, farm, or small business. They range from 400 watts to 1 kW (or) more, and typically consist of a single turbine, while commercial wind farms consist of dozens (or) even hundreds of MW scale turbines. Low power wind generators powered lights, radios and kitchen appliances of modern urban life. In this new century, small wind turbines are an attractive investment for residents in rural areas looking for relief from high-energy costs. Small turbines also contribute a larger public benefit by reducing demand on utility systems now supplied primarily by centralized fossil fuel plants. In recent years, this system has left electricity customers vulnerable to power shortage and sharp price increases.

2.3 VARIABLE SPEED TURBINE

The variable speed operation enhances the low-pass characteristics of the whole system. The relatively high frequency variations of the produced active power in the constant speed operation have been completely eliminated in the variable speed operation. This contributes to the improvement of the produced power quality, an issue particularly important when the wind turbines are connected to weak electrical systems. The mechanical stresses of the wind turbine are also significantly reduced. A significant attenuation of the variability of the electromagnetic torque and the produced active power is achieved in the variable speed mode of operation, compared to the constant speed operation of the same WT. Through the variable speed mode of operation an increase of the energy production is achieved, the accurate assessment of which requires a more extensive investigation.

CHAPTER-3

METHODOLOGY

3.1 OBJECTIVE

The main aim of the project is to design and fabricate an efficient control panel for low power wind turbine and to obtain a constant voltage with constant frequency at the output. The wind turbine converts the kinetic energy presented in the wind into mechanical energy, which drives the permanent magnet synchronous generator through gearbox. The PMSG input AC voltage is rectified using diode bridge rectifier and the voltage is boosted up by a Boost chopper. Then this voltage is inverted by a PWM inverter. To obtain the required output, the control circuit is designed, simulated using MATLAB, and implemented in the Hardware.

3.2 PARAMETERS MONITORED

The control panel is designed to monitor the following parameters,

- Frequency
- Voltage
- Current
- Speed

3.4 WIND VELOCITY ANALYSIS

First, we started with analyzing wind velocity in our area by using our PC interfaced recordable anemometer. The velocity of the wind is analyzed and found to be varying with seasons, days and hours. As we know the maximum required wind velocity to generate the power in the existing system is around 3 m/s, but in our case, we got only 1.0-5.0 m/s wind velocity even in the windy season itself.

Therefore, to overcome this situation we decided to design a low power wind turbine to generate electric power satisfactorily with the available low wind velocity (1.5 m/s). The wind velocity is represented graphically.

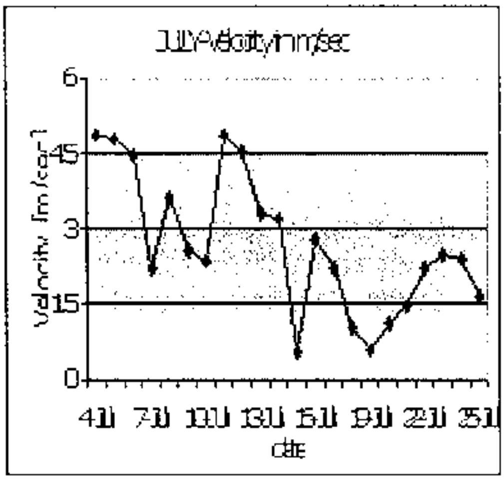


Fig. 3.1 July-velocity in m/sec

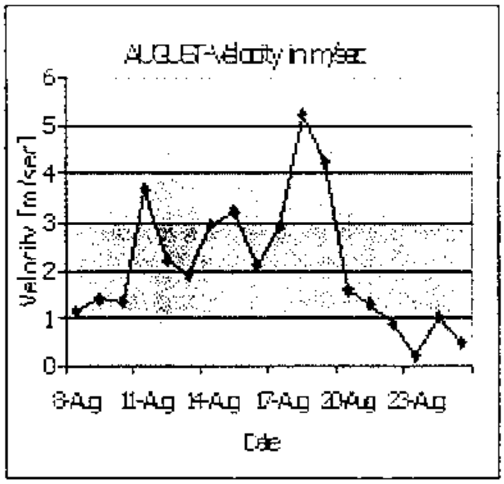


Fig. 3.2 August-velocity in m/sec

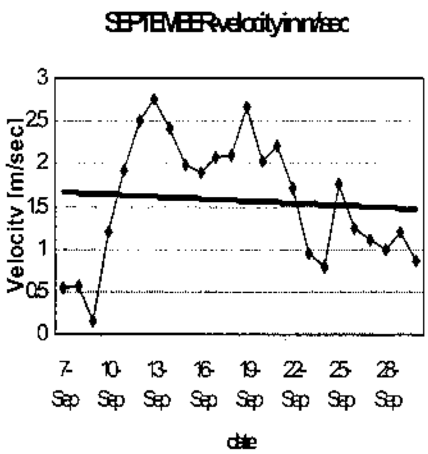


Fig. 3.3 September-velocity in m/sec

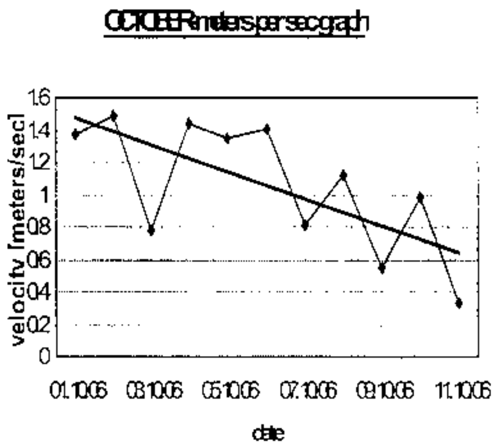


Fig. 3.4 October-velocity in m/sec

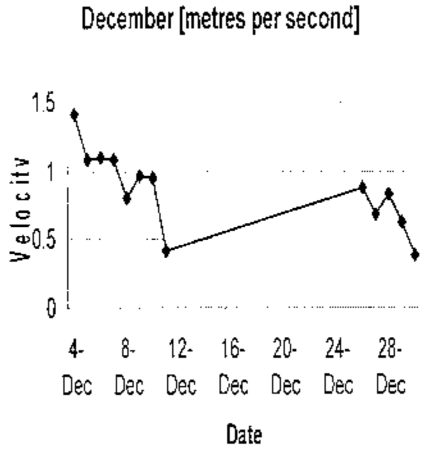


Fig. 3.5 December-velocity in m/sec

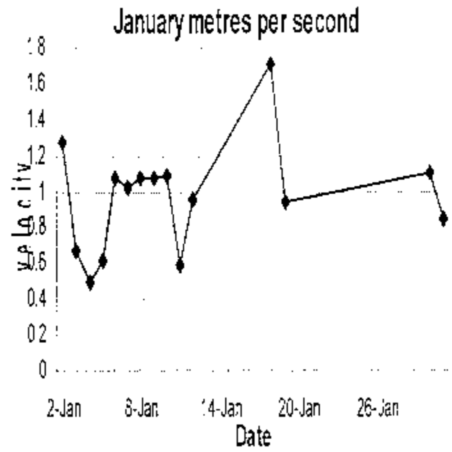


Fig. 3.6 January-velocity in m/sec

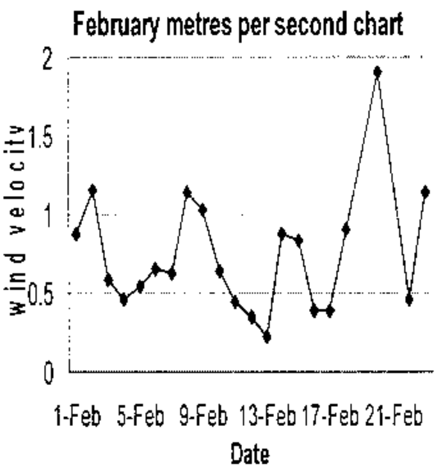


Fig. 3.7 February -velocity in m/sec

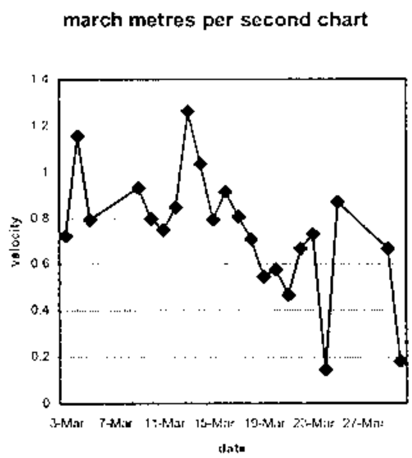


Fig. 3.8 March-velocity in m/sec

3.3.1.1 ANALYSIS

During the investigation of the wind availability and the operation of various existing systems, it is observed that the maximum wind availability not only depends on the seasons and hours, but also depends on the windy area.

CHAPTER-4

WIND TURBINE SYSTEM

4.1 COMPONENTS OF CONTROL PANEL

The basic components of a control panel circuit proposed in this project are as shown in Figure 4.1. Wind Turbine converts wind energy in to rotary mechanical energy. A mechanical interface consists of step up gear and a suitable coupling transmitter, which is connected between wind turbine and Permanent Magnet Synchronous Generator (PMSG). The electric power from generator is connected to local load through power converters, where output with constant voltage and constant frequency can be obtained.

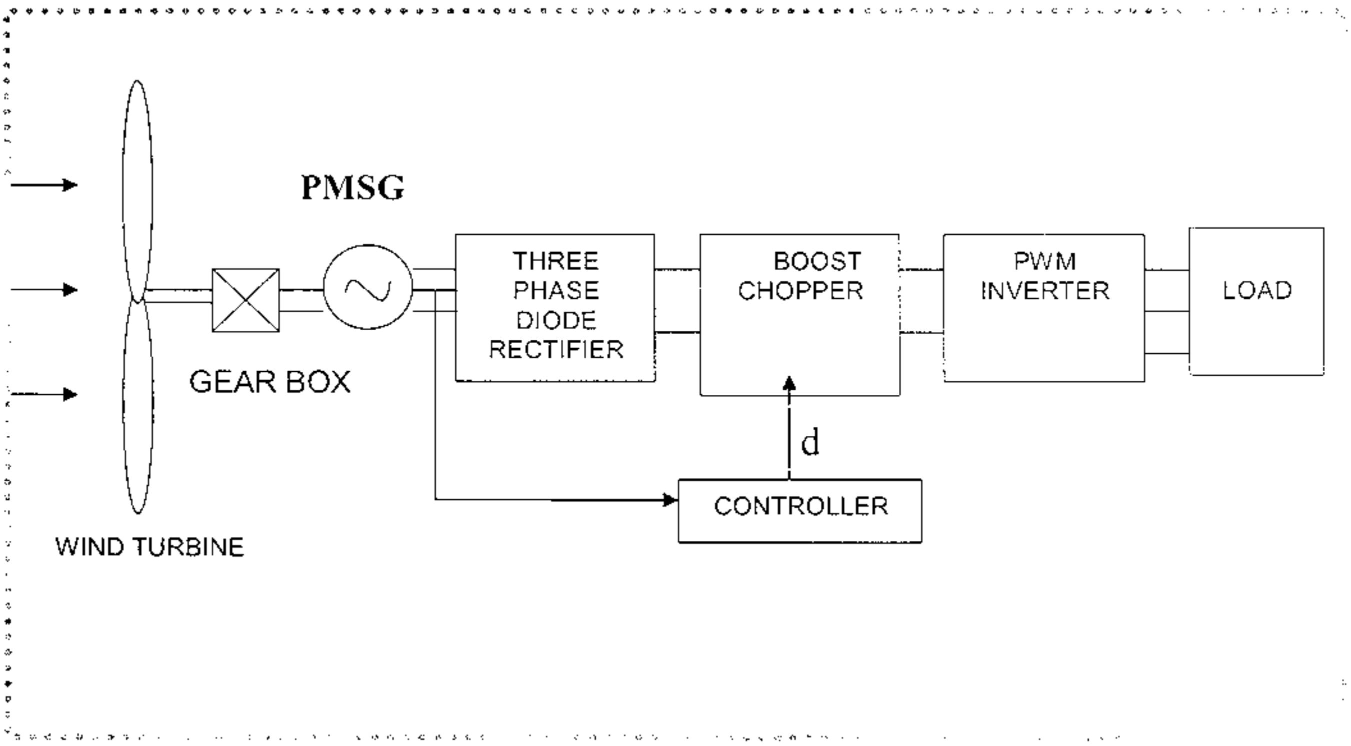


Fig. 4.1 BLOCK DIAGRAM

Where, d -- Duty ratio to control Boost chopper circuit

The wind turbine converts the kinetic energy presented in the wind into mechanical energy, which drives the permanent magnet synchronous generator through gearbox. Since the wind is intermittent source of energy, the output voltage and frequency from generator will vary for different wind velocities. The variable AC power from the generator is first converted into DC using a diode bridge rectifier. The voltage across the rectifier terminal is regulated for constant voltage by controlling the duty ratio of DC/DC converter. The available DC power is fed to the load at the required level of voltage and frequency by PWM inverter. The output from the PMSG is taken from its duty ratio d can be calculated. The duty ratio d is used to control the Boost chopper voltage, to maintain constant output voltage.

4.2 WIND TURBINE

Most of the wind turbine generators use Horizontal axis wind turbine due to the advantages of ease in design and cheaper in cost for higher power ratings. The principal components of a modern wind power plant are the tower, the rotor and the nacelle. The nacelle accommodates the transmission mechanism, generator and the yaw systems for steering in response to changes in wind directions. The wind turbine consists of a hub, rotor blades and blade extenders to increase the rotor diameter. Most turbines have either two or three blades. The rotor blades are made up of reinforced glass fiber molded on a steel shaft. The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity.

Pitch angle of a wind turbine is defined as the angle between the rotor axis and airfoil chord. Blades are turned or pitched out of the wind to keep the rotor from turning the winds that are too high or too low to produce electricity. In Stall regulated machines the pitch angle is fixed at the time of installation whereas in pitch-regulated machine, it varies for various wind velocities to maintain the output power constant at rated value.

By the means of a clamping unit, the main shaft of the wind turbine is coupled to the gearbox. The gear has a hollow shaft that fits over the rear end of the main shaft. Torque between the two components is transferred by friction between the two. Transferred torque is dependent upon friction between the main shaft and the hollow shaft.

The mechanical energy is stepped up by suitable gear transmission, which couples the rotor and the generator. Gears connect the low speed shaft to the high speed and increase the rotational speeds from 30 – 40 rpm, to about 900 – 1000 rpm, which is the rotational speed required by most generators to produce electricity. This mechanical energy is converted into electrical energy using the generator and the power thus generated may be supplied to the grid or to an isolated load.

A cover protects the components inside the Nacelle. Some nacelles are large enough for a technician to stand inside while working. Towers are made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more power.

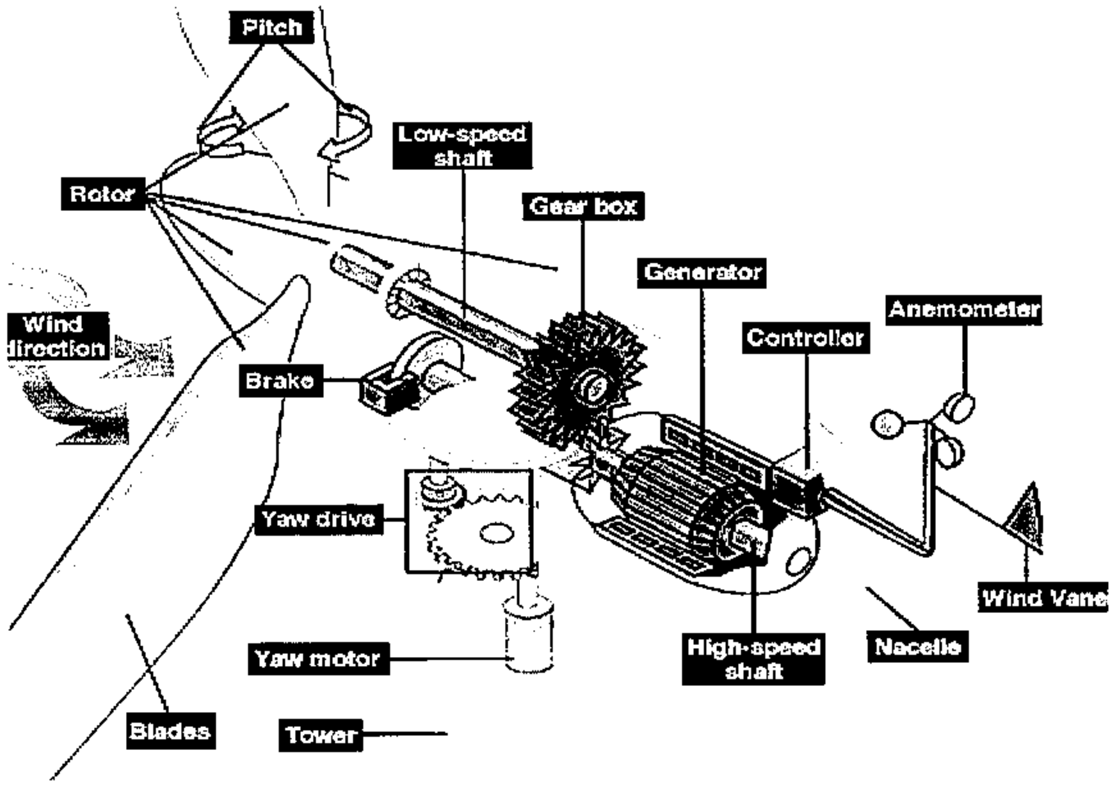


Fig. 4.2 Horizontal Axis Wind turbine

The entire nacelle assembly is placed over the tower through a yaw assembly. Anemometer on the nacelle top is used to measure the wind speed and transmits wind speed data to the controller. The wind vane, which is also located on the top of the nacelle senses the wind direction and communicate with the yaw drive to orient the turbine properly with respect to the wind. Yaw motor powers the yaw drive. The control signal from the controller releases the yaw brakes and the entire nacelle assembly is oriented towards the maximum wind direction.

$$T_g = \frac{3}{2}\frac{P}{2}\left[i_d i_q \left(L_q - L_d + \lambda_m i_q\right)\right] \qquad \text{---------} (2.14)$$

Where,

T_g	→Generator torque
i_d	→Direct axis current
i_q	→Quadrature axis current
L_d, L_q	→Inductance of direct and quadrature axis
λ_m	→Tip speed ratio
T_L	→Load torque
T_t	→Turbine torque

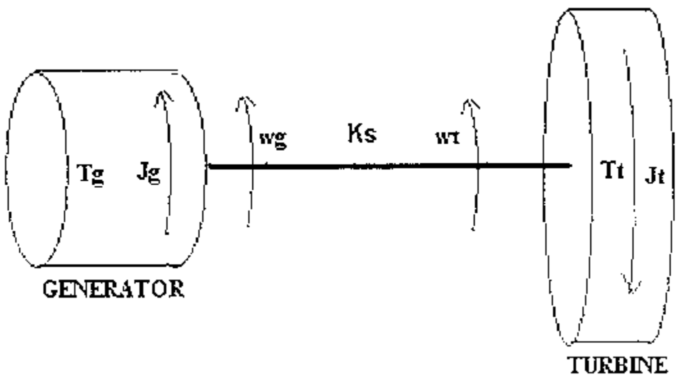


Fig. 4.3 Generator and Turbine torque interaction

4.3 DIODE RECTIFIER CIRCUITS

The generator is connected with rectifier circuits. The AC power generated from the generator is converted into DC power through diode bridge rectifier circuits. Full-Power Converter allows for simplified, more effective power quality control functions including harmonics, reactive power and flicker. Acting as a buffer, the converter protects both the generator and the gearbox from the harmful effects of weak grid systems.

4.4 BOOST CHOPPER CIRCUIT

The AC power output from the generator is converted into DC power through diode rectifier circuit. Generator and rectifier circuits that supply the boost chopper circuit with electric power are replaced by a DC voltage source in the analysis. The inverter circuit connected with the output of the boost chopper circuit was simulated. The load resistance is connected with the DC link and it is controlled and operated at high power factor as a current source.

4.5 PWM INVERTER

The converter that changes a dc voltage to an alternating voltage is called an inverter. For providing adjustable frequency power to industrial applications, three phase inverters are more common than single-phase inverters. Inverters are used in a wide range of applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power. Gating signals for PWM Inverter switches are generated by Sinusoidal Pulse Width Modulation Technique (SPWM). In this SPWM comparing a Sinusoidal, reference signal with a triangular carrier wave of frequency f_c generates gating signals. The frequency of reference signal f_r determines the inverter output frequency f_O and its peak amplitude controls the modulation index and then in turn the rms output voltage. Among all kinds of power converters, the PWM inverter has the most widespread applications such as power supply, active filter, power factor converter, and adjustable speed ac servo drives.

4.5.1 HALF BRIDGE INVERTER

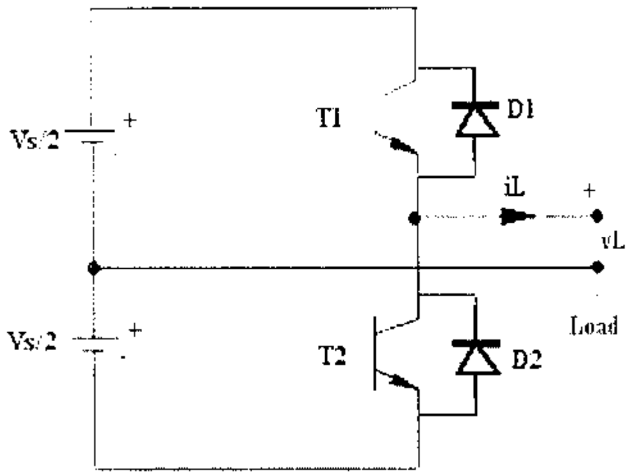


Fig. 4.4 Centre tapped Half Bridge Inverter

4.5.1.1 Circuit Operation

When transistor T1 is ON, a voltage Vs/2 will be applied to the load. If the load draws positive current i_L it will flow through T1 and supply energy to the load. If the load current i_L is negative it will flow back through D1 and Return energy to the DC source.

Similarly, if T2 is ON -Vs/2 will be applied to the load. If i_L is positive, it must flow through D2 returning energy to the DC source. If the current is negative, it must flow through T2 supplying energy to the load.

4.5.2 "H" BRIDGE INVERTER

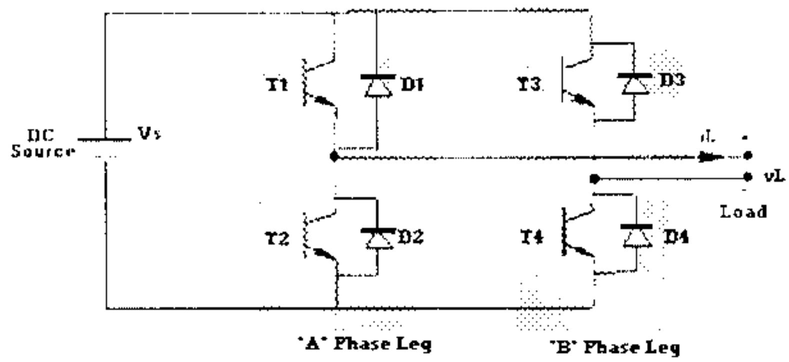


Fig. 4.5 "H" Bridge Inverter

4.5.2.1 Circuit Operation

With four switches [T1, T2, T3, T4], there are six combinations to be examined.

T1-T2 ON or T3-T4 ON:

Both create short circuits across the DC source and are invalid.

T1-T4 ON:

Applies- Vs to the load. With i_L, positive current passes through T1-T4, for i_L negative the current is through D1-D4.

T2-T3 ON:

Applies- Vs across the load. With i_L positive, the current flows through D2-D3 and returns energy to the DC source. With i_L negative, the current flows through T2-T3 and draws energy from the supply.

T1-T3 ON:

Applies 0 volts across the load. For i_L positive, the path is T1-T3 for i_L negative the path is D1-T3.

T2-T4 ON:

Applies 0 volts across the load. For i_L positive the path is through D2-T4. For i_L negative the path is T2-D4.

4.5.3 THREE PHASE INVERTER

The inverter consists of three half-bridge units where the upper and lower switches are controlled complimentarily. The three-phase voltage source inverter is shown in figure 4.6. As the power device's turn-off time is longer than its turn-on time, some dead time must be inserted between the turn-off of one transistor of the half-bridge and turn-on of its complementary device. The output voltage is created by a pulse width modulation (PWM) technique. The 3-phase voltage waves are shifted 120° to each other and thus a 3-phase motor can be supplied.

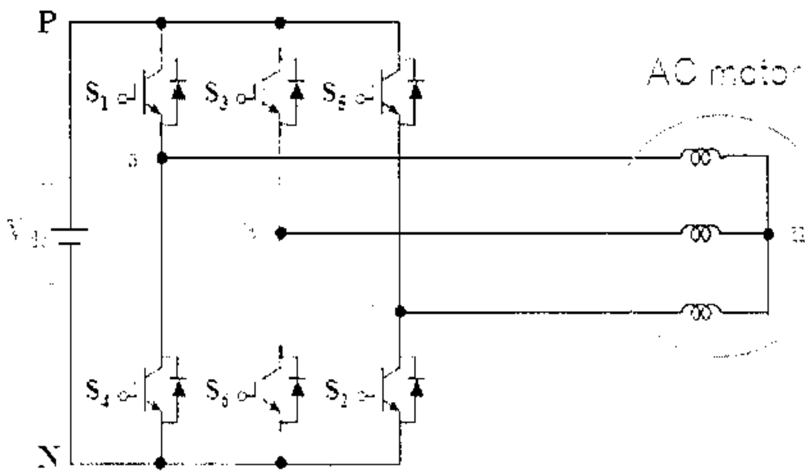


Fig. 4.6 Phase Voltage source inverter

4.5.3.1 Modes of conduction

A three-phase output can be obtained from a configuration of six transistors and six diodes as shown in figure 4.7. Two types of control signals can be applied to the transistors.

- 180°conduction
- 120°conduction

180-degree conduction:

In this mode, each transistor conducts for 180°. Three transistors remain on at any instant of time. When S1 is switched on, terminal *a* is connected to the positive terminal of the dc input voltage. When S4 is switched on, terminal *a* is brought to the negative terminal of the dc source. There are six modes of operation in a cycle with duration of 60° each. The gating signals are provided such that the switching sequence is 612, 123, 234, 345, 456 and 561 as in figure 4.7. The gating signals are shifted by 60° to obtain three phase balanced voltages as in figure 4.8.

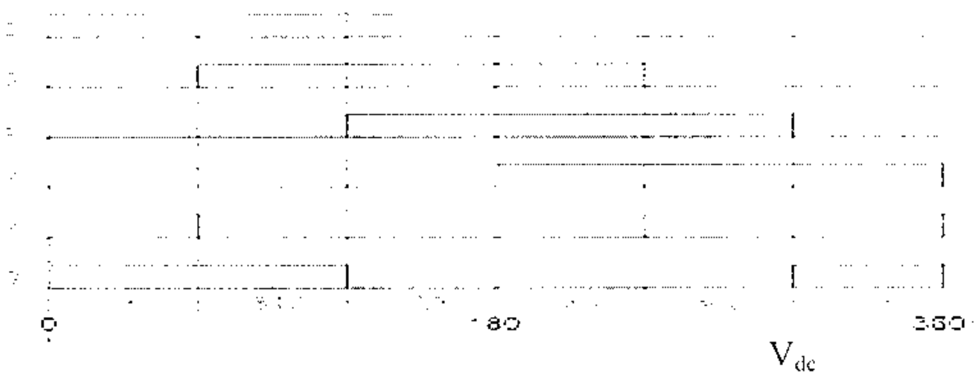


Fig. 4.7 Gating signals for 180° conduction

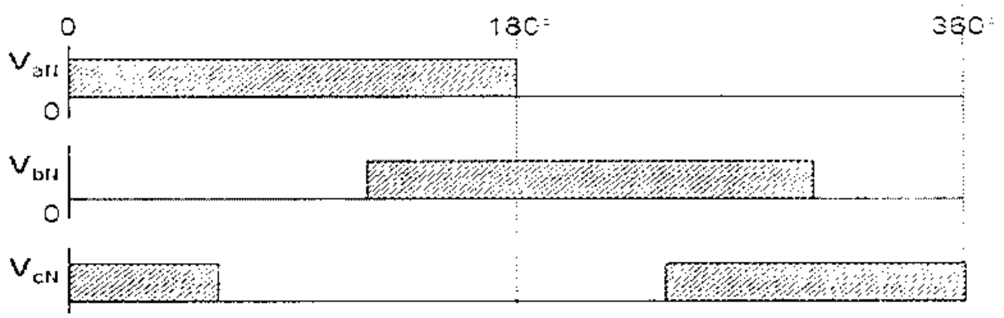
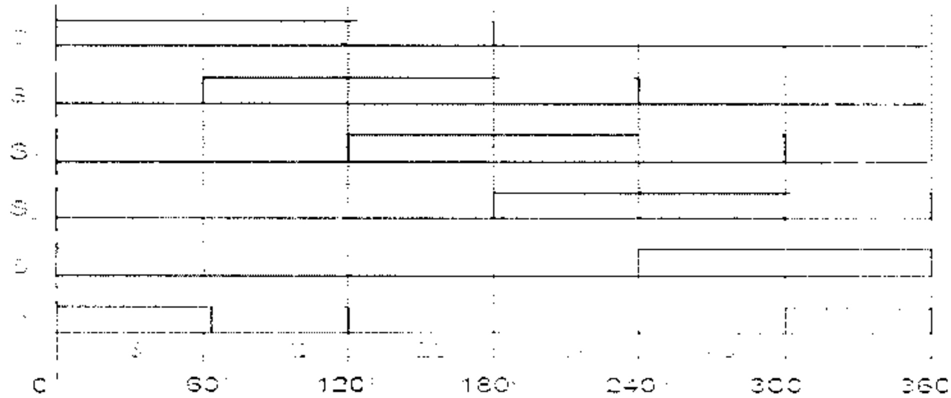


Fig. 4.8 Voltage waveform for 180° conduction

120-degree conduction:

In this mode, each transistor conducts for 120°. Three transistors remain on at any instant of time. There are six modes of operation in a cycle with duration of 60° each. The gating signals are provided such that the switching sequence is 61, 12, 23, 34, 45 and 56 as in figure 3.6. There is a delay of 30° turning off S1 and turning on S4. Thus, there is no possibility of short circuit of the dc supply through one upper and one lower transistor. The voltage waveform is shown in figure 4.10.



V_{dc}

Fig. 4.9 Gating signals for 120° conduction

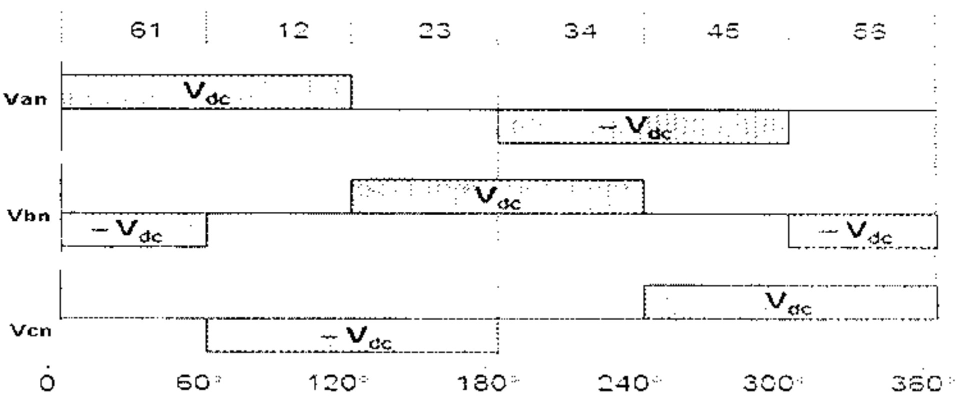


Fig 4.10 Voltage waveform for 120° conduction

4.6 PULSE WIDTH MODULATION

Pulse Width Modulation, abbreviated as PWM, is a modulation technique that generates variable-width pulses to represent the amplitude of an analog input signal. It is a method of transmitting information on a series of pulses. The data that is being transmitted is encoded on the width of these pulses to control the amount of power being sent to a load. In other words, pulse width modulation is a modulation technique for generating variable width pulses to represent the amplitude of an input analog signal or wave. Using digital pulses, we can create some analog value other than just 'high' and 'low' signal levels. Many digital systems are powered by a 5-Volt power supply, so by filtering a signal that has a 50% duty cycle we get an average voltage of 2.5 Volts. Other duty cycles produce any voltage in the range of 0 to 100% of the 'high' voltage, depending upon the PWM resolution. The duty cycle is defined as the percentage of digital 'high' to digital 'low' signals present during a PWM period. The PWM resolution is defined as the maximum number of pulses that can pack into a PWM period. The PWM period is an arbitrarily time period in which PWM takes place. It is chosen to give best results for our particular use. The figure 4.11 shows the PWM pulse generated by comparing the saw tooth carrier and a reference signal.

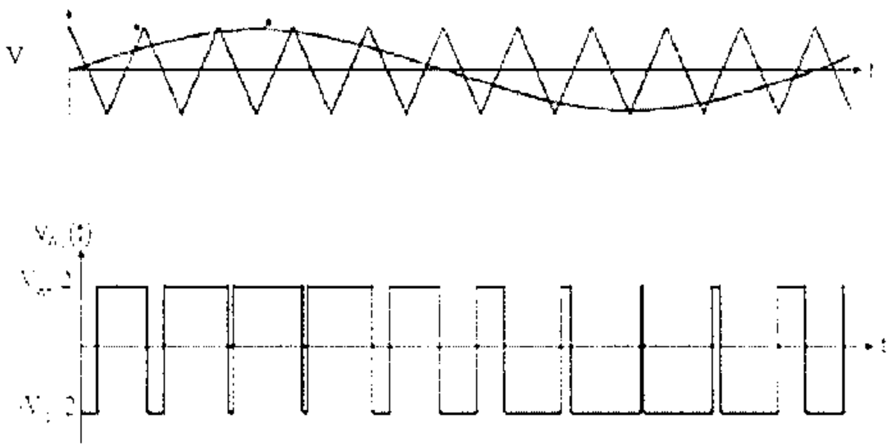


Fig 4.11 Pulse Width Modulation

CHAPTER –5

PERMANENT MAGNET SYNCHRONOUS GENERATOR

5.1 INTRODUCTION

At the present time and for the near future, generators for wind turbines will be synchronous generators, permanent magnet synchronous generators, and induction generators, including the squirrel – cage type and wound rotor type. For small to medium power wind turbines, permanent magnet generators and squirrel – cage induction generators are often used because of their reliability and cost advantages. Permanent magnet synchronous generators provide an optimal solution for variable-speed wind turbines, using either a gearless or single-stage gear configuration. This eliminates the need for separate base frames, gearboxes, couplings, shaft lines, and pre-assembly of the nacelle. The output of a permanent magnet synchronous generator can be fed to the power grid via power converters. This provides a high overall level of efficiency, while keeping the mechanical structure of the turbine simple.

PM machines fall into a generalized classification known as "doubly excited" machines, which have two sources of excitation – usually known as armature and the field (or excitation). In conventional synchronous and DC commutator, machines both of these excitation sources are electrical windings connected to an external source of electrical energy. In PM machines, the excitation or field winding is replaced by a permanent magnet and, of course, no external source of electrical energy is required. In other respects, a PM machine may be directly comparable to conventional synchronous or DC commutator machines and armature windings and magnetic circuit may be identical in PM machines to those in conventional machines. There is no comparison or analogy between PM machines and singly excited machines such as the induction motor alternatively, hysteresis machines. However, PM machines generally have the structural simplicity of singly excited machines and are, therefore, often compared with singly excited machines in terms of cost, ease of assembly, size and volume.

5.2 PRINCIPLE OF OPERATION

Alternate N and S poles are present in the permanent magnet rotor, when the rotor is rotated in anticlockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles. Consequently, emf is induced in the armature conductors due to electromagnetic induction. The induced emf is alternating since N and S poles of rotor alternately pass the armature conductors. The direction of induced emf can be found by Fleming's right hand rule and frequency of the developed emf.

$$f = \frac{NP_n}{120} \qquad \text{--------- (5.1)}$$

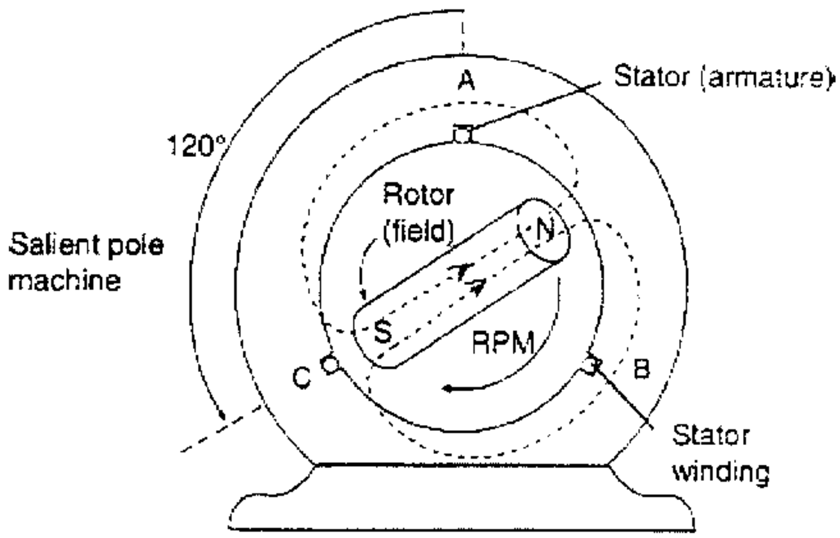


Fig 5.1 Cross section of salient pole synchronous generator

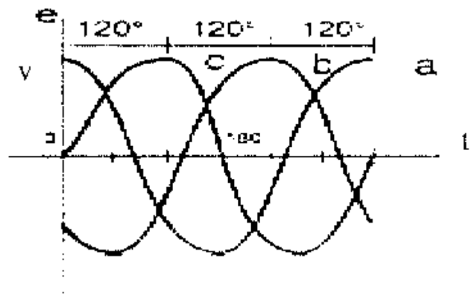


Fig. 5.2 Generated Voltage waveforms generated at the stator terminals

When the rotor is rotated, a three-phase voltage is induced in the armature winding. The magnitude of the induced emf depends upon the speed of rotation and the magnetic flux linkages of the permanent magnet. The magnitude of emf in each phase of the armature winding is the same. However, they differ in phase by 120° electrical as shown in waveforms in Figure 5.2.

The per phase equivalent circuit of permanent magnet synchronous generator can be given by the Figure 5.3.

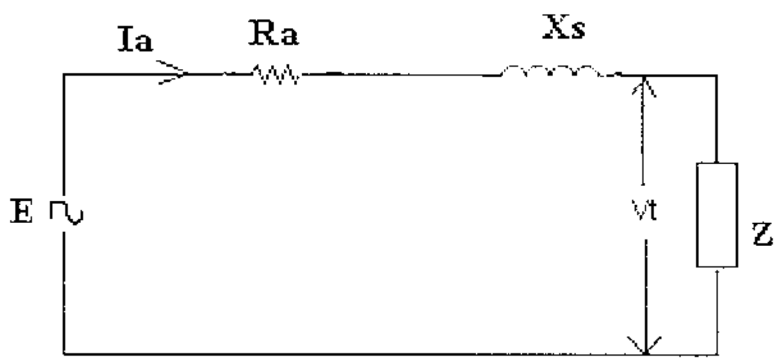


Fig 5.3 Equivalent circuit of PMSG

Generated emf / phase E= V_t+ Ia (Ra+jXs)

$$= V_t + IaZs \qquad \text{-------- (5.2)}$$

Where, Zs= $\sqrt{Ra^2 + Xs^2}$

5.3 MATHEMATICAL ANALYSIS

5.3.1 PERMANENT MAGNENT SYNCHRONOUS GENERATOR

The wind turbine driven PMSG can be represented in the rotor reference frame

$$V_q = -(R_S + Ld)I_q - \omega_r L_d I_d + \omega_r \lambda_m \qquad \text{-------- (5.3)}$$

$$V_d = -(R_S + Lq)I_d + \omega_r L_q I_d \qquad \text{-------- (5.4)}$$

The above equations (2.10) and (2.11) are derived assuming that the q-axis is aligned with the stator terminal voltage phasor (i.e., V_d=0). The expression for the electromagnetic (EM) torque in the rotor is represented as,

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P_n}{2}\right)\left[(L_d - L_q)I_q I_d - \lambda_m I_q\right] \qquad \text{--------- (5.5)}$$

The relationship between the angular frequency of the stator voltage (ω_r) and the mechanical angular velocity of the rotor (ω_m) may be expressed as

$$\omega_r = \frac{P_n}{2}\omega_m G \qquad \text{--------- (5.6)}$$

$$p\omega_r = \frac{P_n}{2J_g}(T_m - T_e) \qquad \text{--------- (5.7)}$$

$$p\theta = \omega_r \qquad \text{--------- (5.8)}$$

Similarly, torque developed by the turbine T_t and the input to the generator T_m is expressed as,

$$T_m = \frac{T_t}{G} \qquad \text{--------- (5.9)}$$

5.4 DIODE BRIDGE RECTIFIERS

A three-phase diode bridge rectifier converts the AC output voltage from the generator terminal, which is variable in magnitude and in frequency, in to DC.

The average output voltage of the three-phase diode rectifier is

$V_{dc} = (3 * V_m) / \ ?$ --------- (5.10)

The average load current of the three-phase diode rectifier

$I_{dc} = V_{dc} / R_L$ --------- (5.11)

The RMS value of load current of the three-phase diode rectifier is

$I_{rms} = V_{rms} / R_L$ --------- (5.12)

5.5 BOOST CHOPPER

The conversion of fixed DC voltage to an adjustable DC output voltage, using semiconductor devices, can be carried out by the use of DC – DC converters or chopper circuits. The output voltage for Chopper is,

Vo = Vs (T/ (T-Ton)) --------- (5.13)

Vo = (Vs / (1-k)) --------- (5.14)

Where,

K → Duty ratio of the chopper

Vo, Vs → output and input voltage of the boost chopper

5.6 PWM INVERTER

In this project, Gating signals for PWM Inverter switches are generated by Sinusoidal Pulse Width Modulation Technique (SPWM). In this SPWM, gating signals are generated by comparing a Sinusoidal reference signal with a triangular carrier wave of frequency f_C. The frequency of reference signal f_r determines the inverter output frequency f_O and its peak amplitude controls the modulation index and then in turn the rms output voltage V_O.

The switches in each leg are never both on or off simultaneously; therefore, the voltages Van, Vbn, and Vcn fluctuate between the input voltage (V_{in}) and zero. By controlling the switches in this manner, the line-line inverter output voltages are AC, with a fundamental frequency corresponding to the frequency of the sinusoidal control voltage (reference signal frequency). In most instances, the magnitude of the triangle wave is held fixed. The amplitude of the inverter output voltages is therefore controlled by adjusting the amplitude of the sinusoidal control voltages. The ratio of the amplitude of the sinusoidal waveforms relative to the amplitude of the triangle wave is the amplitude modulation ratio.

The rms output voltage can be varied by varying the modulation index M. It can be observed that the area of each pulse corresponds approximately to the area under the sine wave between the adjacent midpoints of off periods on the gating signals. If d_m is the width of m^{th} pulse and p is the number of pulse, then the rms output voltage can be found by,

$$V_{ac} = V_{in}\left(\sum_{m=1}^{2pul} \frac{\delta_m}{\pi}\right)^{\frac{1}{2}} \qquad \text{--------- (5.15)}$$

This type of modulation eliminates all harmonics less than or equal to 2p-1.

Where, V_{ac} → R MS Output Voltage

V_{in} → Input Voltage

d_m → width of m^{th} pulse

CHAPTER-6

PIC CONTROL UNIT

6.1 PIC CONTROLLER –PIC 16F87

It has a High-performance RISC CPU and has an operating speed of DC - 20 MHz clock input. It possesses 8K x 14 words of Flash Program Memory, 368 x 8 bytes of Data Memory (RAM), 256 x 8 bytes of EEPROM data memory. It has interrupt capability up to 14 internal/external.

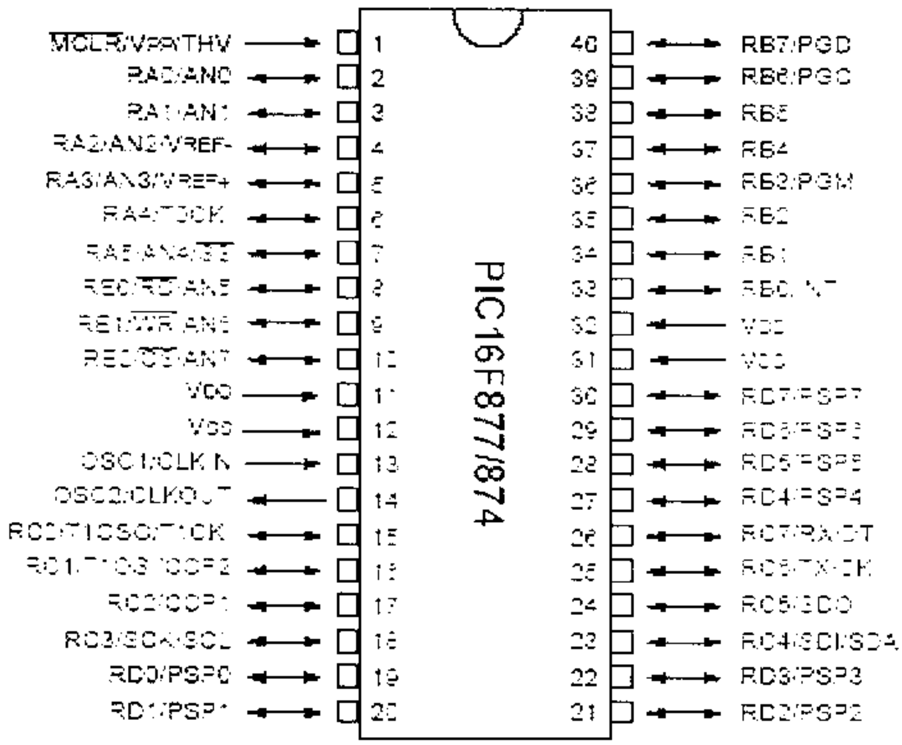


Fig. 6.1 Pin Diagram

6.2 CORE FEATURES

- Eight level deep hardware stack
- Direct, indirect, and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC Oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- In-Circuit Serial Programming (ICSP) via two pins
- Only single 5V source needed for programming capability
- In-Circuit Debugging via two pins
- Wide operating voltage range: 2.5V to 5.5V
- High Sink/Source Current: 25 Ma
- Low-power consumption:

    < 2 mA typical @ 5V, 4 MHz; 20mA typical @ 3V, 32 kHz

    < 1mA typical standby current

6.3 PERIPHERAL FEATURES

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler

• Two Capture, Compare, PWM modules: Capture is 16-bit, max resolution is 12.5 ns, Compare is 16-bit, max resolution is 200 ns, PWM max. Resolution is 10-bit

• 10-bit multi-channel Analog-to-Digital converter

• Synchronous Serial Port (SSP) with SPI. (Master Mode) and I2C. (Master/Slave)

• USART/SCI with 9-bit address detection.

• Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls.

Device	Program flash	Data memory	Data EPROM
PIC 16f877	8k	368 bytes	256 bytes

Table 6.1 Device Configuration

I/O ports:

Some pins for these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general-purpose I/O pin.

Memory Organization:

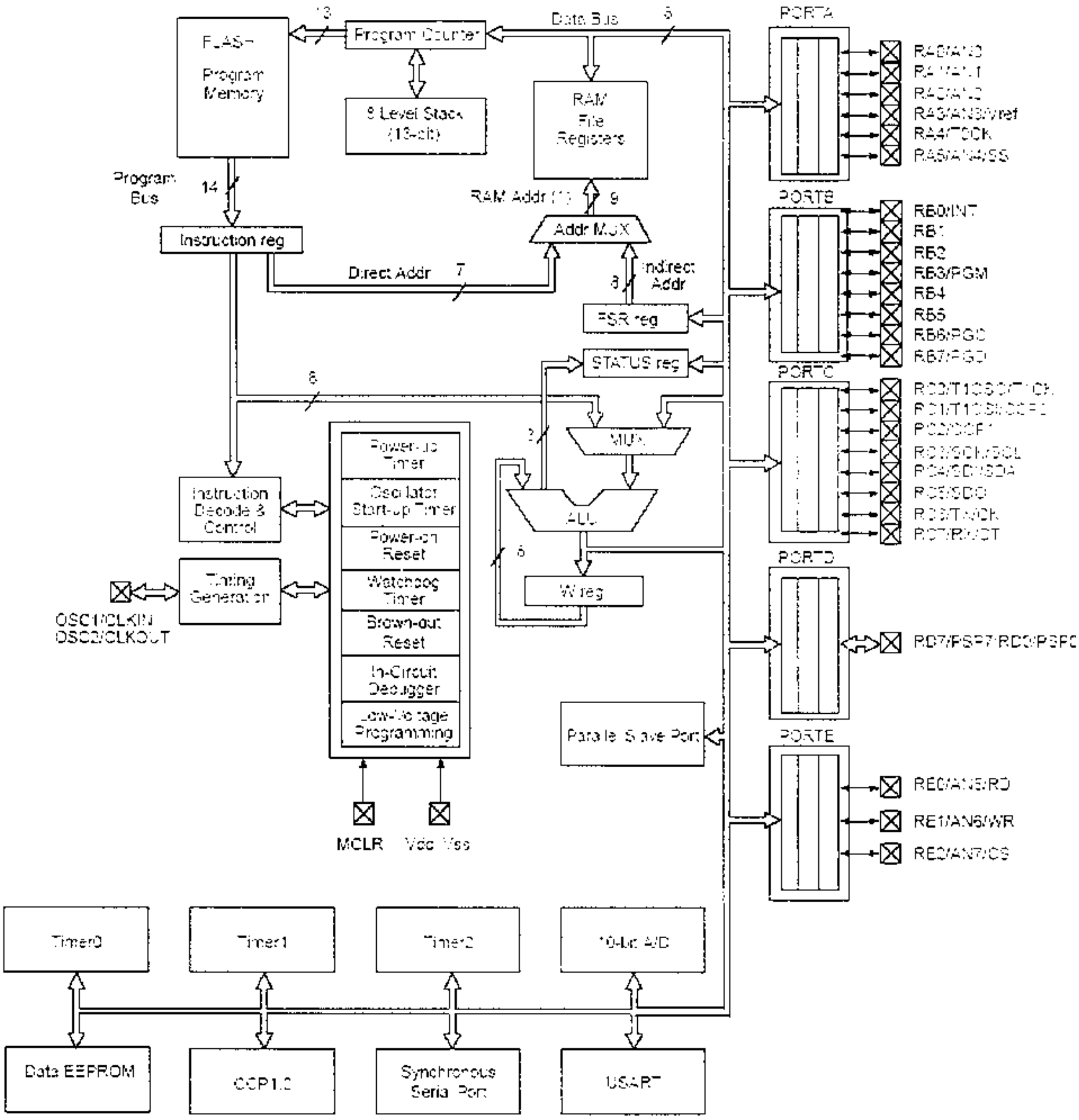
There are three memory blocks in each of the PIC16f877's. The program memory and Data Memory have separate buses so that concurrent access can occur.

Program Memory Organization:

The PIC16f877 devices have a 13-bit program counter capable of addressing 8K *14 words of FLASH program memory. Accessing a location above the physically implemented address will cause a wraparound.

6.4 ARCHITECTURE OF PIC 16F877

Device	Program Flash	Data Memory	Data EEPROM
PIC16F874	4K	192 Bytes	128 Bytes
PIC16F877	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

The Power-on Reset (POR) and Device Reset Timer (DRT) eliminate the need for external Reset circuitry. INTRC Internal Oscillator mode is provided, thereby preserving the limited number of I/O available. Power-Saving Sleep mode, Watchdog Timer and code protection features improve system cost, power and reliability. These devices are available in cost-effective Flash, which is suitable for production in any volume. The customer can take full advantage of Microchip's price leadership in Flash programmable microcontrollers, while benefiting from the Flash programmable flexibility. In addition, PIC's are supported by a full-featured macro assembler, a software simulator, an in-circuit debugger, a 'C' compiler, a low-cost development programmer and a full featured programmer. The Flash technology makes customizing application programs (transmitter codes, appliance settings, receiver frequencies, etc.) extremely fast and convenient. The small footprint packages, for through hole or surface mounting, make these microcontrollers well suited for applications with space limitations.

Data Memory Organization

The data memory is partitioned into multiple banks, which contain the General Purpose Registers and the special functions Registers. Bits RP1 (STATUS<6) and RP0 (STATYUS<5>) are the bank selected bits. Each bank extends up to 7Fh (1238 bytes). The lower locations of each bank are reserved for the Special Function Registers. Above the Special Function Registers are General Purpose Registers, implemented as static RAM. All implemented banks contain special function registers. Some frequently used special function registers from one bank may be mirrored in another bank for code reduction and quicker access.

6.5 PIC MICROCONTROLLER CODING

```
\\ PIC program:
include<lcd.h>
long i,i1,d0,d1,d2,d3,d4,d5,s,s1;
void main()
{     TRISB=0X00;
    TRISD=0X00;
    TRISA=0XFF;
    ADCON1=0X02;
    T2CON=0XF4;
    PR2=0x1f;
    GIE=1;
    PEIE=1;
    lcd_init();
    print_line("    PWM PULSES  ",0x80);
    print_line("                ",0xC0);
start:  s=take_adc(0);
    s1=s;
    if(s1>25 && s1<50)
    {       CCPR1L=250;         }
    if(s1>50 && s1<75)
    {       CCPR1L=240;         }
    if(s1>75 && s1<100)
    {       CCPR1L=230;         }
    if(s1>100 && s1<125)
    {       CCPR1L=220;         }
    if(s1>125 && s1<150)
    {       CCPR1L=210;         }
    if(s1>150 && s1<175)
    {       CCPR1L=200;         }
    if(s1>175 && s1<200)
    {       CCPR1L=190;         }
    if(s1>200 && s1<225)
    {       CCPR1L=180;         }
    if(s1>225 && s1<250)
    {       CCPR1L=170;         }
    if(s1>250 && s1<275)
    {       CCPR1L=160;         }
    if(s1>275 && s1<300)
    {       CCPR1L=150;         }
    if(s1>300 && s1<325)
    {       CCPR1L=140;         }
    if(s1>325 && s1<350)
    {       CCPR1L=130;         }
    if(s1>350 && s1<375)
    {       CCPR1L=120;         }
    if(s1>375 && s1<450)
    {       CCPR1L=110;         }
```

```
 if(s1>450 && s1<475)
    {       CCPR1L=100;             }
    if(s1>500 && s1<525)
    {       CCPR1L=90;              }
    if(s1>525 && s1<550)
    {       CCPR1L=80;              }
    if(s1>550 && s1<575)
    {       CCPR1L=70;              }
    if(s1>575 && s1<600)
    {       CCPR1L=60;              }
    if(s1>600 && s1<625)
    {       CCPR1L=50;              }
    if(s1>625 && s1<650)
    {      CCPR1L=45;               }
    if(s1>650 && s1<675)
    {       CCPR1L=40;              }
    if(s1>675 && s1<700)
    {       CCPR1L=35;              }
    if(s1>725 && s1<750)
    {       CCPR1L=30;              }
    if(s1>750 && s1<775)
    {       CCPR1L=25;              }
    if(s1>775 && s1<800)
    {       CCPR1L=20;              }
    if(s1>800 && s1<825)
    {       CCPR1L=15;              }
    if(s1>850 && s1<875)
    {       CCPR1L=10;              }
    if(s1>875 && s1<900)
    {       CCPR1L=5;               }
    i=s1;
    d2=i/100;
    i=i%100;
    d1=i/10;
    d0=i%10;
    lcd_command(0xc0);
    lcd_data(d2+0x30);
    lcd_data(d1+0x30);
    lcd_data(d0+0x30);
    i1=CCPR1L;
    d5=i1/100;
    i1=i1%100;
    d4=i1/10;
    d3=i1%10;
    lcd_command(0xcD);
    lcd_data(d5+0x30);
    lcd_data(d4+0x30);
    lcd_data(d3+0x30);
goto start;
    }
```

CHAPTER –7

SIMULATIONS

7.1 SIMULATION MODEL OF OVERALL BLOCK DIAGRAM

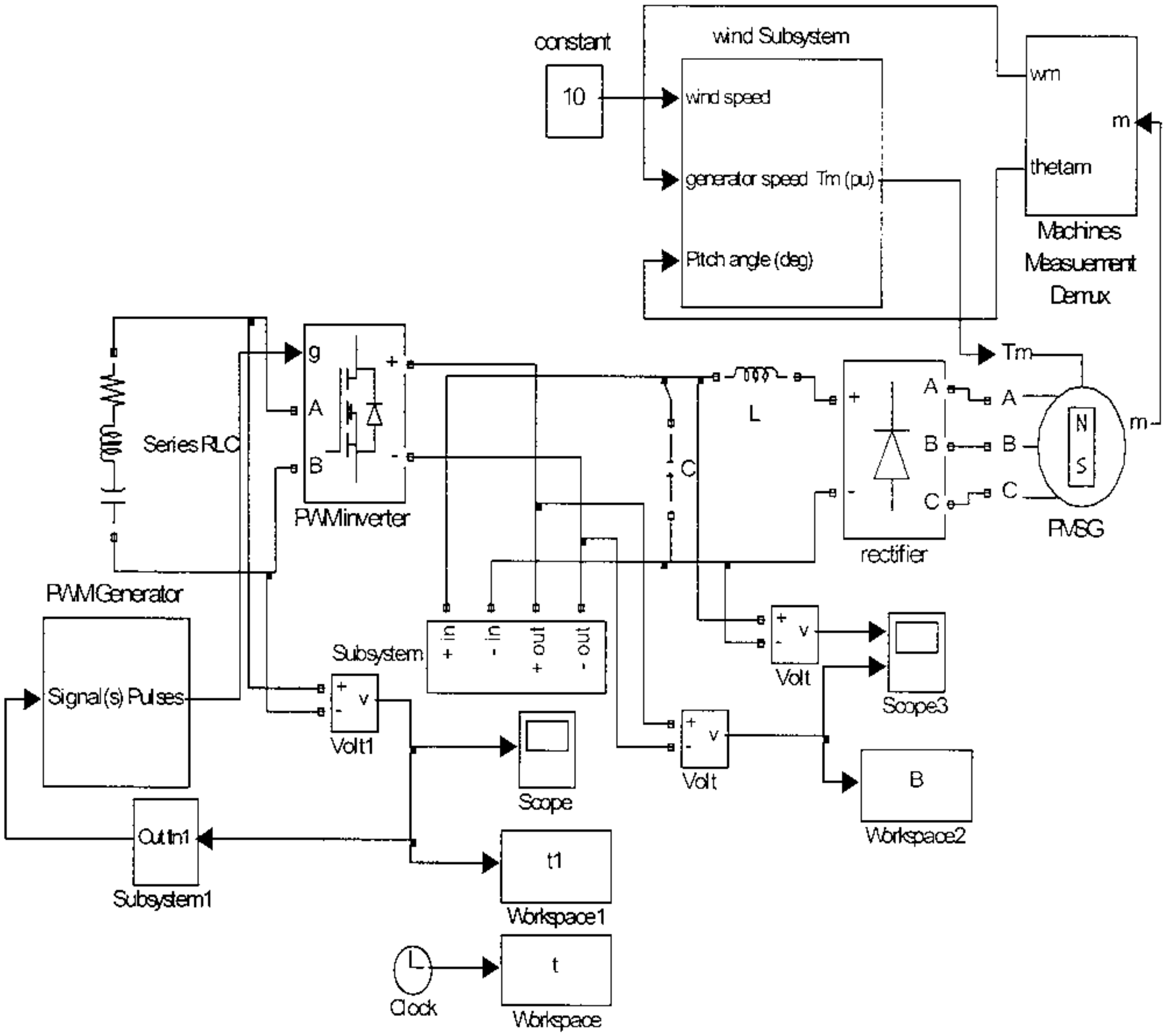


Fig. 7.1 Overall Simulation model of Wind Electric System.

This model is simulated for various wind velocities, analysis is done, and a constant voltage at the output has been obtained.

7.2 SIMULINK DIAGRAM FOR WIND TURBINE

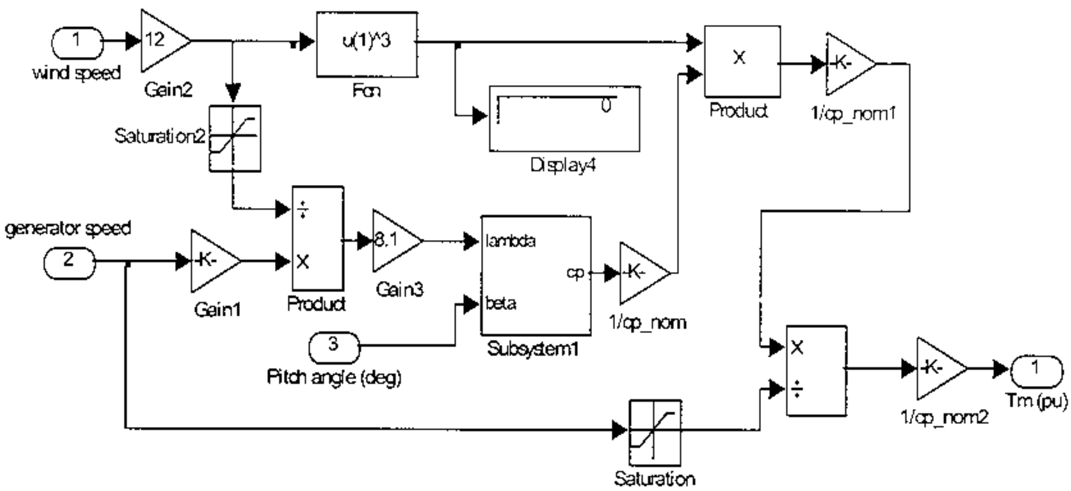


Fig. 7.2 Simulation Model Of The Wind Turbine.

The small wind turbine model has been simulated as used as a subsystem in the overall wind electric system. The input given to this sub system is the wind speed and possesses a feedback input of generator speed. The output of this system is the torque, which in turn is fed to the generator input.

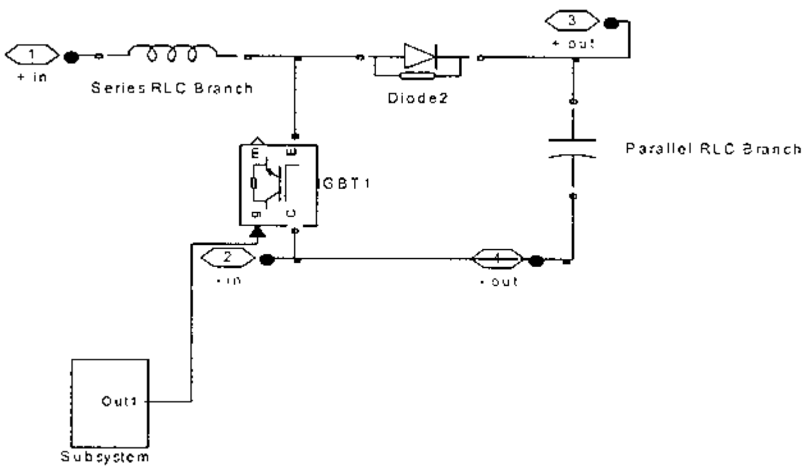


Fig. 7.3 Simulation Model Of The Booster chopper

7.3 SIMULATION RESULTS

The simulation results are shown in Figures 8.3 to 8.8 for the wind velocity of 6 m/s

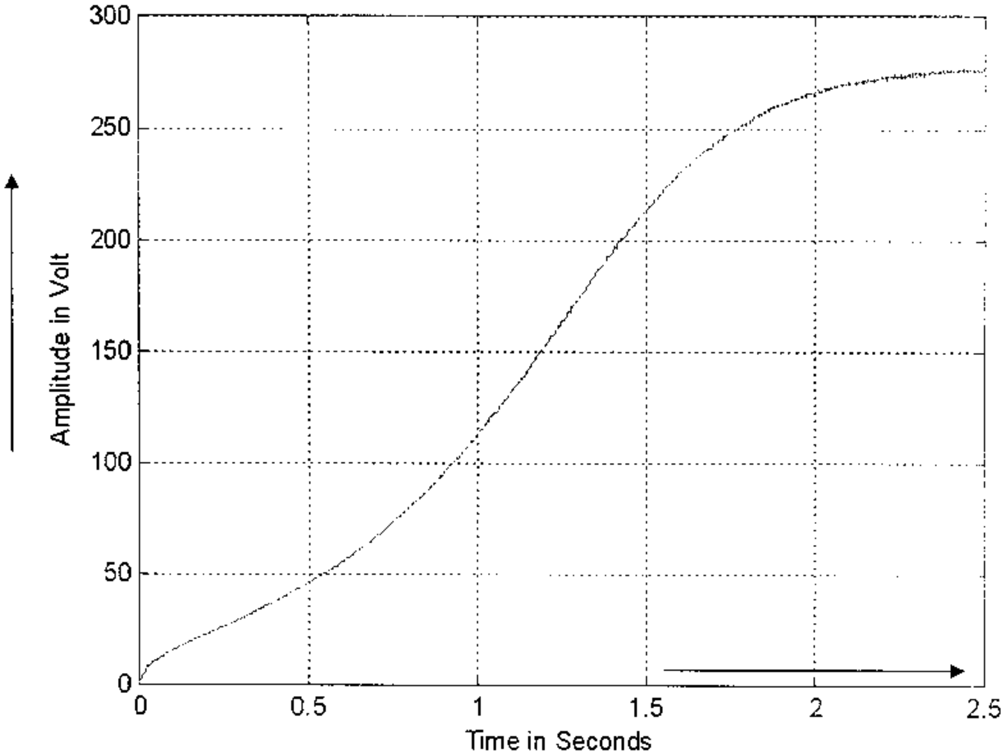


Fig. 7.4 Boost Chopper Output Voltage Curve

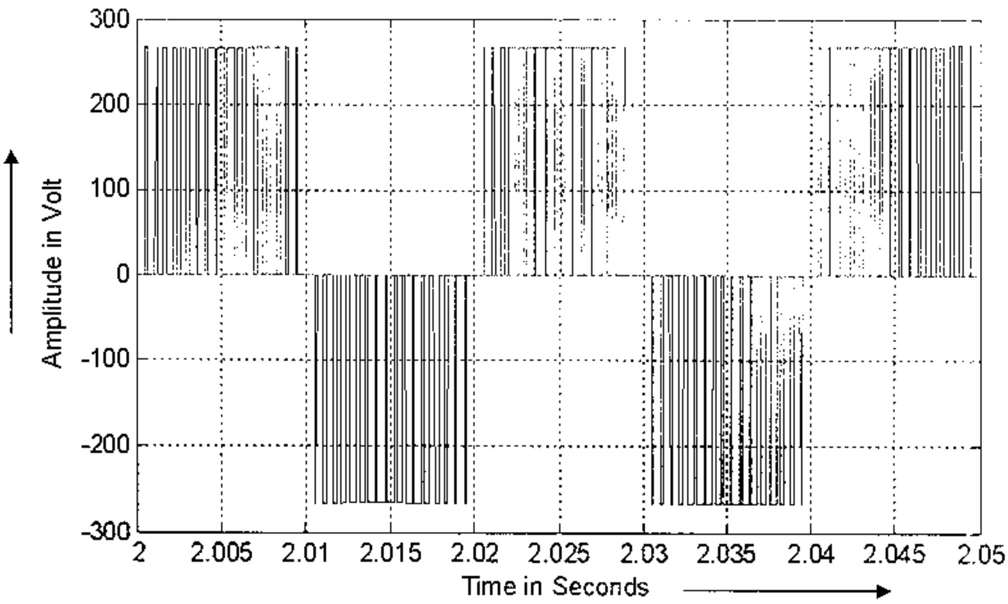


Fig. 7.5 PWM Inverter Output Voltage

7.4 POWER UTILISATION

There are two types of system:

- Battery based
- battery-less grid tie.

For a battery-based system, you will require:

A Turbine that captures and converts energy from the wind

Panels – Captures and converts energy from wind

Support Structure – Mounts the turbine in airflow (the higher the better)

Batteries - Stores the generated energy as low voltage DC.

Charge Control Unit – Prevents the batteries from becoming over or undercharged

Inverter – Converts the low voltage electricity to 230V 50Hz alternating current.

An inverter is not always required as low voltage lighting and appliances can be used. These will operate directly from the battery bank. This type of system has the advantage of independence from the grid. This is especially important in remote or rural areas where no mains electricity is available. Another advantage of this type of system is that you can still run your lights when there is a grid failure (power cut).

A battery-less grid tie system is much more efficient in terms of energy and costs less to install. However, the grid tie inverter must be connected to a mains supply and will only operate whilst the grid is online.

7.5 FUTURE ENHANCEMENTS

- Blade Twisting mechanism.
- Changing the direction of wind turbine according to the direction of flow of wind.
- Rotor breaking mechanism.
- Design of anti-vibration system to prevent vibrations from the turbine from being transmitted to the building.
- Design of quietest turbines to low TSR (Tip Speed Ratio) rotor blades.

CHAPTER 8

CONCLUSION

CONCLUSION

The control unit for the low power wind turbine is modeled using MATLAB/SIMULINK tool and analyzed for various wind speeds. The hardware is fabricated and tested for various wind velocities. As the wind velocity increases, due to this PMSG output voltage also increases. Then PMSG output voltage is converted into DC through Diode bridge rectifier and rectified output is given to the Step up chopper in order to boost up the voltage. Step up chopper produces constant DC voltage irrespective of wind velocities. The constant DC voltage from the Step up chopper is given to the input of Sinusoidal Pulse Width Modulated (SPWM) inverter to obtain an AC output voltage of constant amplitude with constant frequency. Then output from the PMSG is used to control the duty ratio of the chopper to obtain constant voltage. The simulated circuit was analyzed for various wind velocities [from to] and it produced a constant output of There by Constant output voltage with constant frequency is obtained from the proposed Wind Electric System MATLAB/SIMULINK model. Since a constant voltage is obtained as output, the system can be directly connected to the loads o could also be used in charging batteries.

APPENDICES

PIC 16F877 PORT FUNCTIONS:

Table 1: PORT A FUNCTIONS

Name	Bit#	Buffer	Function
RA0/AN0	bit0	TTL	Input/output or analog input
RA1/AN1	bit1	TTL	Input/output or analog input
RA2/AN2	bit2	TTL	Input/output or analog input
RA3/AN3/VREF	bit3	TTL	Input/output or analog input or VREF
RA4/T0CKI	bit4	ST	Input/output or external clock input for Timer0 Output is open drain type
RA5/$\overline{SS}$/AN4	bit5	TTL	Input/output or slave select input for synchronous serial port or analog input

Table 2: PORT B FUNCTIONS

Name	Bit#	Buffer	Function
RB0/INT	bit0	TTL/ST(1)	Input/output pin or external interrupt input. Internal software programmable weak pull-up.
RB1	bit1	TTL	Input/output pin. Internal software programmable weak pull-up.
RB2	bit2	TTL	Input/output pin. Internal software programmable weak pull-up.
RB3/PGM	bit3	TTL	Input/output pin or programming pin in LVP mode. Internal software programmable weak pull-up.
RB4	bit4	TTL	Input/output pin (with interrupt on change). Internal software programmable weak pull-up.
RB5	bit5	TTL	Input/output pin (with interrupt on change). Internal software programmable weak pull-up.
RB6/PGC	bit6	TTL/ST(2)	Input/output pin (with interrupt on change) or In-Circuit Debugger pin. Internal software programmable weak pull-up. Serial programming clock.
RB7/PGD	bit7	TTL/ST(2)	Input/output pin (with interrupt on change) or In-Circuit Debugger pin. Internal software programmable weak pull-up. Serial programming data.

Legend: TTL = TTL input, ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.

2: This buffer is a Schmitt Trigger input when used in serial programming mode.

Table 3: PORTC FUNCTIONS

Name	Bit#	Buffer Type	Function
RC0/T1OSO/T1CKI	bit0	ST	Input/output port pin or Timer1 oscillator output/Timer1 clock input
RC1/T1OSI/CCP2	bit1	ST	Input/output port pin or Timer1 oscillator input or Capture2 input/ Compare2 output/PWM2 output
RC2/CCP1	bit2	ST	Input/output port pin or Capture1 input/Compare1 output/PWM1 output
RC3/SCK/SCL	bit3	ST	RC3 can also be the synchronous serial clock for both SPI and I^2C modes.
RC4/SDI/SDA	bit4	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	bit5	ST	Input/output port pin or Synchronous Serial Port data output
RC6/TX/CK	bit6	ST	Input/output port pin or USART Asynchronous Transmit or Synchronous Clock
RC7/RX/DT	bit7	ST	Input/output port pin or USART Asynchronous Receive or Synchronous Data

Legend: ST = Schmitt Trigger input

Table 4: PORTD FUNCTIONS

Name	Bit#	Buffer Type	Function
RD0/PSP0	bit0	ST/TTL(1)	Input/output port pin or parallel slave port bit0
RD1/PSP1	bit1	ST/TTL(1)	Input/output port pin or parallel slave port bit1
RD2/PSP2	bit2	ST/TTL(1)	Input/output port pin or parallel slave port bit2
RD3/PSP3	bit3	ST/TTL(1)	Input/output port pin or parallel slave port bit3
RD4/PSP4	bit4	ST/TTL(1)	Input/output port pin or parallel slave port bit4
RD5/PSP5	bit5	ST/TTL(1)	Input/output port pin or parallel slave port bit5
RD6/PSP6	bit6	ST/TTL(1)	Input/output port pin or parallel slave port bit6
RD7/PSP7	bit7	ST/TTL(1)	Input/output port pin or parallel slave port bit7

Legend: ST = Schmitt Trigger input TTL = TTL input

Note 1: Input buffers are Schmitt Triggers when in I/O mode and TTL buffer when in Parallel Slave Port Mode.

Table 5: PORTE FUNCTIONS

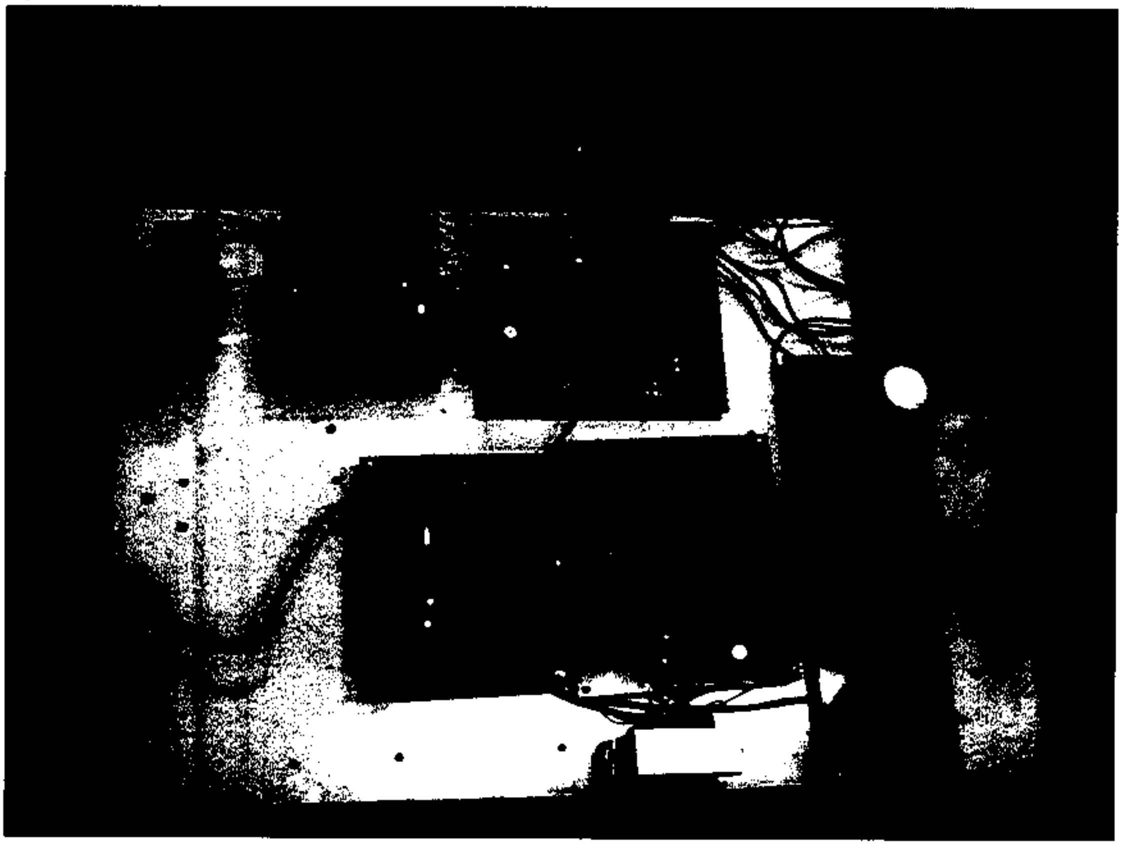
Name	Bit#	Buffer Type	Function
RE0/$\overline{RD}$/AN5	bit0	ST/TTL(1)	Input/output port pin or read control input in parallel slave port mode or analog input: $\overline{RD}$ 1 = Not a read operation 0 = Read operation. Reads PORTD register (if chip selected)
RE1/$\overline{WR}$/AN6	bit1	ST/TTL(1)	Input/output port pin or write control input in parallel slave port mode or analog input: $\overline{WR}$ 1 =Not a write operation 0 =Write operation. Writes PORTD register (if chip selected)
RE2/$\overline{CS}$/AN7	bit2	ST/TTL(1)	Input/output port pin or chip select control input in parallel slave port mode or analog input: $\overline{CS}$ 1 = Device is not selected 0 = Device is selected

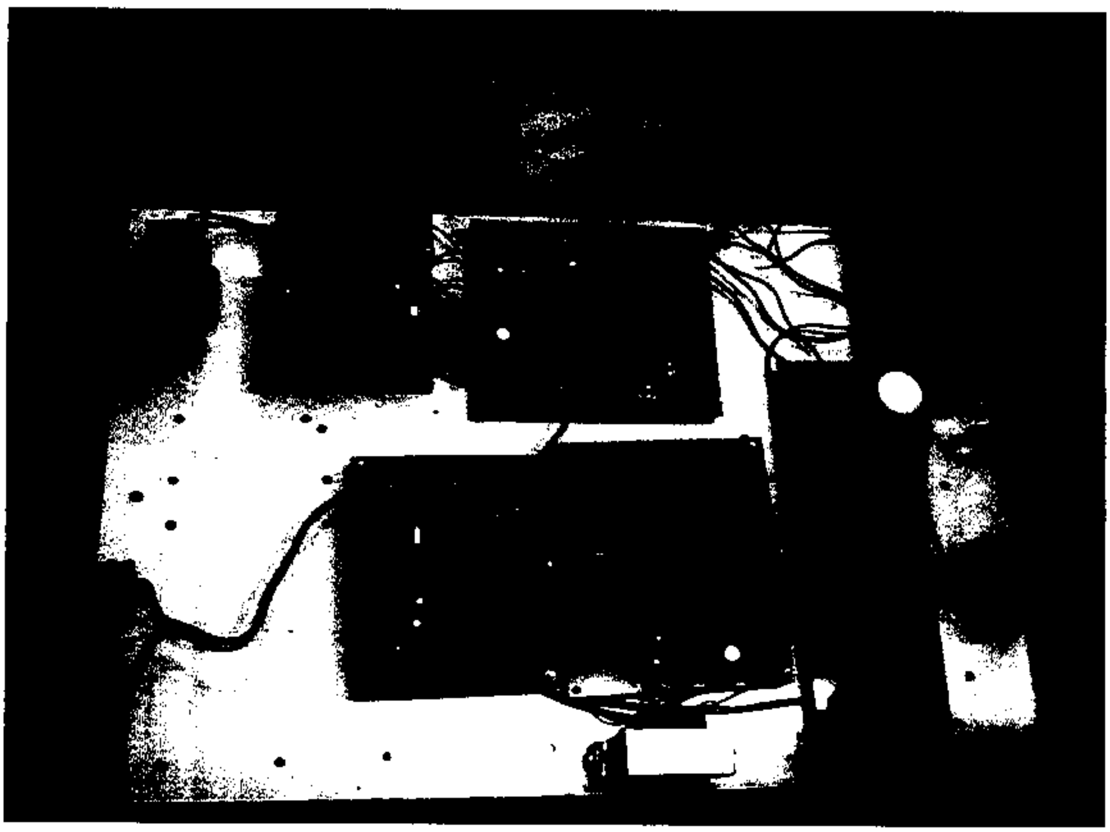
Legend: ST = Schmitt Trigger input TTL = TTL input

Note 1: Input buffers are Schmitt Triggers when in AD mode and TTL buffers when in Parallel Slave Port Mode.

Table 6: DATA MEMORY ORGANISATION

RP1:RP0	Banks
00	0
01	1
10	2
11	3





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