CHAPTER ONE

INTRDUCTION

1.1 General Concepts

The harnessing of natural phenomena such as sunlight, wind, water flow, ocean waves, etc. for some form of productive use has always been part of the human activity. The widespread and large-scale use of these resources, however, is a fairly recent development. The fossil fuels which still form the backbone of energy production in most industrialized countries draw on finite resources, which are already dwindling and thus becoming more expensive or their retrieval is becoming ever more environmentally damaging.

Wind power is the fastest growing renewable energy and is promising as the number one source of clean energy in the near future. Among various generators used to convert wind energy, the induction generator has attracted more attention due to its lower cost, lower requirement of maintenance, variable speed, higher energy capture efficiency, and improved power quality .Generally, there are two types of induction generators widely used in wind power systems – Squirrel-Cage Induction Generator (SCIG) and Doubly-Fed Induction Generator (DFIG). The straightforward power conversion technique using SCIG is widely accepted in fixed-speed applications with less emphasis on the high efficiency and control of power flow. However, such direct connection with grid would allow the speed to vary in a very narrow range and thus limit the wind turbine utilization and power output. Another major problem with SCIG wind system is the source of reactive power; that is, an external reactive power compensator is required to hold distribution line voltage and prevent whole system from overload.

1.2 Problem statement

The problem of this project is to verify if we can generation clean, low cost and continuous energy. The reasons for choosing induction generator in wind energy system are that its very reliable tends to be comparatively inexpensive, light weight, and low maintenance.

1.3 Objectives

The main objectives of project are:

- Study of renewable energy.
- Study wind energy.
- Study the induction generator.
- Discover how we can use induction generator in wind energy system.

1.4 Methodology

This project of study of induction generator which have been used in wind turbine. The steady state characteristics of wind energy system using induction generator are studied and also the dynamic state. This study done by collection information from references and scientific papers.

1.5 Thesis layout

The project consists five chapters: chapter one contain overview about the project, the problem statement, objectives and methodology. Chapter two gives literature review about renewable energy including the different types of it, Chapter three gives an overview about wind energy. Chapter four includes the using of induction generator in wind energy, and the way by how we can control it. Chapter five includes the conclusion and recommendation.

CHAPTER TWO

RENEWABLE ENERGY

2.1 Introduction

Renewable energy sources derive their energy from existing flows of energy from on-going natural processes, such as sunshine, wind, flowing water, biological processes, and geothermal heat flows.

A general definition of renewable energy sources is that renewable energy is captured from an energy resource that is replaced rapidly by a natural process such as power generated from the sun or from the wind [1].

Renewable Energy Resources is a numerate and quantitative text covering subjects of proven technical and economic importance worldwide. Energy supplies from renewable (such as solar, thermal, photovoltaic, wind, hydro, bio fuels, wave, idal, ocean and geothermal sources) are essential components of every nation's energy strategy, not least because of concerns for the environment and for sustainability. In the years between the first and this second edition, renewable energy has come of age: it makes good sense, good government and good business [2].

The world demand for electricity is growing rapidly. It surpasses demands for any other energy end-use. The IEA's World Energy Outlook foresees that with an annual average growth rate of 2.8%, electricity will almost double between (1997) and (2020). Primary world energy supply is expected to increase by 30% in (2010) relative to (1997), and by nearly 60% by (2020). Annual electricity demand grows unevenly in developed countries (projected to be 1.6%), and developing countries (projected growth rate 4.6%). It should be noted here that the developing world is in urgent need of energy, since more than 1.6 billion people until recently have lived without the benefit of modern energy services. With such increasing demands, the present growth pattern is strongly influenced by the domination of fossil fuels. In developing countries where electricity supplies are inadequate, renewable energy can offer an alternative to expensive extensions of the grid to sparsely populated or rural areas, or a contribution to the grid-based energy mix to meet rapidly expanding electricity demand in urban areas. Other associated benefits include economic and social development, healthier environment, income generation for local communities, capacity building, and development of local employment and expertise. Gradually renewable energy and its different energy conversion technologies have become economically viable, capable of competing with fossil-fuelled technologies in the energy market [3].

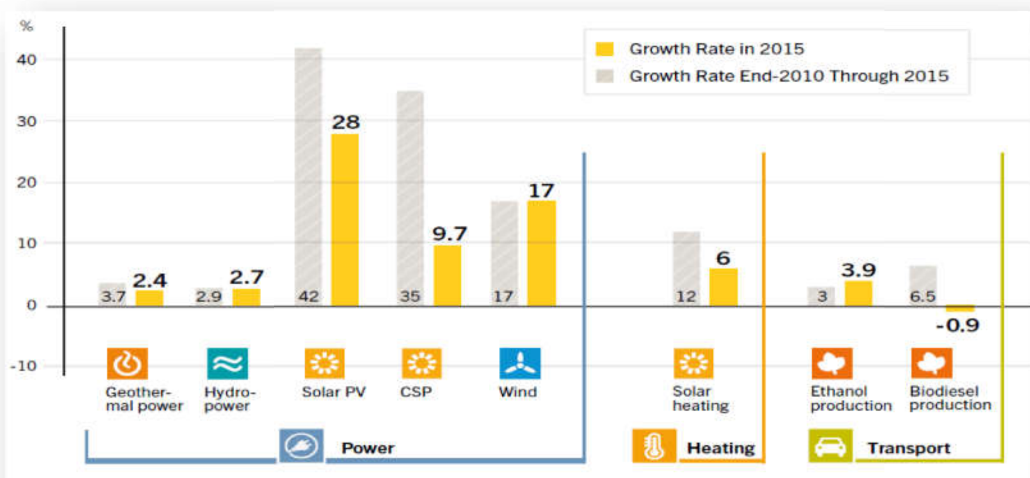

Figure 2.1: Average annual growth rates of renewable energy capacity and bio fuels production, end-2010 to end-2015 [5].

And the world now adds more renewable power capacity annually than it adds (net) capacity from all fossil fuels combined. In 2015, renewable accounted for an estimated more than 60% of net additions to global power generating capacity, and for far higher shares of capacity added in several countries around the world.

By year's end, renewable comprised an estimated 28.9% of the world's power generating capacity – enough to supply an estimated 23.7% of global electricity, with hydropower providing about 16.6% [5].

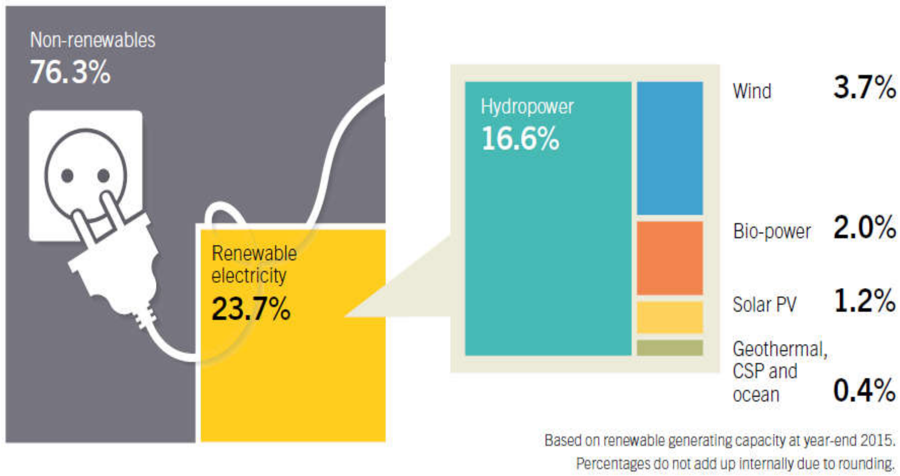

Figure2.2 Estimated renewable energy share of global electricity production, end–2015[5].

Our world has been powered primarily by carbon fuels for more than two centuries, with some demand met by nuclear power plants over the last five decades .The increasing environmental concerns in recent years about global warming and the harmful effects of carbon emissions have created a new demand for clean and sustainable energy sources [4].

Many energy scientists and economists believe that the renewable would get many more federal and state incentives if their social benefits were given full credit .For example, the value of not generating 1 t of CO_2, SO_2, and NO_X, and the value of not building long high-voltage transmission lines through rural and urban areas are not adequately reflected in the present evaluation of the renewable. If their renewable get due credit for pollution elimination of 600 t of CO_2 per million kWh of electricity consumed, they would get a further boost with greater incentives than those presently offered by the U.S. government.

The renewable energy has many other benefits such as: Create significant new employment opportunities in energy infrastructure, manufacturing, installation and etc, Contribute to the securing of long term, cost-effective environmentally, sustainable energy supplies and offer low operating costs[2].

The most promising (aka economically most feasible) alternative energy sources include:

- wind power.
- solar power.
- hydroelectric power.
- geothermal.
- ocean energies.
- biomass.
- ethanol.

2.2 Wind Power

The first use of wind power was to sail ships in the Nile some 5000 yr ago. Many civilizations used wind power for transportation and other purposes: The Europeans used it to grind grains and pump water in the 1700s and 1800s. The first windmill to generate electricity in the rural U.S. was installed in 1890. An experimental grid-connected turbine with as large a capacity as 2 MW was installed in 1979 on Howard Knob Mountain near Boone, NC, and a 3-MW turbine was installed in 1988 on Berger Hill in Orkney, Scotland [4].

Today, even larger wind turbines are routinely installed, commerce- ally competing with electric utilities in supplying economical, clean power in many parts of the world. The average turbine size of wind installations was 300 kW until the early 1990s. New machines being installed are in the 1- to 3-MW capacity range. Wind turbines of 8 MW capacity have been fully developed and are under operation in several countries, including the U.S.

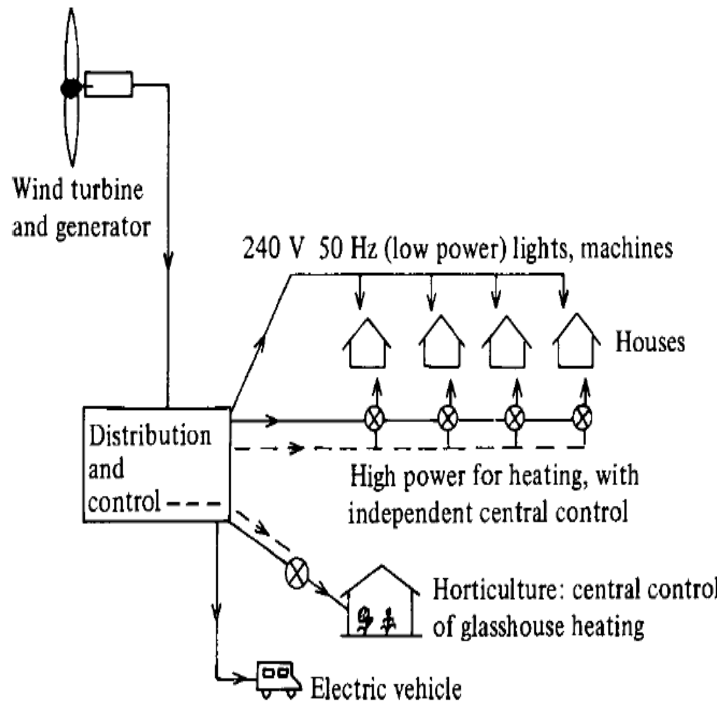

Figure2.3: Wind energy conversion system for Fair Isle, Scotland.
Electrical loads are switched by small changes in the supply frequency, so presenting a matched load to the generator over a wide range of wind speeds

2.3 Solar Power

The solar power system is the collect of the thermal energy in solar radiation, Solar radiation reaches the Earth's surface at a maximum flux density of about $1.0kWm^{-2}$ in a wavelength band between 0.3 and 2.5_m. This is called short wave radiation and includes the visible spectrum. For inhabited areas, this flux varies depending on place, time and weather, the temperatures of the Earth's atmosphere, at about 230 K, and the Earth's surfaces, at about 260–300 K, remain in equilibrium at much less than the 6000K temperature of the Sun [2].

Modern residential solar power systems use photovoltaic (PV) to collect the sun's energy. Photo "means" produced by light and voltaic "is" electricity produced by a chemical reaction PV cells use solar energy to generate a chemical reaction that produces electricity. Each cell contains a Semiconductor; most commonly silicon in one of several forms (single-crystalline, multi-crystalline, or thin-layer) [1].
These Cells are joined together by a circuit and frame into a module. Semiconductors allow the electrons freed from impurities by the sun's rays to move rapidly and into the circuit, generating electricity.
Commercial residential PV modules range in power output from 10 watts to 300 watts, in a direct current. A PV module must have an inverter to change the DC electricity into alternating current energy in order to be usable by electrical devices and compatible with the electric grid PV.

Figure2.4 Solar radiation by regions of the world (higher energy potential in the white areas)[4].

2.3 Hydroelectric Power

Hydropower the most reliable, efficient, and economical. Furthermore, the concept behind hydroelectric power is fairly simple and has been in use for a significant span of time.

The earliest reference to the use of the energy of falling water is found in the work of the Greek in the 4th century. Indeed, the word “hydro” comes from the Greek language meaning “water.” Several centuries later, the Romans were the first to utilize the waterwheel[1].

Water energy was first converted into electricity on Sept. 30, 1882 near Appleton, Wisconsin. By 1980 hydroelectric power accounted for about 25% of global electricity and 5% of total world energy use, which amounted to approximately 2,044 billion kilowatt hours (kW h) (1). Harvesting energy from water is possible due to the gravitational potential energy stored in water. As water flows from a high potential energy (high ground) to lower potential energy(lower ground), the potential energy difference thereby created can be partially converted into kinetic, and in this case electric, energy through the use of a generator.

There are essentially two major designs in use that utilize water to produce electricity: the hydroelectric dam, and the pumped-storage plant , but the waterwheel is currently no longer in use and has been replaced by the far more economical and efficient dam. Both the waterwheel and the dam work on the same general principle, but the dam has the advantage of being more reliable due to the reservoir behind it.

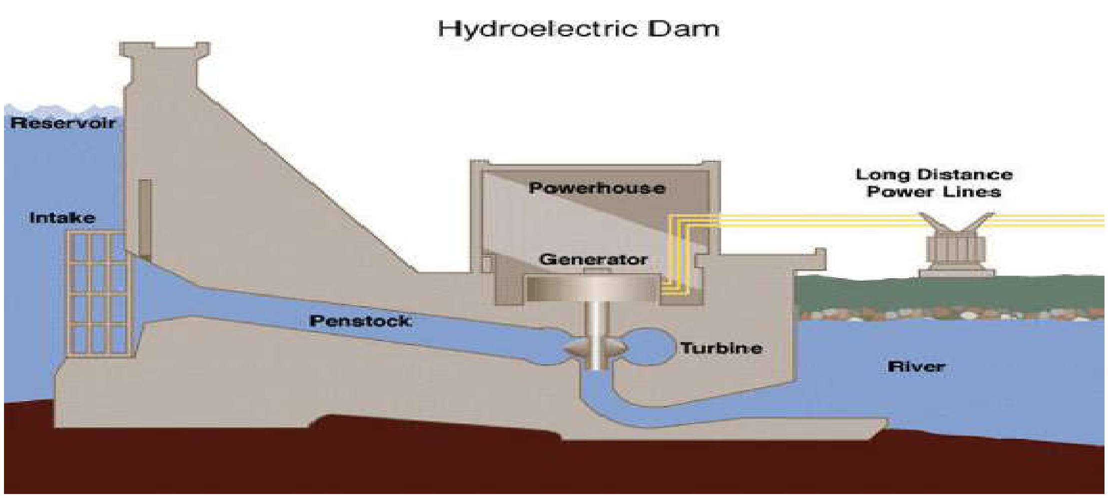

Figure 2.5: hydroelectric dam

There are two main applications of geothermal energy, which include producing The principle of the work of the hydroelectric dam is simple: the force of the water being released from the reservoir through the penstock of the dam spins to the blades of a turbine. The turbine is connected to the generator that produces electricity. After passing through the turbine, the water reenters the river on the downstream side of the dam [1].

Hydro installations and plants are long-lasting with routine maintenance, e.g. turbines for about fifty years, dams and waterways for perhaps hundred years. Long turbine life is due to the continuous, steady operation without high temperature or other stress. Consequently, established plant often produces electricity at low cost with consequent economic benefit.

Hydro turbines have a rapid response for power generation and so the power may be used to supply both base load and peak demand requirements on a grid supply. Power generation efficiencies may be as high as 90%[2].

The main disadvantages of hydro-power are associated with effects others, particularly for large systems. These include possible adverse environmental impact, effect on fish, silting of dams, corrosion of turbines in certain water conditions, social impact of displacement of people from the reservoir site, loss of potentially productive land (often balanced by the benefits of irrigation on other land) and relatively large capital costs compared with those of fossil power stations [2].

2.4 Geothermal

Geothermal energy is one of the only renewable energy sources not dependent on the Sun. Instead, it relies on heat produced under the surface of the Earth , while The inner core of the earth reaches a maximum temperature of about 4000 ℃.

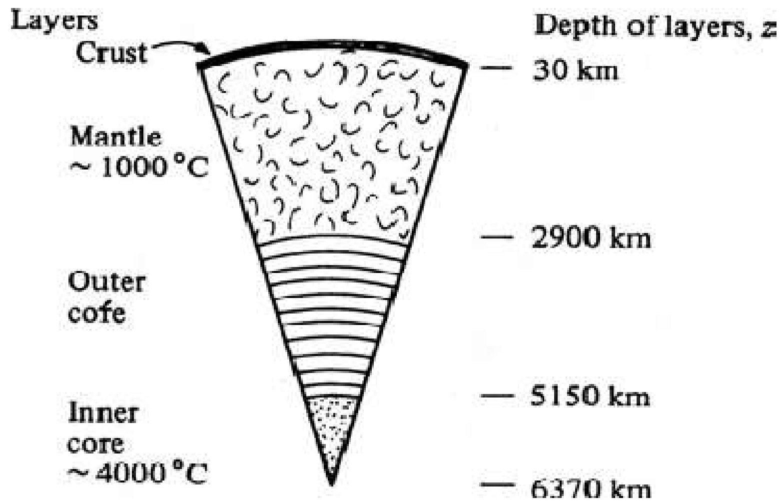

Figure2.6: Section through the Earth, showing average lower depths of named layers. The crust has significant variation in composition and thickness over a local scale of several kilo meters

Electricity at specialized power plants, and direct-heating, which puts to direct use the temperature of water piped under the earth's surface.

geothermal energy reduces the United States dependence on foreign oil, it's extremely reliable due to the constant source of heat emanating from the earth, and it has almost no negative environmental impact. In 2004, the US produced approximately.

2300 MW of electricity, and the Department of Energy estimates that the figure could reach 15000 MW per year within a decade. however, geothermal energy accounted for only about 0.34% of total U.S. energy consumption, and 0.4% of renewable energy consumption.

Geothermal power plants take on several types of forms, depend on the type of geothermal area from which they extract energy. In any case, the plants depend on steam to power turbines and generate electricity.

The process involves drilling deep into the surface of the Earth where temperatures are hot, and then injecting water into cracks of rock, which is heated and then pumped back to the surface. and this called "hot dry rock technology"

(HDR), and it proves effective, then more geothermal plants could operate in more locations, since much of the Earth's surface is underlain by hot, dry rock.

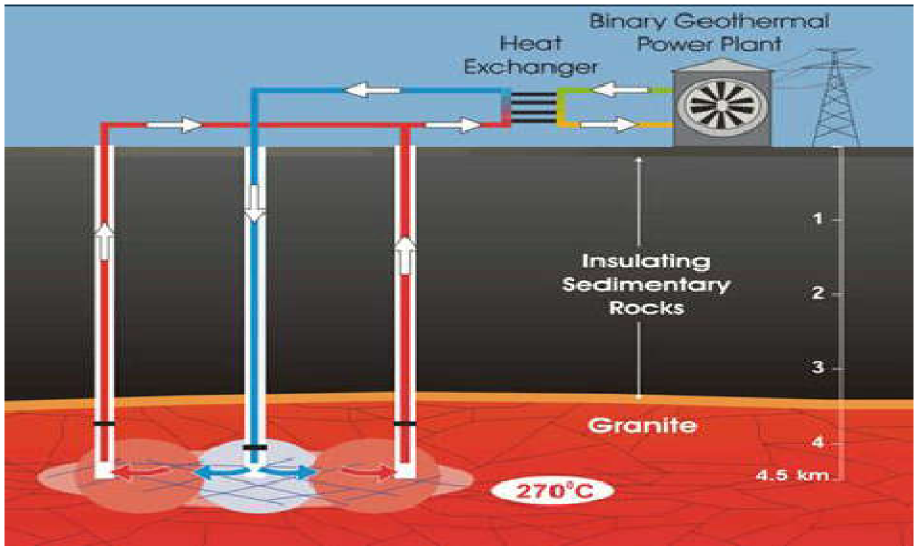

Figure 2.7: Geothermal station

Some problems that geothermal energy faces are depletion of both water and heat in geothermal areas. The first problem has been partially addressed by re-injecting water into reservoirs, thus sustaining the plant's ability to operate.

Heat depletion of geothermal areas is more problematic than water depletion in the long run, since it cannot be avoided. It is caused by a natural cooling-off of the earth's crust, and in these cases, plants would become less and less efficient over several decades until they were rendered useless the next problem is the high cost of Geothermal plants, Geothermal plants can be expensive, depending on factors such as how deep the wells must be drilled.

Another problem that adds cost to geothermal plants is the problem of connecting to energy grids. This is a critical issue because geothermal plants are built where geothermal resources Permit and it can be far away from any to energy grid [2].

2.5 Ocean Energies

Nearly seventy percent of the Earth's surface is covered by oceans, which have the potential to supply humans with an enormous amount of renewable energy. Humans have exploited the vast energy potential of Earth's oceans by taking advantage of wave movement ,tides, ocean currents, and ocean thermal energy.

2.5.1 Ocean thermal energy

The ocean is the world's largest solar collector. In tropical seas, temperature differences of about 20−25_C may occur between the warm, solar-absorbing near-surface water and the cooler 500–1000m depth 'deep' water at and below the thermo cline. Subject to the laws and practicalities of thermodynamics, heat engines can operate from this temperature difference across this huge heat store [2].

The term ocean thermal energy conversion (OTEC) refers to the conversion of some of this thermal energy into useful work for electricity generation. Given sufficient scale of efficient equipment, electricity power generation could be sustained day and night at 200kW from access to about 1km2 of tropical sea, equivalent to 0.07% of the solar input.

The disadvantages of this power is the major problems with sitting power plants and various economic obstacles [1].

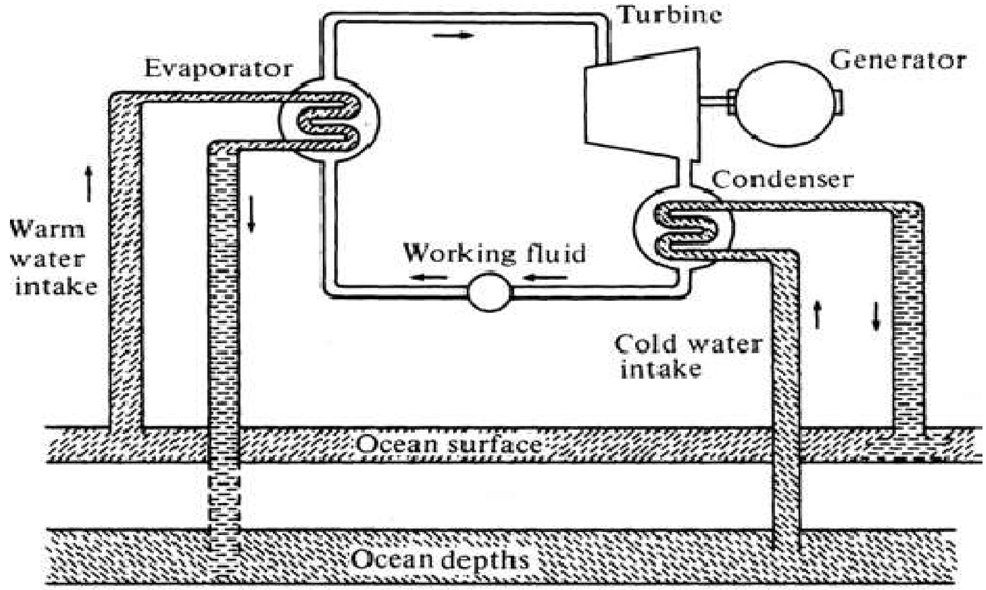

Figure 2.8: Schematic diagram of an OTEC system. A heat engine operates between the warm water from the ocean surface and the cold water from the ocean depths [2]

2.5.2 Waves power

Very large energy fluxes can occur in deep water sea waves. The power in the wave is proportional to the square of the amplitude and to the period of the motion. Therefore the long period (~10 s), large amplitude (~2m) waves have considerable interest for power generation, with energy fluxes commonly averaging between 50 and 70kWm−1 width of oncoming wave [2].

The possibility of generating electrical power from these deep water waves has been recognized for many years, and there are countless ideas for machines to extract the power. For example, a wave power system was used in California in 1909 for harbor lighting [2].

As with all renewable energy supplies, the scale of operation has to be determined, and present trends support moderate power generation at about 100 kW–1MW from modular devices each capturing energy from about 5 to 25m of wave front.

The distinctive advantages of wave power are the large energy fluxes available and the predictability of wave conditions over periods of days. Waves are created by wind, and effectively store the energy for transmission over great distances [2].

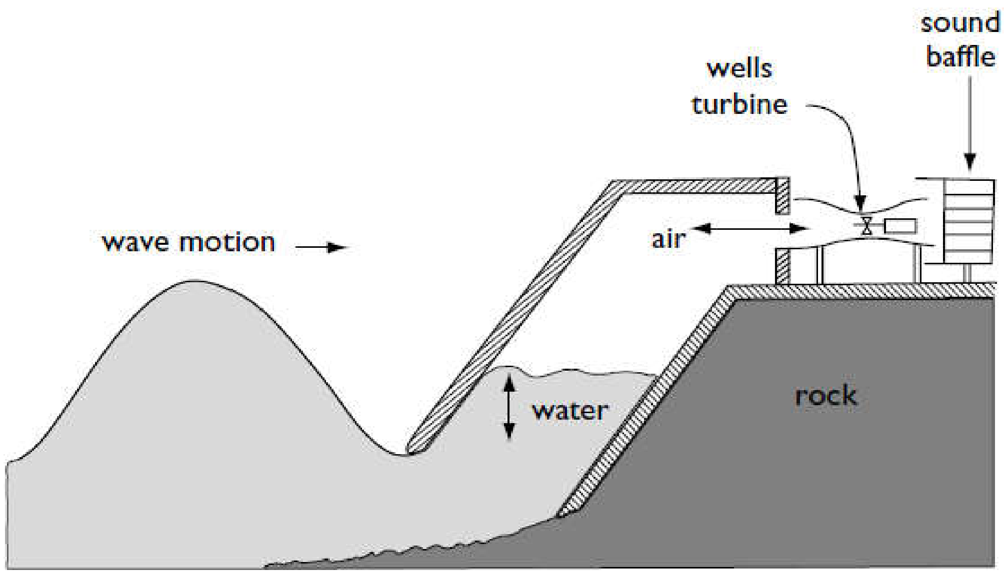

figure 2.9: Schematic diagram of a wave power system operate on the island of Islay, west of Scotland, for grid connected electricity generation [2]

2.5.3 Tidal power

The level of water in the large oceans of the Earth rises and falls according to predictable patterns. The main periods τ of these tides are diurnal at about 24 h and semidiurnal at about 12 h 25 min. The change in height between successive high and low tides is the range, R. This varies between about 0.5m in general and about 10m at particular sites near continental land masses. The movement of the water produces tidal currents, which may reach speeds of (□5ms−1) in coastal and inter-island channels. The seawater can be trapped at high tide in an estuarine basin of area A behind a dam or barrier to produce tidal range power. If the water of density ρ runs out through turbines at low tide, that the average power produced is:

$$P = \rho A R^2 g/(2\tau) \tag{2.1}$$

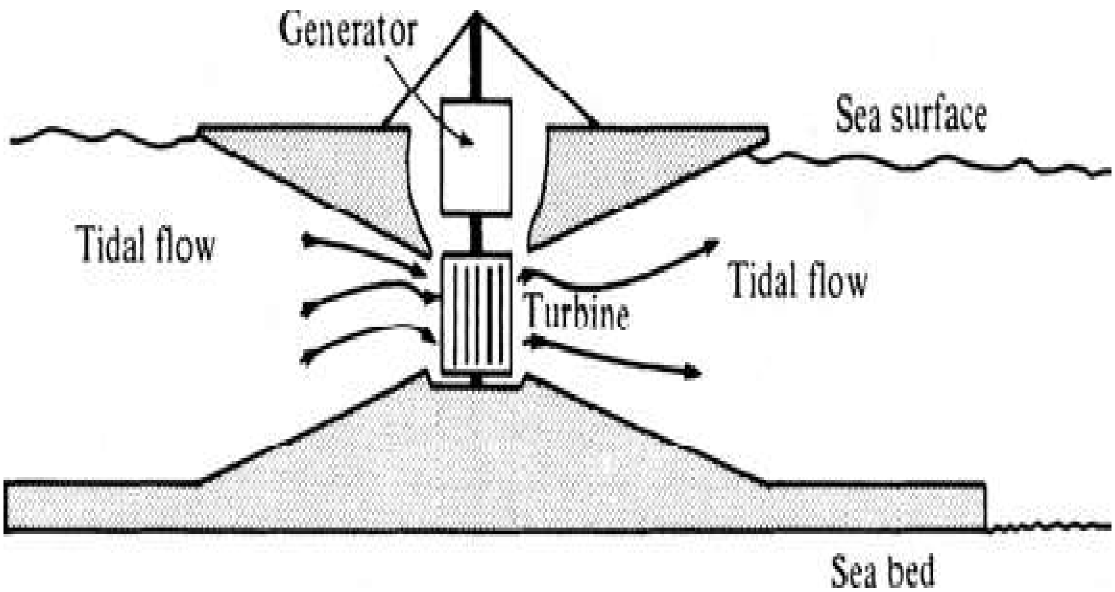

Figure 2.10: Tidal current power device [2]

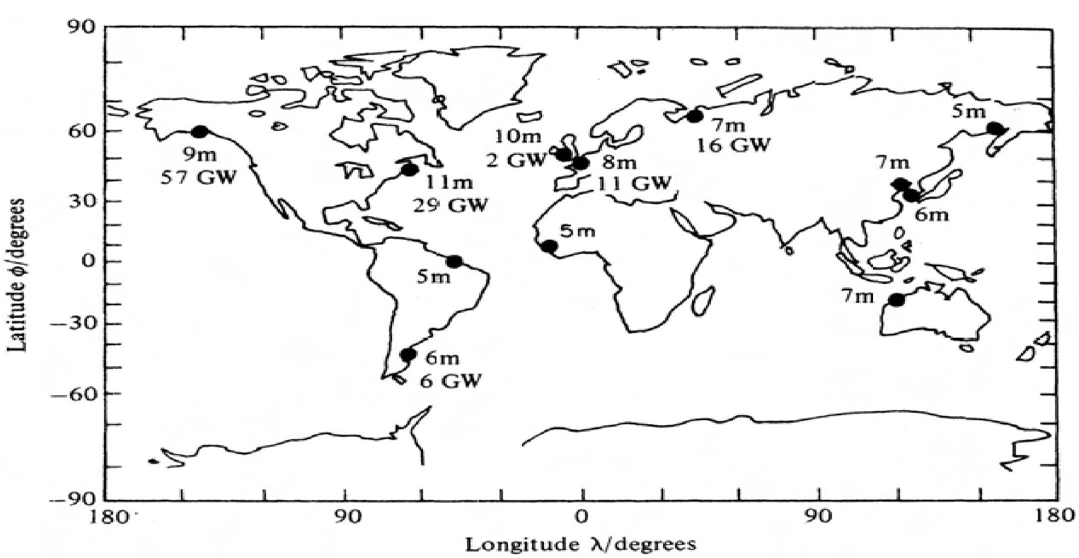

Figure 2.11: Location of major world tidal power sites, showing the average tidal power range and power potential

The range, flow and periodic behavior of tides at most coastal regions are well documented and analyzed because of the demands of navigation and oceanography. The behavior may be predicted accurately, within an uncertainty of less than ±4%, and so tidal power presents a very reliable and assured form of renewable power. The major drawbacks are:

- The requirement for large water volume flow at low head, necessitating many specially constructed turbines set in parallel.
- The very large capital costs of most potential installations.
- The location of sites with large range may be distant from the demand for power [2].

2.6 Biomass

Biomass can be converted into fuels through a number of different processes, including solid fuel combustion, digestion, pyrolysis , and fermentation and catalyzed reactions.

Electricity is generated in many places through solid fuel combustion. The majority of America's electricity is fueled by coal combustion. However, many states, especially California, are encouraging companies to use biomass fuels to generate electricity. These products are usually wood matter, vegetation, waste from lumber yards ,Power plants burn such fuels to heat a boiler, and the resulting steam powers turbines & generators. This process still releases a lot of carbon dioxide and other polluting gases into the environment, but helps eliminate waste efficiently.

Digestion is another process that makes use of existing waste. The term is a misnomer. Digestion is the naturally occurring process of bacteria feeding on decaying matter and making it decompose.

A third process, paralysis, creates a product much like charcoal, with double the energy density of the original biomass, making the fuel highly transportable and more efficient. Anhydrous pyrolysis heats the biomass at intense temperatures in the absence of oxygen or water. Scientists assume that this is the process that originally produced fossil fuels (under different conditions). Most industrial processes of pyrolysis convert the biomass under pressure and at temperatures above 800° F (430° C). A liquid fuel can also be produced using this process.
Using biomass could be the answer to the energy questions made more imminent by the recent crises that have further threatened on our oil supply [1].

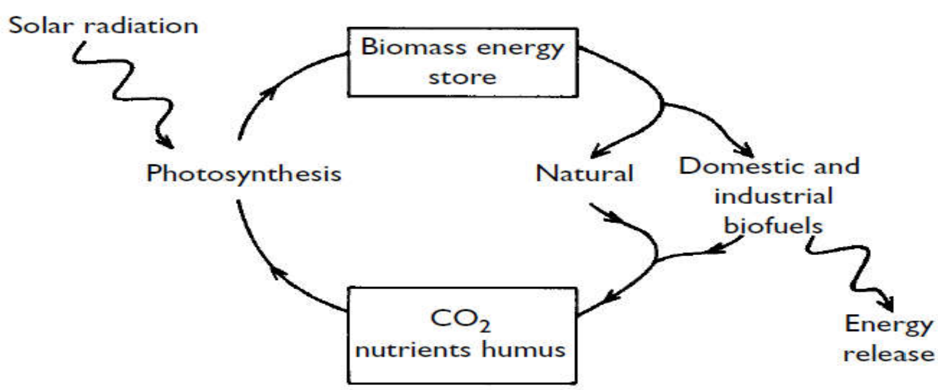

Figure 2.12: Natural and managed biomass systems

2.7 Ethanol

Ethanol is beneficial for car-owners, the economy and the environment. This growing technology is looking to be an immediate part of the solution to the forthcoming energy crisis. Ethanol, also known as ethyl alcohol or grain alcohol, is a colorless, clear liquid .The chemical formula is CH_3CH_2OH. Fuel-quality ethanol goes through more processes than do alcoholic beverages.
Ethanol is not used by itself to fuel cars. Instead, it’s mixed with gasoline. The two most common blends are E10 and E85. The number refers to the percentage of ethanol in the blend. E10 is a blend of ten percent ethanol and ninety percent

gasoline. E85, the most mainstream alternative fuel, is eighty-five percent ethanol and fifteen percent gasoline. Using ethanol increases the octane rating and decreases the amount of damaging emissions associated with fuel consumption. It is for this second reason that ethanol use is so strongly recommended and endorsed by state and federal governments.

Increase in use of ethanol as fuel will benefit farmers economically. The majority of ethanol used today comes from corn, and it is the farmer-owned ethanol plants that are driving the industry's growth. Half of the operating plants are owned by farmers and local investors.

Table 2.1: gives outline data of ethanol production

Crop	Liters of ethanol per ton of crop
Sugarcane	70
Cassava	180
Sweet sorghum	86
Sweet potato	125
Corn	370
Wood	160

2.8 Conclusion

The technologies used for conversion of renewable energy sources to heat, electricity and/or fuels are plentiful. Their development has contributed to the gradual lowering of technology prices on the one hand, and to improvement in their efficiency. renewable should provide continuous with unlimited supply of energy. However, technical difficulties, the intermittent nature of some of the renewable energy resources, as well as other constraints still pose limits to their wider deployment.

CHAPTER THREE

WIND ENERGY

3.1 Introduction

Wind energy is a converted form of solar energy which is produced by the nuclear fusion of hydrogen (H) into helium (He) in its core. The H → He fusion process creates heat and electromagnetic radiation streams out from the sun into space in all directions. Though only a small portion of solar radiation is intercepted by the earth, it provides almost all of earth's energy needs.

Wind energy represents a mainstream energy source of new power generation and an important player in the world's energy market. Compared with traditional energy sources, wind energy has a number of benefits and advantages. Unlike fossil fuels that emit harmful gases and nuclear power that generates radioactive wastes, wind power is a clean and environmentally friendly energy source. As an inexhaustible and free energy source, it is available and plentiful in most regions of the earth. In addition, more extensive use of wind power would help reduce the demands for fossil fuels, which may run out sometime in this century, according to their present consumptions. Furthermore, the cost per kWh of wind power is much lower than that of solar power .Thus, as the most promising energy source, wind energy is believed to play a critical role in global power supply in the 21st century.

Wind power is the conversion of wind energy into a suitable form of energy, such as using wind turbines to generate electricity, windmills for mechanical power, wind pumps for water pumping, or sails to propel ships. The total amount of economically extractable power available from the wind is considerably more than present human power use from all sources. Wind power, as an alternative to fossil fuels, is abundant, renewable, widely spread, clean, and produces no greenhouse gas emissions during operation. Wind power is the world ‘s rapid growing source of energy [6].

And we can define Wind energy as a form of solar energy produced by heating of the earth’s surface. As a power source, wind power is less predictable than solar power, but it is also typically available for more hours in a given day. Wind resources are influence by the type of the land surface and the elevation of the land surface. Generally, if the land is in high elevation then it is good for wind energy conversion and visa versa. Since the wind speed is extremely important for the amount of energy a wind turbine can convert it to electricity. The power in the wind can be defined as follows,

$$P_W = 0.5\rho A V^3 \qquad (3.1)$$

Where :

ρ: Air density, kg/m^3

A: Cross sectional area of wind parse, m^2.

V: The wind speed, m/sec.

From (1.1), it is clear that the wind power is affected by the wind speed. The wind speed increases with the height most rapidly near the ground, increasing less rapidly with greater height [10].

The wind speed at which electric power production starts called the cut-in wind speed. The turbine will develop enough mechanical power to rotate itself at slightly lower speeds, but this wind speed will actually supply all the generator and transmission losses so that useful electric power cannot be produced. At rated wind speed the power input to the wind turbine will reach the limit for continuous operation (rated power). When the wind speed exceeds this level the excess, power in the wind must be discarded by varying the pitch angle of the blades to prevent the turbine overloading. The power is maintained at its rated value until a maximum wind speed is reached the cut-off wind speed (Cut-off) then the turbine will shut down. The actual WTG output power with the wind speed is shown in Fig. 1.2.

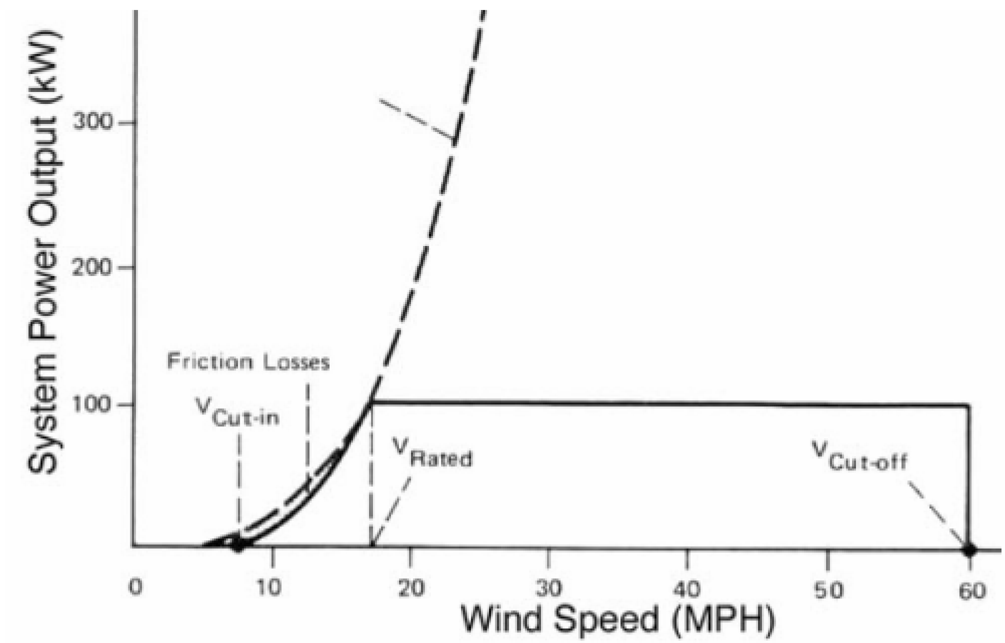

Figure 3.1: Actual WTG output power with the wind speed[10].

3.2 History of Wind Energy

The use of wind energy can be traced back thousands of years to many ancient civilizations. The ancient human histories have revealed that wind energy was discovered and used independently at several sites of the earth.

Since early recorded history, people have been harnessing the energy of the wind. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200 B.C., simple windmills in China were pumping water, while vertical-axis windmills with woven reed sails were grinding grain in Persia and the Middle East.

Early in the twentieth century, windmills were commonly used across the Great Plains to pump water and to generate electricity.

New ways of using the energy of the wind eventually spread around the world. By the 11th century, people in the Middle East were using windmills extensively for food production; returning merchants and crusaders carried this idea back to Europe. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches, and later, to generate electricity for homes and industry .Industrialization, first in Europe and later in America, led to a gradual decline in the use of windmills. The steam engine replaced European water-pumping windmills. In the 1930s, the Rural Electrification Administration's programs brought inexpensive electric power to most rural areas in the United States.

However, industrialization also sparked the development of larger windmills to generate electricity. Commonly called wind turbines, these machines appeared in Denmark as early as 1890. In the 1940s the largest wind turbine of the time began operating on a Vermont hilltop known as Grandpa's Knob. This turbine, rated at 1.25 megawatts in winds of about 30 mph, fed electric power to the local utility network for several months during World War II.

The popularity of using the energy in the wind has always fluctuated with the price of fossil fuels. When fuel prices fell after World War II, interest in wind turbines waned. But when the price of oil skyrocketed in the 1970s, so did worldwide interest in wind turbine generators.

The wind turbine technology R&D that followed the oil embargoes of the 1970s refined old ideas and introduced new ways of converting wind energy into useful power. Many of these approaches have been demonstrated in "wind farms" or wind power plants — groups of turbines that feed electricity into the utility grid — in the United States and Europe.

Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity very close in cost to the power from conventional utility generation in some locations. Wind energy is the world's fastest-growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come [8].

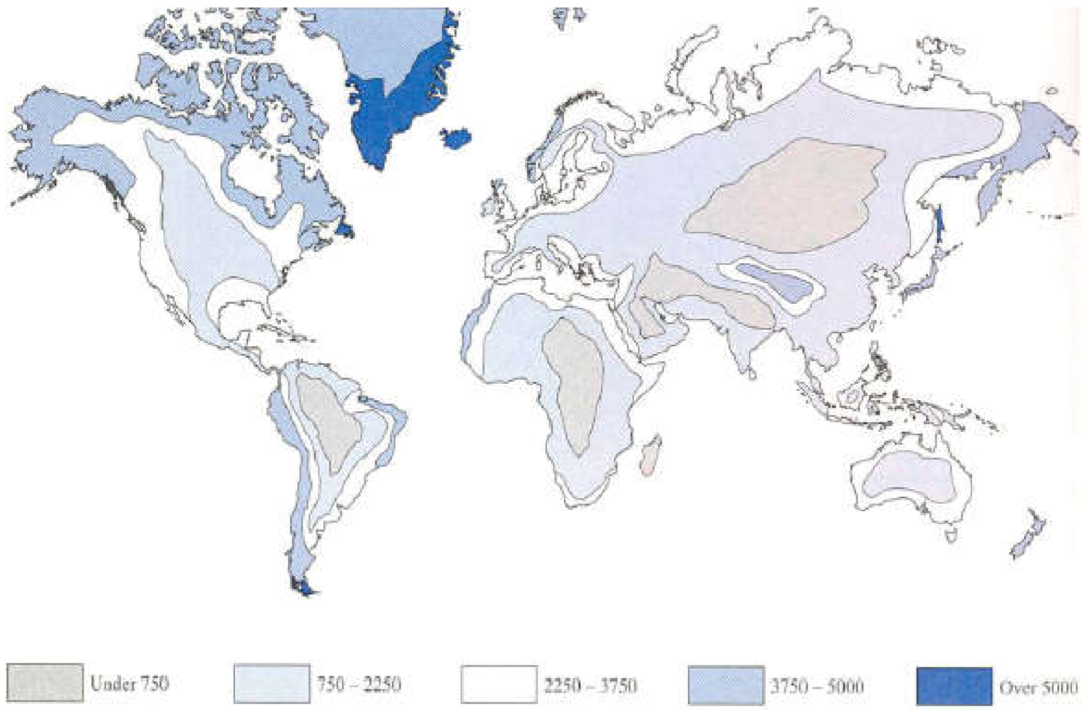

Figure 3.2:The world's energy potential for land-based wind turbines (estimated energy output in kWh/kW from a wind turbine that is dimensioned for 11 m/s)

3.3 Wind Generation

Wind results from the movement of air due to atmospheric pressure gradients. Wind flows from regions of higher pressure to regions of lower pressure. The larger the atmospheric pressure gradient, the higher the wind speed and thus, the greater the wind power that can be captured from the wind by means of wind energy-converting machinery.

The generation and movement of wind are complicated due to a number of factors. Among them, the most important factors are uneven solar heating, the Coriolis effect due to the earth's self-rotation, and local geographical conditions [9].

3.3.1 Uneven solar heating

Among all factors affecting on the wind generation, the uneven solar radiation on the earth's surface is the most important and critical one. The unevenness of the solar radiation can be attributed to four reasons.

First, the earth is a sphere revolving around the sun in the same plane as its equator. Because the surface of the earth is perpendicular to the path of the sunrays at the equator but parallel to the sunrays at the poles, the equator receives the greatest amount of energy per unit area, with energy dropping off toward the poles. Due to the spatial uneven heating on the earth, it forms a temperature gradient from the equator to the poles and a pressure gradient from the poles to the equator. Thus, hot air with lower air density at the equator rises up to the high atmosphere and moves towards the poles and cold air with higher density flows from the poles towards the equator along the earth's surface. Without considering the earth's self-rotation and the rotation-induced Coriolis force, the air circulation at each hemisphere forms a single cell, defined as the meridional circulation. Second, the earth's self-rotating axis has a tilt of about 23.5° with respect to its ecliptic plane. It is the tilt of the earth's axis during the revolution around the sun that results in cyclic uneven heating, causing the yearly cycle of seasonal weather changes.

Third, the earth's surface is covered with different types of materials such as vegetation, rock, sand, water, ice/snow, etc. Each of these materials has different reflecting and absorbing rates to solar radiation, leading to high temperature on some areas (e.g. deserts) and low temperature on others (e.g. iced lakes), even at the same latitudes. The fourth reason for uneven heating of solar radiation is due to the earth's topographic surface. There are a large number of mountains, valleys, hills, etc. on the earth, resulting in different solar radiation on the sunny and shady sides[9].

3.3.2 Coriolis force

The earth's self-rotation is another important factor to affect wind direction and speed. The Coriolis force, which is generated from the earth's self-rotation, deflects the direction of atmospheric movements. In the north atmosphere wind is deflects to the right and in the south atmosphere to the left. The Coriolis force depends on the earth's latitude; it is zero at the equator and reaches maximum values at the poles. In addition, the amount of deflection on wind also depends on the wind speed; slowly blowing wind is deflected only a small amount, while stronger wind deflected more. In large-scale atmospheric movements, the combination of the pressure gradient due to the uneven solar radiation and the Coriolis force due to the earth's self-rotation causes the single meridional cell to break up into three convectional cells in each hemisphere: The Hadley cell, the Ferrell cell, and the Polar cell (Fig.1) Each cell has its own characteristic circulation pattern.

In the Northern Hemisphere, the Hadley cell circulation lies between the equator and north latitude 30°, dominating tropical and sub-tropical climates. The hot air rises at the equator and flows toward the North Pole in the upper atmosphere . This moving air is deflected by Coriolis force to create the northeast trade winds. At approximately north latitude 30°, Coriolis force becomes so strong to balance the pressure gradient force. As a result, the winds are defected to the west. The air accumulated at the upper atmosphere forms the subtropical high-pressure belt and thus sinks back to the earth's surface, splitting into two components: one returns to the equator to close the loop of the Hadley cell; another moves along the earth's surface toward North Pole to form the Ferrell Cell circulation, which lies between north latitude 30° and 60°. The air circulates toward the North Pole along the earth's surface until it collides with the cold air fl owing from the North Pole at approximately north latitude 60°. Under the influence of Coriolis force, the moving air in this zone is deflected to produce westerly. The Polar cell circulation lies between the North Pole and north latitude 60°. The cold air sinks down at the North Pole and flows along the earth's surface toward the equator. Near north latitude 60° [9].

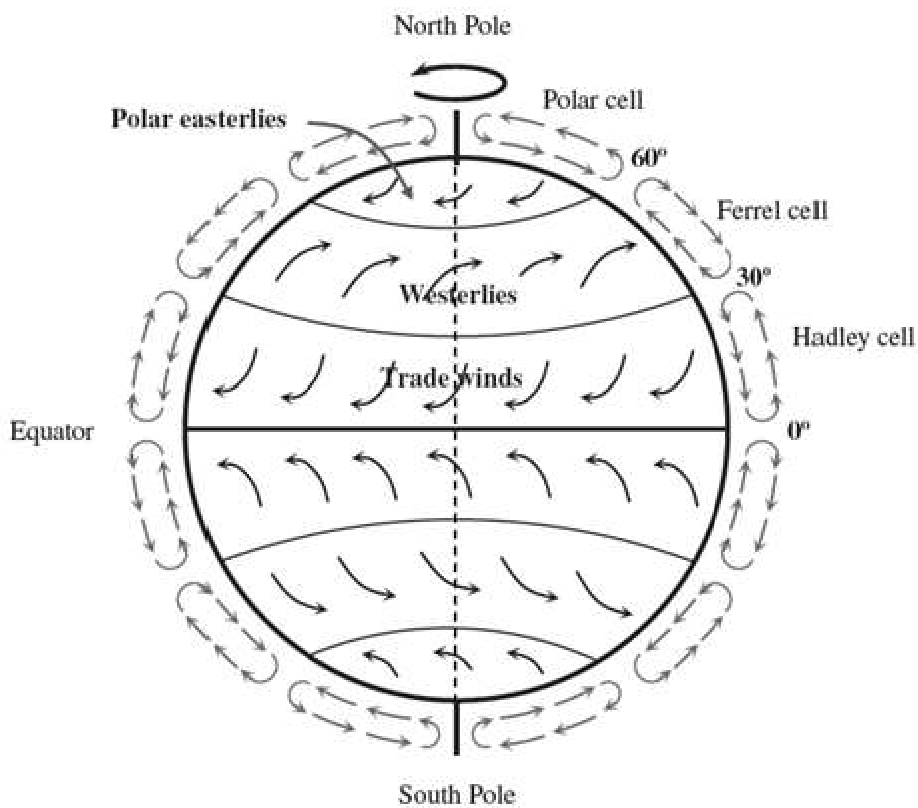

Figure 3.3: idealized atmospheric circulations.

3.3.3 Local geography

The roughness on the earth's surface is a result of both natural geography and manmade structures. Frictional drag and obstructions near the earth's surface generally retard with wind speed and induce a phenomenon known as wind shear. The rate at which wind speed increases with height varies on the basis of local conditions of the topography, terrain, and climate, with the greatest rates of increases observed over the roughest terrain. A reliable approximation is that wind speed increases about 10% with each doubling of height In addition, some special geographic structures can strongly enhance the wind intensity. For instance, wind that blows through mountain passes can form mountain jets with high speedsp[9].

3.4 Wind Characteristics:

Wind varies with the geographical locations, time of day, season, and height above the earth's surface, weather, and local landforms. The understanding of the wind characteristics will help optimize wind turbine design, develop wind measuring techniques, and select wind farm sites[6].

3.4.1 Wind speed

Wind speed is one of the most critical characteristics in wind power generation. In fact, wind speed varies in both time and space, determined by many factors such as geographic and weather conditions. Because wind speed is a random parameter, measured wind speed data are usually dealt with using statistical methods.

3.4.2 Weibull distribution

The variation in wind speed at a particular site can be best described using the Weibull distribution function, which illustrates the probability of different mean wind speeds occurring at the site during a period of time.

3.4.3 Wind turbulence

Wind turbulence is the fluctuation in wind speed in short time scales, especially for the horizontal velocity component. The wind speed at any instant time t can be considered as having two components.

3.4.4 Wind gust

Wind gust refers to a phenomenon that a wind blasts with a sudden increase in wind speed in a relatively small interval of time. In case of sudden turbulent gusts, wind speed, turbulence, and wind shear may change drastically. Reducing rotor imbalance while maintaining the power output of wind turbine generator constant during such sudden turbulent gusts calls for relatively rapid changes of the pitch angle of the blades. However, there is typically a time lag between the occurrence o a turbulent gust and the actual pitching of the blades based upon dynamics of the pitch control actuator and the large inertia of the mechanical components. As a result, load imbalances and generator speed, and hence oscillations in the turbine components may increase considerably during such turbulent gusts,and may exceed the maximum prescribed power output level Moreover, sudden turbulent gusts may also significantly increase tower fore-aft and side-to-side bending moments due to increase in the effect of wind shear.

3.4.5 Wind direction

Wind direction is one of the wind characteristics. Statistical data of wind directions over a long period of time is very important in the site selection of wind farm and the layout of wind turbines in the wind farm.

3.4.6 Wind shear

Wind shear is a meteorological phenomenon in which wind increases with the height above the ground. The effect of height on the wind speed is mainly roughness on the earth's surface and can be estimated.

3.5 Advantages and Disadvantages of Wind Energy

There are a range of advantages and disadvantages of wind energy to look at, including the many problems associated with wind turbines. In this day and age, the world needs to look at the different natural energy sources available to us.

Global warming could be due our energy craving lifestyle, so we should look into more environmentally friendly energy sources [7].

3.5.1 Advantages

- Wind energy is friendly to the surrounding environment, as no fossil fuels are burnt to generate electricity from wind energy.
- Wind turbines take up less space than the average power station. Windmills only have to occupy a few square meters for the base, this allows the land around the turbine to be used for many purposes, for example agriculture.
- Newer technologies are making the extraction of wind energy much more efficient. The wind is free, and we are able to cash in on this free source of energy.
- Wind turbines are a great resource to generate energy in remote locations, such as mountain communities and remote countryside. Wind turbines can be a range of different sizes in order to support varying population levels.
- Another advantage of wind energy is that when combined with solar electricity, this energy source is great for developed and developing countries to provide a steady, reliable supply of electricity.

3.5.2 Disadvantages

- The main disadvantage regarding wind power is down to the winds unreliability factor. In many areas, the winds strength is too low to support a wind turbine or wind farm, and this is where the use of solar power or geothermal power could be great alternatives.
- Wind turbines generally produce allot less electricity than the average fossil fueled power station, requiring multiple wind turbines to be built in order to make an impact.

- Wind turbine construction can be very expensive and costly to surrounding wildlife during the build process.
- The noise pollution from commercial wind turbines is sometimes similar to a small jet engine. This is fine if you live miles away, where you will hardly notice the noise, but what if you live within a few hundred meters of a turbine? This is a major disadvantage.
- Protests and/or petitions usually confront any proposed wind farm development. People feel the countryside should be left intact for everyone to enjoy its beauty.

3.6 Wind Applications

- Windmill
- wind turbine

3.6.1 Windmill

A windmill is a machine that converts the energy of wind into rotational energy by means of vanes called sails or blades. Originally, windmills were developed for milling grain for food production. Over the course of history, windmill machinery has been adapted to serve many other industrial uses.

The majority of modern windmills take the form of wind turbines used to generate electricity, or wind pumps used to pump water, either for land drainage or to extract groundwater.

The practical vertical axis windmills were built in Sistine (eastern Persia) for grain grinding and water pumping, as recorded by a Persian geographer in the ninth century. The horizontal axis windmills were invented in northwestern Europe in 1180s. The earlier windmills typically featured four blades and mounted on central posts – known as Post mill. Later, several types of windmills, e.g. Smock mill, Dutch mill, and Fan mill, had been developed in the Netherlands and Denmark, based on the improvements on Post mill. The horizontal axis windmills have become dominant in Europe and North America for many centuries due to their higher operation efficiency and technical advantages over vertical axis windmills [8].

Figure 3.4: Dutch windmill (gallery type) [11].

3.6.2 Wind turbines

A wind turbine is a device that converts kinetic energy from the wind into electrical power. A wind turbine used for charging batteries may be referred to as a wind charger. The result of over a millennium of windmill development and modern engineering, today's wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making small contributions to a domestic power supply whilst selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

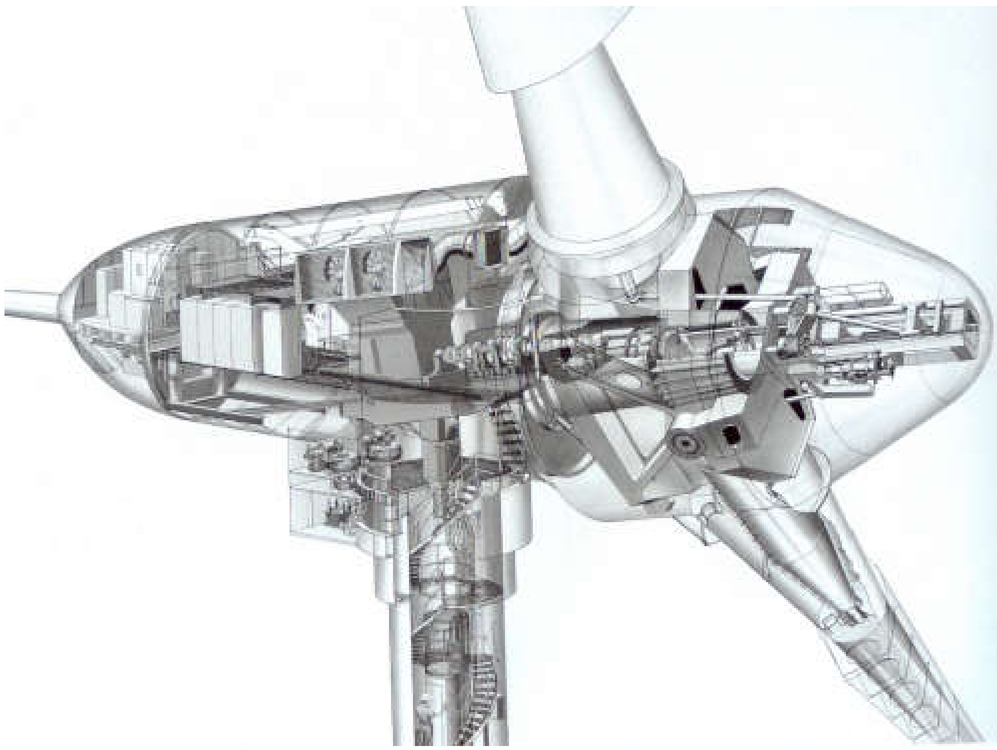

Figure 3.5: Nacelle and teetered hub of Growian of wind turbine[11].

3.7 Wind Turbine Classification

There two main types of (WTGs), which are:

3.7.1 Horizontal Axis WTGs (HA-WTGs)

This is the most famous type of WTGs. There are many configurations for this type, which are shown in Fig. 1.3. The main advantages of HA-WTGs are a self-starting, large variety of the rated output power (Suitable for small WTGs as well as very large WTGs) and it has a comparatively low cost.

The main disadvantages of this type are, it must be reoriented as the wind changes its direction. The second disadvantage is the generator and gearbox and control system are all located in the top of the WTG tower, which make the maintenance, is a problem[6].

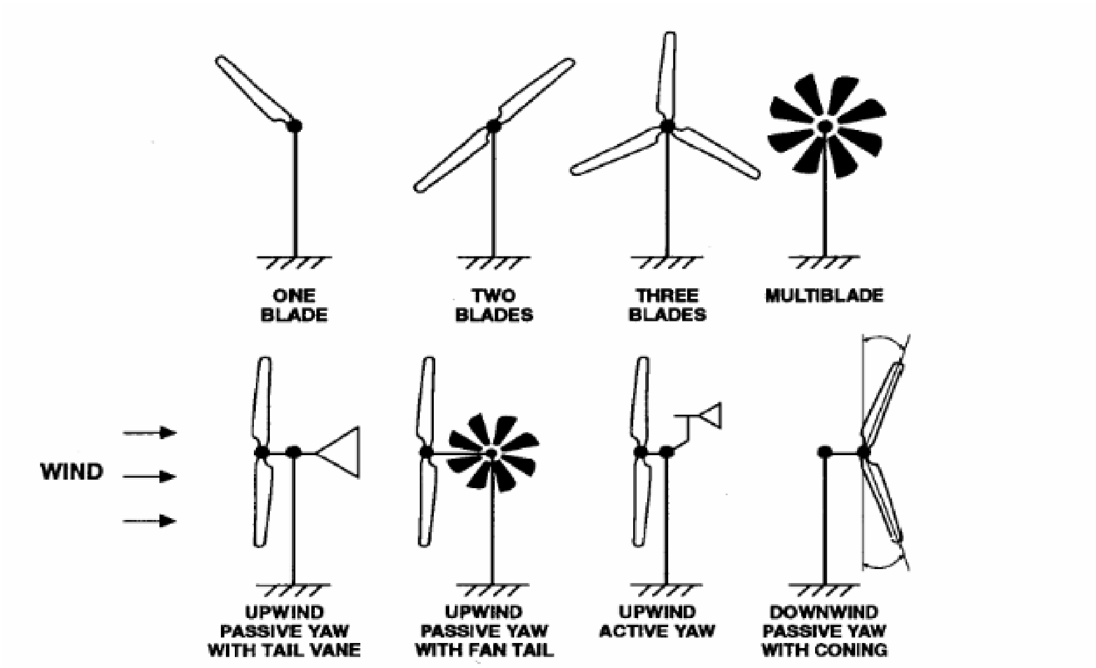

Figure 3.6: The HA-WTG configuration[7]

3.7.2 Vertical Axis WTGs (VA-WTGs)

VA-WTGs type are lower in number than the HA-WTGs due to some problems in design. The main advantages of VA-WTGs, are no additional cost is required to change the VA-WTGs direction when the wind direction changes and the gearbox and generator and control system are in the ground level, then their maintenance is very simple. Fig1.4 Shows the VA-WTGs configurations. A complete comparison between HA-WTGs and VA-WTGs is shown in table [6].

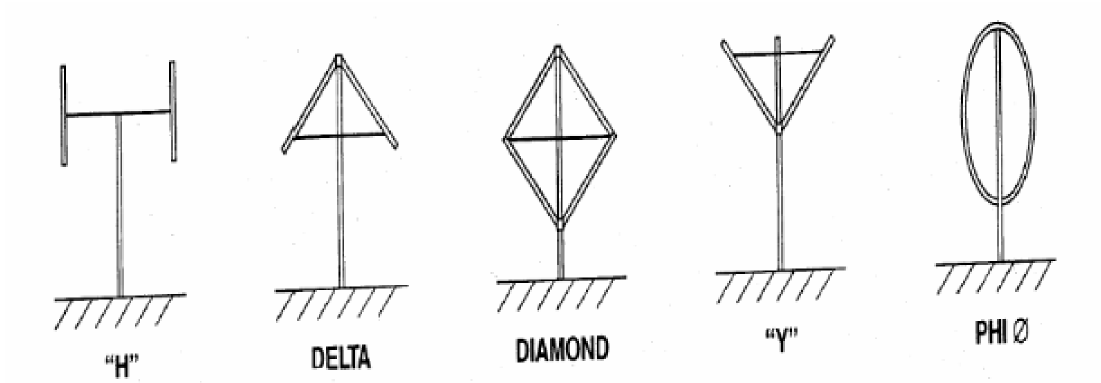

Figure 3.7:The VA-WTGs Configurations[7]

Table 3.1: Comparison between HA-WTGs and VA-WTGs[7]

Item	HA-WTGS	VA-WTGS
Output power	Wide range	Narrow
Starting	Self starting	Need starting means
Efficiency	Higher	Lower
Cost	Lower	Higher
Wind direction	Need redirected when the wind change its direction	Does not Need redi-rected into the wind di-rection
Generator and gear box	At the top of the tower	At the ground level
Maintenance	Difficult	Easy

3.8 The Structure of a Wind Turbine:

A wind turbine is made up of the following components:

- **Tower and Foundation:**

In order to guarantee the stability of a wind turbine a pile or flat foundation is used, depending on the consistency of the underlying ground .

The tower construction doesn’+
t just carry the weight of the nacelle and the rotor blades, but must also absorb the huge static loads caused by the varying power of the wind. Generally, a tubular construction of concrete or steel is used. An alternative to this is the lattice tower form.

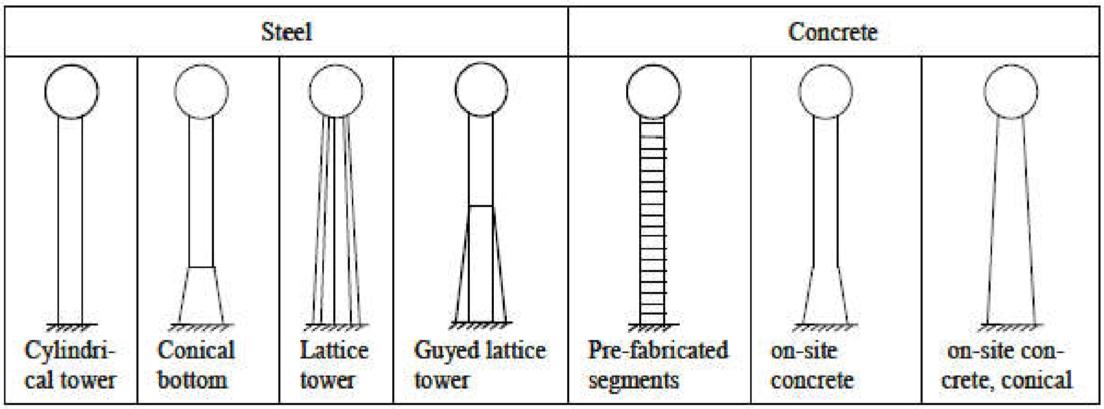

Figure 3.8: Tower and Foundation

- **Rotor and Rotor blades:**

The rotor is the component which, with the help of the rotor blades, converts the energy in the wind into rotary mechanical movement .Currently, the three-blade, horizontal axis rotor dominates. The rotor blades are mainly made of glass-fiber or carbon-fiber reinforced plastics. The blade profile is similar to that of an aero plane wing. They use the same principle of lift: on the lower side of the wing the passing air generates higher pressure, while the upper side generates a pull. These forces cause the rotor to move forwards to rotate.

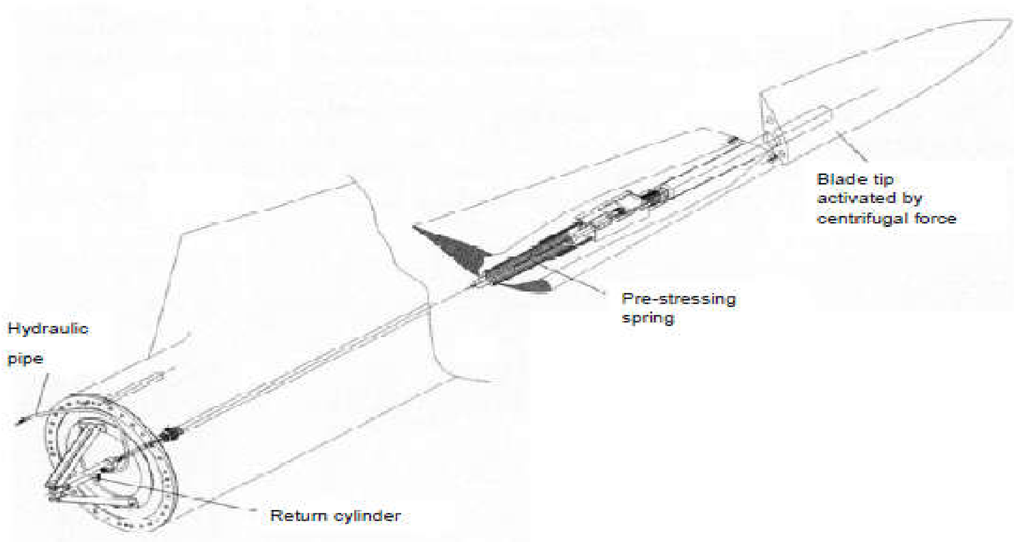

Figure 3.9: Rotor blade

- **Nacelle with Drive Train:**

The nacelle holds all the turbine machinery. Because it must be able to rotate to follow the wind direction it is connected to the tower via bearings. The build-up of the nacelle shows how the manufacturer has decided to position the drive train components (rotor shaft with bearings, transmission, generator, coupling and brake) above this machine bearing.

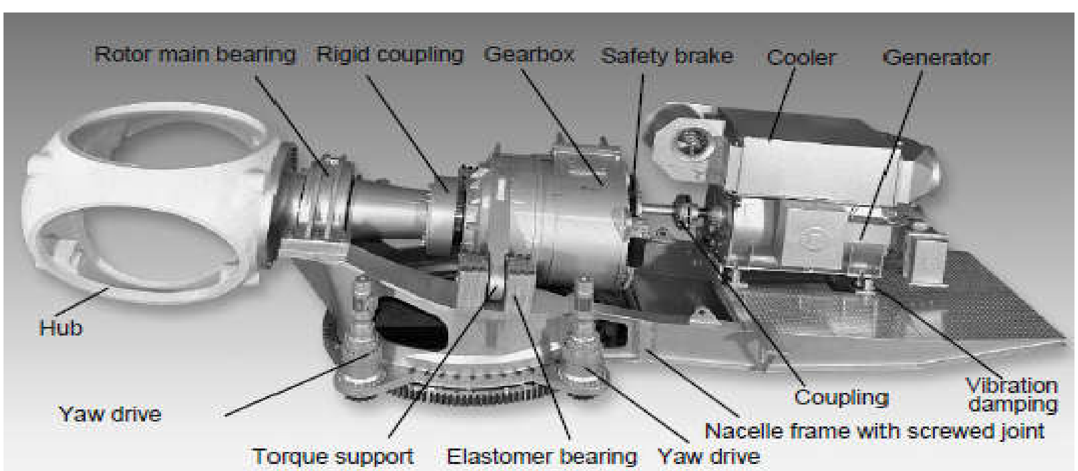

Figure 3.10: Drive Train

- **Gearbox:**

The gearbox converts the rotor motion of 18-50 rpm into the approx. 1,500 rpm which the generator requires. The gearbox thus takes on the task of matching the rotation speeds of the slow-moving rotor and the fast-moving generator, and generally has several steps to cover for various wind conditions .If a specially developed multi-pole ring generator is used, the gearbox is no longer required (best-known manufacturer of direct drive turbines.

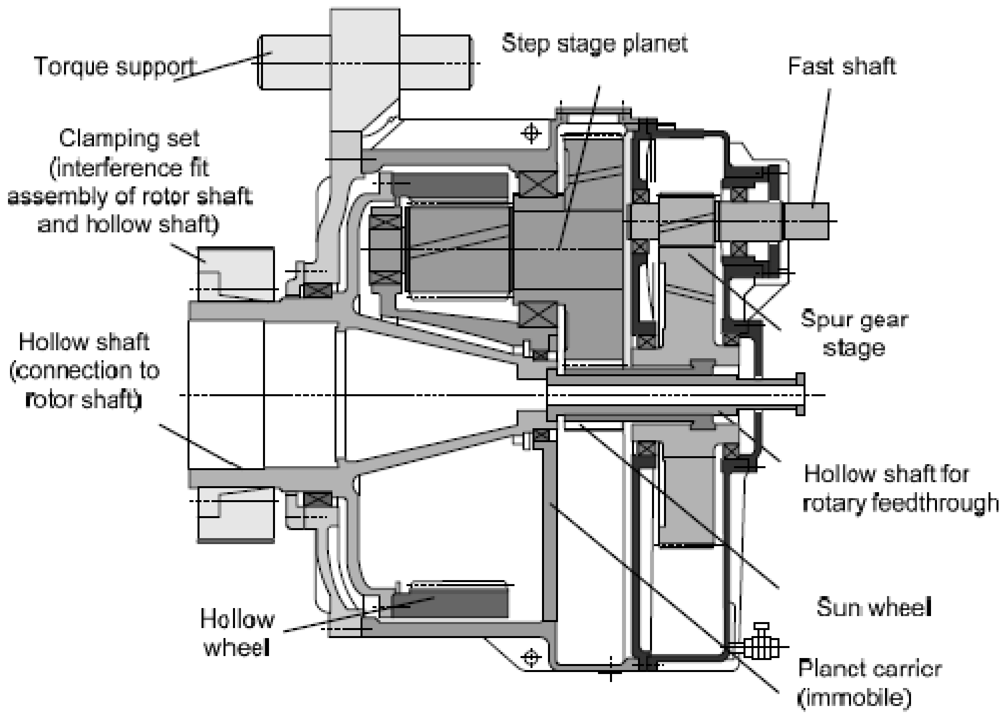

Figure 3.11: Three-stage gearbox for wind turbines with fixed hollow wheel

- **Generator:**

For high power wind turbines, doubly-fed asynchronous generators are most frequently used. Here, the operating rotation speed can be varied somewhat, unlike when using conventional asynchronous generators. Another concept uses synchronous generators. A grid connection of synchronous generators is only possible via transformers, due to the fixed rotation behavior. The disadvantage of requiring complicated control systems is countered by the overall efficiency and better grid compatibility.

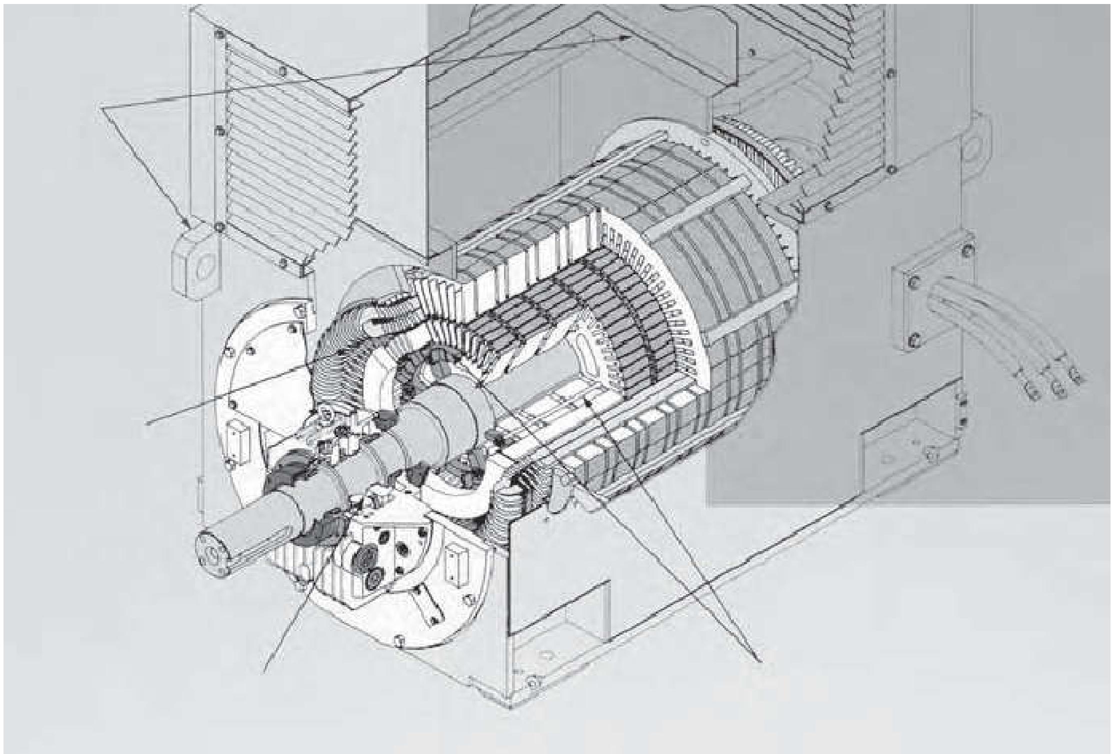

Figure 3.12: induction machine. (From Teco Westinghouse Motor Company, Round Rock, TX. With permission.) [7]

- **Coupling and Break:**

Because of the enormous torque, the coupling between the main shaft and the transmission is a rigid one. The type of brake depends on the control mechanism for the blade.

Figure 3.13: Coupling shaft between gearbox and generator with brake disc and two couplings

- **Electronic Equipments:**

The electronic equipment of a wind turbine is composed of the generator), the system for the grid in feed of the electricity, and various sensors .The sensors for measuring temperature, wind direction, wind speed and many other things can be found in and around the nacelle, and assist in turbine control and monitoring.

- **Other Component:**

Finally, the wind turbine contains components for following the wind direction, for cooling, heating and lightning protection, as well as lifting gear (winches for spare parts) and fire extinguishing equipment.

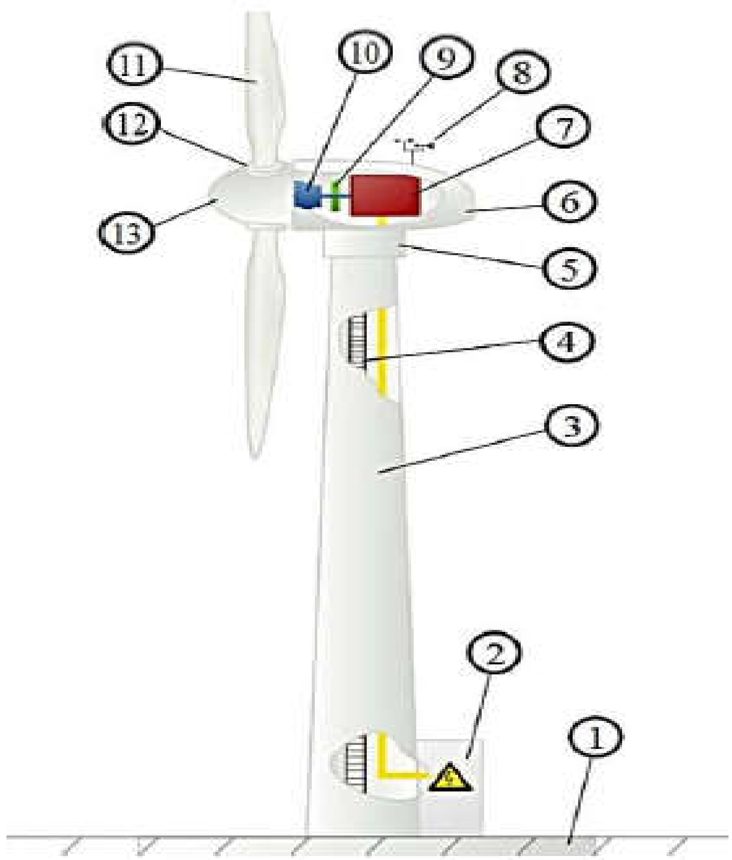

Figure 3.14:Wind Turbine Element

1. Foundation	2. Control panel	3. Tower
4. Power cables	5. Yaw system	6. Nacelle
7. Generator	8. Anemometer	9. Brake
10. Gearbox	11. Blade	12. Pitch system
13. Hub		

3.9 Characteristics Of Wind Turbine :

A wind turbine extracts kinetic energy from the swept area of the blades. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time. That is:

$$P_{\text{air}} = 0.5\rho A V_{\infty}^{3} \quad (3.2)$$

Where Pair is the power contained in wind (in watts) , ρ is the air density (1.225 kg/m3 at 15°C and normal pressure), A is the swept area in (square meter), and V∞ is the wind velocity without rotor interference, i.e., ideally at infinite distance from the rotor (in meter per second).

Although the above equation gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient,Cp

$$Cp = \frac{\text{P wind turbine}}{\text{Pair}} \quad (3.3)$$

Maximum value of Cp is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum Cp values in the range 25-45%.

3.9.1 Solidity

The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intercepted. The projected blade area is the blade area met by the wind or projected in the direction of the wind.

Solidity has a direct connection with the torque and speed. High-solidity rotors have high torque and low speed, and are employed for pumping water. Low-solidity rotors, on the other hand, have high speed and low-torque, and are usually suited for electrical power generation.

3.9.2 Tip Speed Ratio

Tip speed ratio of a wind turbine (λ) is defined as:

$$\lambda = \frac{\omega R}{V_\infty} \quad (3.4)$$

Where ω is rotational speed of rotor (in rpm), R is the radius of the swept area (in meter).The tip speed ratio λ and the power coefficient Cp are the dimensionless and so can be used to describe the performance of any size of wind turbine rotor.

3.9.3 Specified Rated Capacity

Specified Rated capacity (SRC) is an important index which is used to compare a variety of wind turbine designs.

$$SRC = \frac{Power\ Rating\ Of\ Generator}{Rotor\ Swept\ Area} \quad (3.5)$$

It varies between 0.2 (for small rotors) and 0.6 (large rotors).

3.9.4 Power-Speed Characteristics

Mechanical Power transmitted to the shaft is:

$$p_m = 0.5\rho A C_p V_\infty^3 \quad (3.6)$$

Where :

Cp is a function of tip speed ratio (TSR) and pitch angle α For wind turbine with radius.

The following curves show the relationship between mechanical power extracted from the wind and the rotor speed at various wind speeds. For each wind speed there is an optimum turbine speed at which maximum power is extracted.

Such a group of wind turbine curves can be represented by a single dimension-less characteristic curve, explicitly, the Cp-λ curve as shown in figure below :

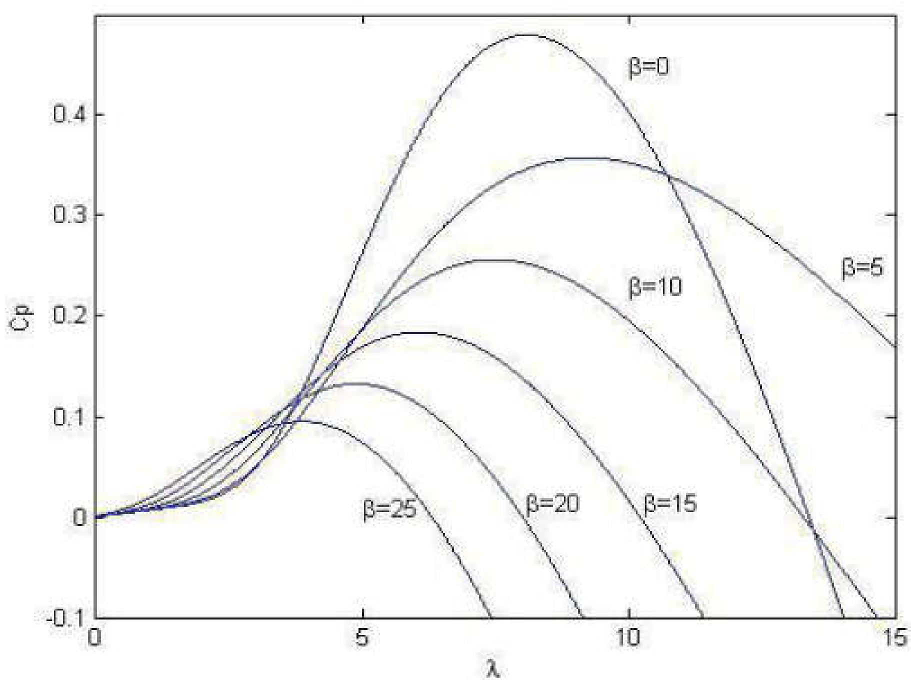

Figure 3.15:Typical Power versus speed characteristics of a wind turbine

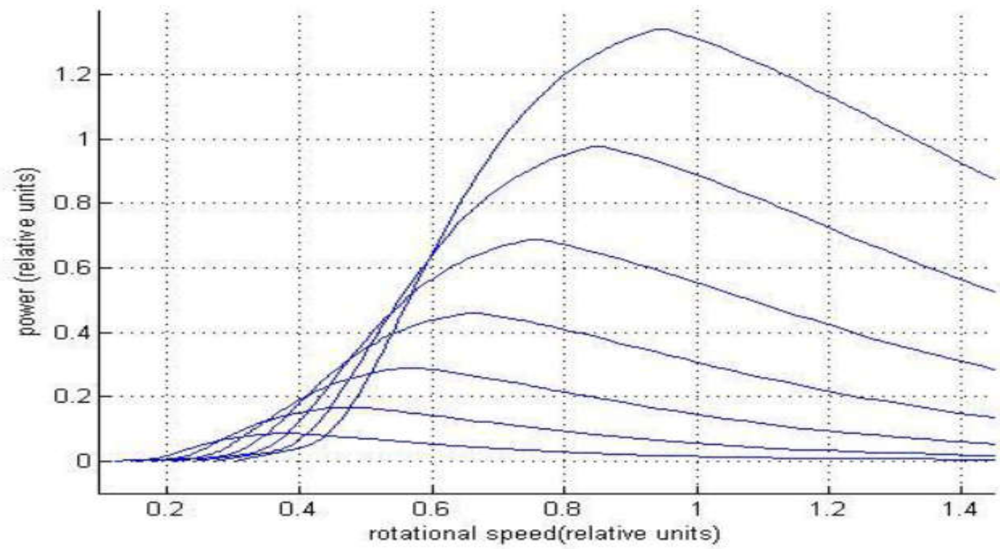

Figure 3.16:Typical curves of power coefficient (Cp) Versus Tip speed ratio (λ) for various angles of pitch angle

3.9.5 Torque–Speed Characteristics

The typical torque versus speed characteristics of horizontal axis (two blade propeller type) wind turbine is shown:

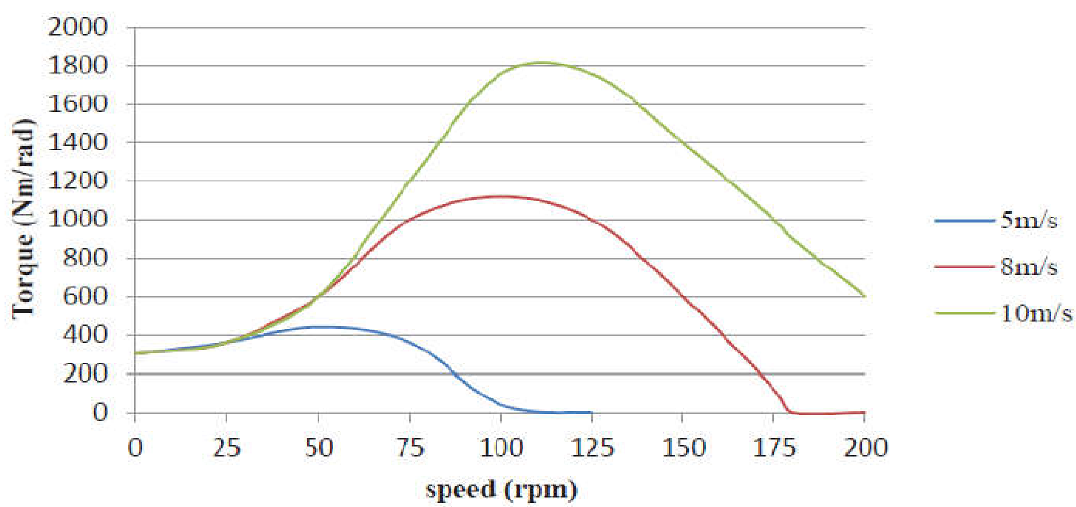

Figure 3.17:Torque versus speed characteristics

The direct relationship between Torque and Power is:

$$T_m = \frac{P_m}{\omega} \quad (3.7)$$

Using the optimum values of Cp and , the maximum value of aerodynamic torque

$$T_{max} = 0.5\rho C_{p_{opt}} \pi (\frac{R^5}{\lambda_{opt}^3}) \omega^3 \quad (3.8)$$

The curve shows that for any wind speed the torque reaches peak value at a definite rotational speed, and this maximum torque varies in the order of the square of rotational speed. Generally the load torque depends on the electrical loading. The torque can be made to vary as the square of the rotational speed by choosing the load properly.

3.10 Conclusion

The wind energy has several advantages for instance clean, unlimited, and its potential to provide sustainable electricity in area not served by the conventional power grid.

CHAPTER FOUR

USING OF INDUCTION GENERATOR IN WIND ENERGY

4.1 Introduction

The induction generator is the most common generator in wind energy system applications due to its simplicity and ruggedness, more than 50 years life time, same machine can be used as motor or generator without modification, high power per unit mass of materials and flexibility in speed range of operation. The main drawbacks in induction generator are its lower efficiency and the need for reactive power to build up the terminal voltage. However, the efficiency can be improved by modern design and solid-state converters can be used to supply reactive power required**.**

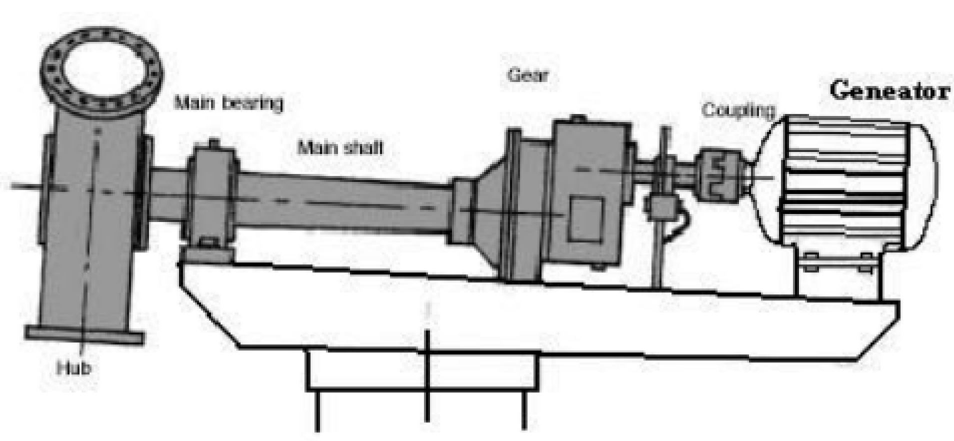

Figure 4.1: Induction generator inside WES

There are two types of induction generator:

- Normal type (non isolated), where excitation required are provided by an external A.C source.

- Isolated type (self excited) in which excitation is provided by a terminal capacitor.

In the first type, the frequency and voltage are equal to that of system. However, in the second type, the frequency and induced voltage change with speed, excitation capacitor, load impedance and its associated power factor. The frequency of the induced voltage is always less than the synchronous frequency (corresponding to input shaft speed) [9].

The generators used in wind energy applications should be simple to use with low maintenance, and have low initial cost. Induction generator satisfies most of these requirements. Also, the WTGs employ permanent magnet, synchronous and variable reluctance generator systems.

4.2 Equivalent Circuit of an Induction Machine

4.2.1 Transformer Model of an Induction Machine

The per-phase equivalent circuit, representing the operation of induction machine is shown in Figure (4.2):

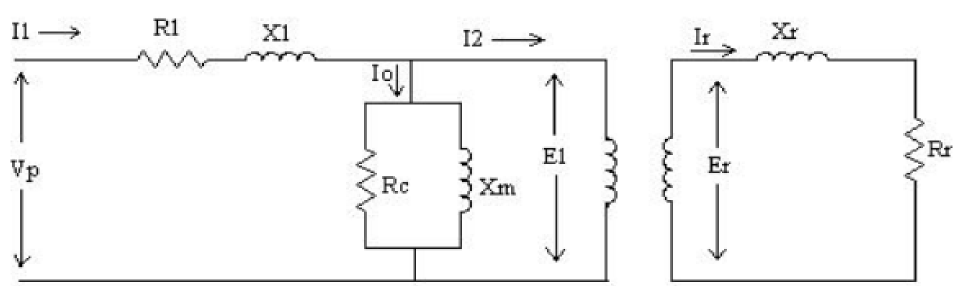

Figure 4.2: The induction machine with rotor and stator connected by an ideal transformer

Like any transformer, there is a certain resistance and self-inductance in the primary (stator) windings, which must be represented in the equivalent circuit of the machine. The stator resistance will be called $R_1$and the stator leakage reactance will be called X_1. These two components appear right at the input to the machine model. Like any transformer with an iron core, the flux in the machine is related to the integral of the applied voltage E1. The magnetomotiveforce-versus-flux curve (magnetization curve) for this machine is compared to a similar curve for a power transformer.

4.2.2 Rotor Circuit Model

In an induction machine when the voltage is applied to the stator windings. A voltage is induced in the rotor windings of the machine. In general, the greater the relative motions between the rotor and the stator magnetic fields, the greater the resulting rotor voltage. The largest relative motion occurs when the rotor is stationary, called the locked-rotor or blocked rotor condition, so the largest voltage is induced in the rotor at the condition .The smallest voltage (OV) occurs when the rotor moves at the same speed as the rotor magnetic field, resulting in no relative motion. The voltage induced in the rotor at any speed between these extremes is directly proportional to the slip of the rotor. Therefore ,if the induced rotor voltage at locked-rotor conditions is called E_{ro}, the induced voltage at any slip will be given by the equation :

$$E_r = sE_{ro} \tag{4.1}$$

This voltage is induced in a rotor containing both resistance and reactance .The rotor resistance R_r is a constant, independent of slip, while the rotor reactance is effected in a more complicated way by slip.

The reactance of an induction motor rotor depends on the inductance of the rotor and the frequency of the voltage and current in the rotor. With a rotor inductance of L_r, the rotor reactance is given by :

$$X_r = 2\pi sF_{ro}L_r \tag{4.2}$$

From that equation (4.2) :

$X_r = 2\pi s f_e L_r$

$X_r = s(2\pi f_e) L_r$

$$X_r = sX_{ro} \tag{4.3}$$

Where X_{ro} is the blocked-rotor reactance.

The resulting rotor equivalent circuit is shown in Fig. (4.3). The rotor current flow can be found as:

$$I_r = \frac{sE_{ro}}{R_r + jsX_{ro}} \tag{4.4}$$

Or

$$I_r = \frac{sE_{ro}}{R_r + jsX_{ro}} \tag{4.5}$$

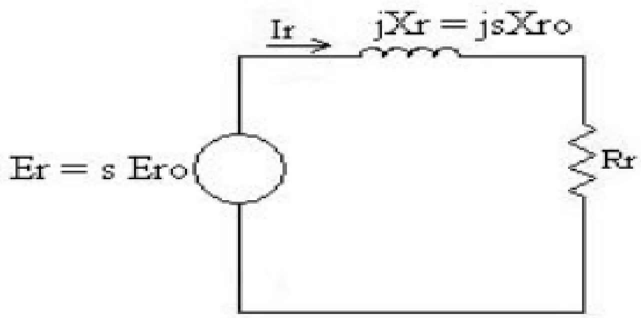

Figure 4.3:The rotor circuit model of an induction machine.

The equivalent rotor impedance from this point of view is:

$$Z_r, e_q = \frac{R_r}{s} + jX_{ro} \tag{4.6}$$

And the rotor equivalent circuit using this convention :

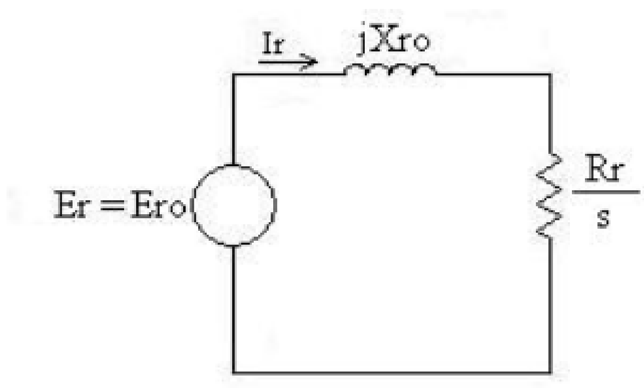

Figure 4.4:The rotor circuit model with slip effects concentrated in resistance R_r.

4.2.3 Final Equivalent Circuit

It is necessary to refer the rotor part of the model over to the stator side. The rotor circuit model that will be referred to the stator side is the model shown in Fig (4.5), which has all the speed variation effects concentrated in the impedance term.

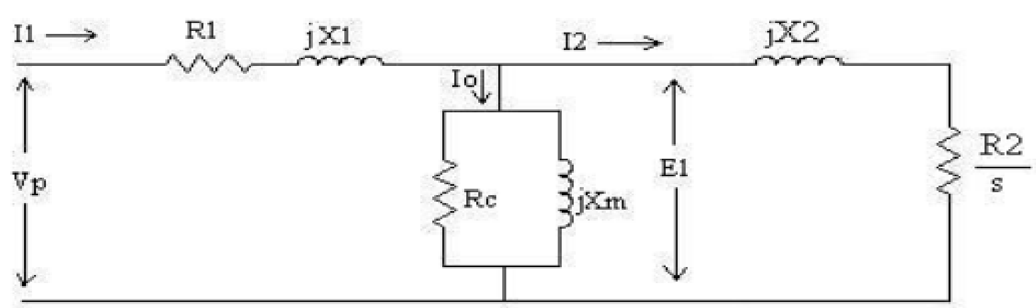

Fig4.5: The per-phase equivalent circuit of induction machine

Referring the voltage, currents, and impedances on the secondary side of the device to the primary side by means of the turns ratio of the transformer:

$$V_p = V_s' = V_s \qquad (4.7)$$

$$I_p = I_s' = \frac{I_s}{a} \qquad (4.8)$$

And

$$Z_s^{'} = a^2 Z_s \qquad (4.9)$$

Exactly the same sort of transformation can be done for the induction motor's rotor circuit .If the effective turns ratio of an induction motor is a_{eff} , then the transformer rotor voltage becomes :

$$E_1 = E_r^{'} = a_{eff} E_{ro} \qquad (4.10)$$

The rotor current becomes

$$I_2 = \frac{I_r}{a_{eff}} \qquad (4.11)$$

And the rotor impedance becomes

$$Z_2 = a_{eff}^2 (\frac{R_r}{S} + X_{ro}) \qquad (4.12)$$

If we know make the following definitions:

$$R_2 = a_{eff}^2 R_r \qquad (4.13)$$

$$X_2 = a_{eff}^2 X_{ro} \qquad (4.14)$$

Then the final per-phase equivalent circuit of the inducting motor is as shown above in Figure (4.5).

4.3 Induction Generator Operation

The induction motor can also run as a generator. This simply happens when you, instead of forcing the rotor to turn at a rotational speed lower than the synchronous speed, exceed this synchronous speed by applying an outside energy source, such as a diesel motor or a set of wind turbine rotor blades. Once again, the greater the difference between the rotating magnetic field of the stator and the speed of the rotor, the greater the torque produced by the rotor. When it is a working as a generator, the rotating field however acts as a brake in slowing the rotor. The stator experiences a variable magnetic field from the rotor that 'drags' its rotating magnetic field and thereby induces an electrical current in the stator. In comparison to motor operation the induced currents in the rotor and stator will flow in the opposite direction, which means that power will be sent to the grid. The faster the rotor turns in relation to the rotating magnetic field of the stator, the greater the induction in the stator and the greater the production of power.

In practice the difference between the speed of rotational magnetic field of the stator and the rotational speed of the rotor is very little. A rotor will typically turn about 1% faster at full power production. If the synchronous rotational speed is 1500 rpm then the rotor rotational speed at full power will be 1515 rpm. The interesting torque curve of the induction electric motor, also operating as a generator, is shown below in Figure (4.6) . At speeds below the synchronous rotational speed, the motor yields a positive torque.

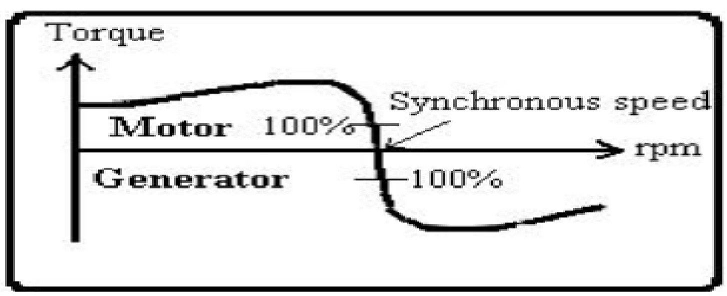

Fig.4.6: Induction machine characteristics[8]

4.4 Induction in wind

The most promising classifications in induction generator wind systems are fixed-speed ,limited-variable-speed, and variable-speed wind systems, according to the operations of induction generator speed. Comparisons between these wind power systems have been intensively conducted, based on different speed variation levels. A summary of their advantages and disadvantages is presented in Table 1. The fixed-speed concept has been successfully applied in SCIG wind systems. The drive train applies multiple-stage gearbox and a SCIG is directly connected to the grid via a transformer. To support the grid, external reactive power compensation and soft starter are necessary [10,11].

The limited variable-speed system is an improved version of the SCIG type but it uses a wound rotor induction generator instead ,which allows the stator to be connected to the grid, and the rotor to have a variable resistance controlled by a power converter. Through the control of rotor resistance, the slip of the generator is varied. The variable-speed system is a concept commonly used in large power rating applications (>1.5 MW). Different combinations among DFIG, SCIG, partial or full converters would lead to variable-speed operation systems. The control system maintains the optimal generator speed, thus the optimal output power, through controlling the generator currents and voltages. Due to the high efficiency and capability of Faults Ride Through (FRT), this type of wind power system dominates the high-capacity power market nowadays[9].

Table 4.1: Comparison among different wind power systems

	Advantages	**Disadvantages**
Fixed-speed system	- Simple construction and robust. - Low cost and maintenance. - Easy control.	- Not optimal operation, thus low efficiency. - Easy power fluctuation caused by wind speed and tower pressure. - External reactive power compensation is needed. - Weak capability of FRT.
Limited-speed sys-	- limited speed variation is implemented.	- Speed variation range depends on the size of the vari-

tem	- The slip ring may be replaced by optical coupling.	able rotor resistance (<10%). - The controlled rotor power must be dissipated by heat in the resistor. - Still need reactive power compensation and cannot support the grid alone.
Variable-speed system	- Large range of speed variation. . Appropriate control enables optimal operation for maximum power extraction. - No external power compensation is needed and is able to support the grid. - High FRT capability. - Suitable and commonly used for large-scale wind farms.	- Relatively complicated control system. - Higher converters and control costs. - May need a multistage gearbox and slip ring in DFIG system. - May need expensive PM material and large diameter design in direct drive.

4.5 Model of wind power and wind turbine

As a typical kinetic energy, wind energy is extracted through wind turbine blades and then transferred by the gearbox and rotor hub to mechanical energy in shaft. The shaft drives the generator to convert the mechanical energy to electrical energy. According to Newton's law, the kinetic energy for the wind with particular wind speed V_W is described as:

$$E_K = \frac{1}{2} m V_w^2 \tag{4.15}$$

Where m represents the mass of the wind, and its power can be written as:

$$P_w = \frac{\partial E_k}{\partial t} = \frac{1}{2}\frac{\partial m}{\partial t} V_w^2 = \frac{1}{2}(\rho A V_w) V_w^2 = \frac{1}{2}\rho A V_w^2 \tag{4.16}$$

Where ρ and A are the air density and turbine rotor swipe area, respectively. The extracted mechanical power can thus be expressed as:

$$P_m = C_p(\lambda, \beta) P_w = C_p(\lambda, \beta) \frac{1}{2}\rho A V_w^2 \tag{4.17}$$

Where P_m is the mechanical output power in watt, which depends on performance coefficient $C_p(\lambda, \beta)$, C_p depends on tip speed ratio λ and blade pitch angle β, and determines how much of the wind kinetic energy can be captured by the wind turbine system. A nonlinear model describes $C_p(\lambda, \beta)$ as:

$$C_p(\lambda, \beta) = C_1(C_2 - C_3\beta - C_4\beta^2 - C_5)e^{-c_6} \tag{4.18}$$

where, c_1=0.5, c_2=116/λ_i, c_3=0.4, c_4=0, c_5=5, c6=21/λ_i and

$$\lambda_i = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{4.19}$$

With the dependence on the λ and β , maximum value of C_p could be reached and maintained through controlling the pitch angle and generator speed at particular wind speed. A group of typical (C_p-λ)curves for different β is shown below and there is always a maximum value for C_p at one particular wind speed. Correspondingly, the output power is determined by different C_p and also the generator speed at different wind speed, as shown below , where there is always one maximum power value for each wind speed, which is the goal of the MPPT control[4].

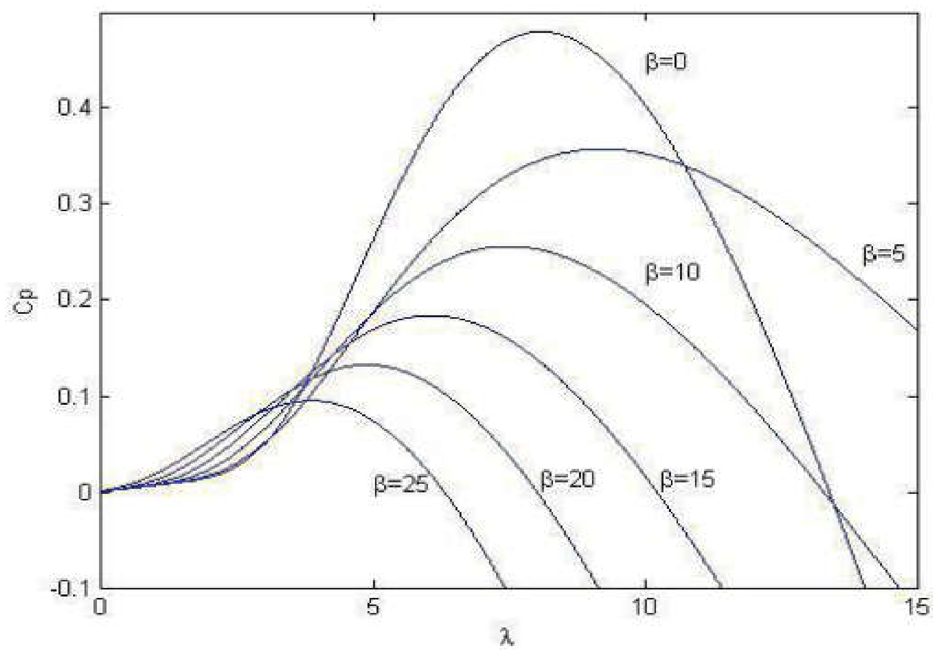

Figure 4.7: Power coefficients versus tip speed ratio

4.6 Model and Control of SCIG

As a fixed-speed wind power system, SCIG is directly connected to the grid through transformer and thus operates at almost constant speed without controlling from power electronics interface. It was commonly used in Denmark during 1980s and 1990s and thus is also called “Danish Concept” system. The robust and simple configuration qualifies such system for many applications where the cost is a higher priority concern than efficiency. Figure (4.8) shows the schematics of entire SCIG wind system including the wind turbine, pitch control, and reactive power compensator.

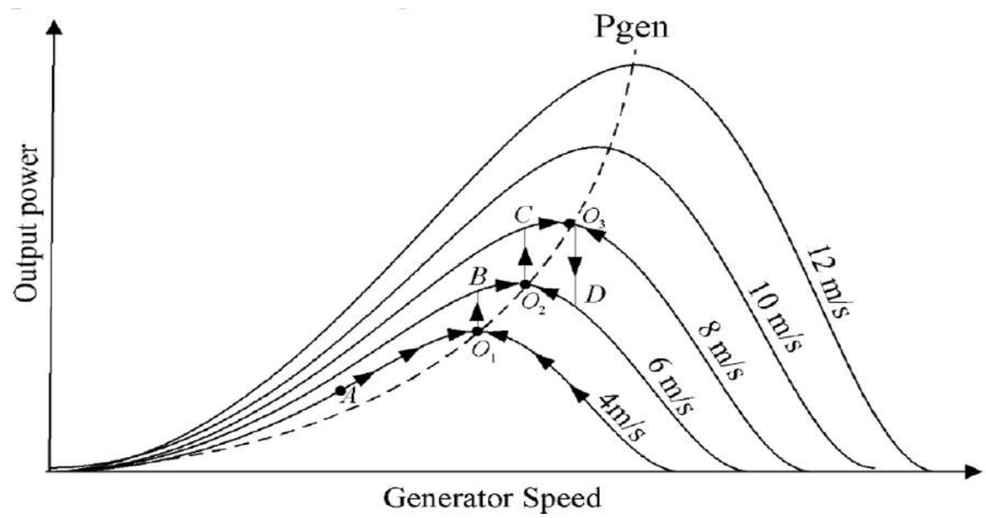

Figure 4.8: Power versus generator speed curve for wind turbine [5]

The entire system includes three stages for delivering the energy from wind turbine to the power grid. The first one is wind farm stage which handles with low voltage V_{wt}; the second is distribution stage which has medium-voltage V_{dis}; the third is grid transmission stage which has high-voltage V_{grid}. The three-phase transformers take care of the interface between two stages[9]. The nominal power is considered as active power reference to regulate the pitch angle, while the distribution line-to-line voltage and phase current are monitored to favor the reactive power compensation for distribution line. This fairly straightforward technique was firstly used since it is simple, with rugged construction, has reliable operation and is low cost. However, the fixed-speed nature and potential voltage instability problem severely limit the operations of SCIG wind system.

It is clear from Figure(4.8) that at a particular wind speed, the output active power is also a fixed value in the case of fixed generator speed. Thus, the output power is exclusively wind speed dependent until the nominal power is reached. The wind speed at nominal power is called nominal wind speed. Beyond this wind speed, the pitch angle system will prevent the output power from exceeding the nominal value. The pitch angle is determined by an open-loop control of regulated output active power and, as shown in Figure 3. Due to the huge size of blade and thus the huge inertia, pitch angle has to change at a slow rate and within a reasonable range. It is also worth noting that without reactive power source, the SCIG system tends to a voltage droop in distribution line which will cause overload problem.

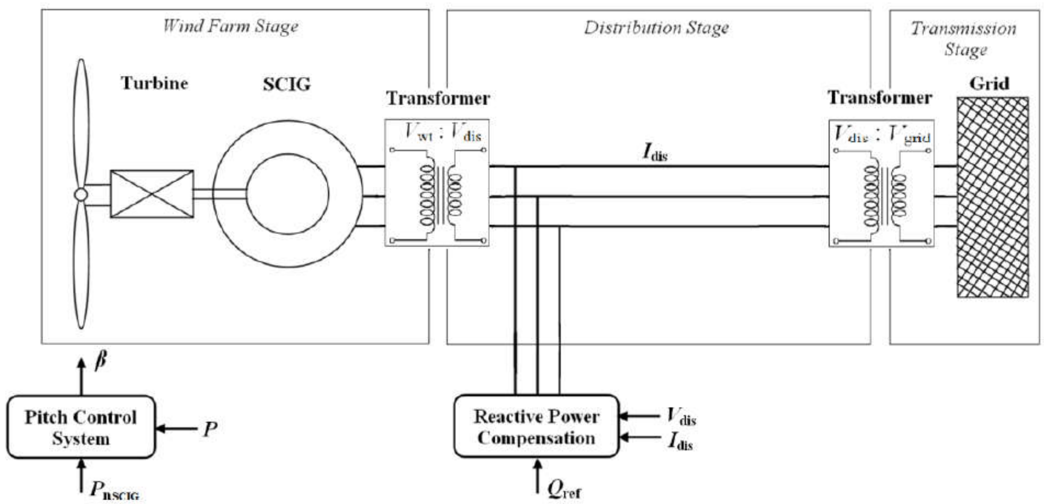

Figure 4.9: SCIG wind power system configuration

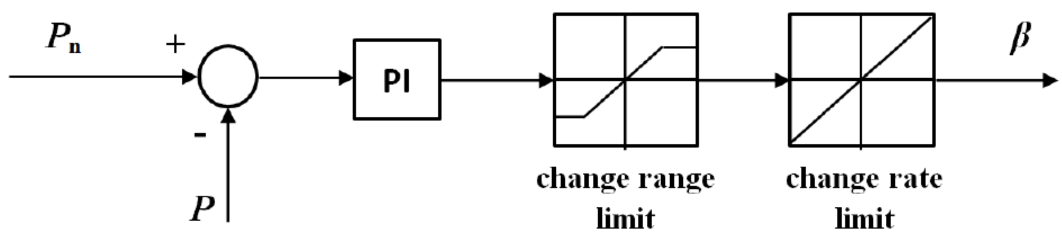

Figure 4.10 Pitch angle control

It is known that the generator speed can only vary in very small range around 1 p.u . and thus it is impossible to attain the optimal output power. Also, without independent control ability, SCIG system consumes reactive power of 0.41 Mvar at the steady state, which will lead to line voltage droop. To provide necessary reactive power, a Static Synchronous Compensator (STATCOM) is applied in distribution line. As in Figure 9, distribution line voltage can drop by approximately 0.055 p.u. in SCIG system without STATCOM, which will be a potential induction of overload in system. In contrast, SCIG system with STATCOM can hold distribution voltage at 0.99 p.u., which is favorable to grid system stability. The compensated reactive power from STATCOM is shown in Figure 6 and is equal to 0.3 Mvar at the steady state. Although STACOM provides impressive help to a constant distribution line voltage[10].

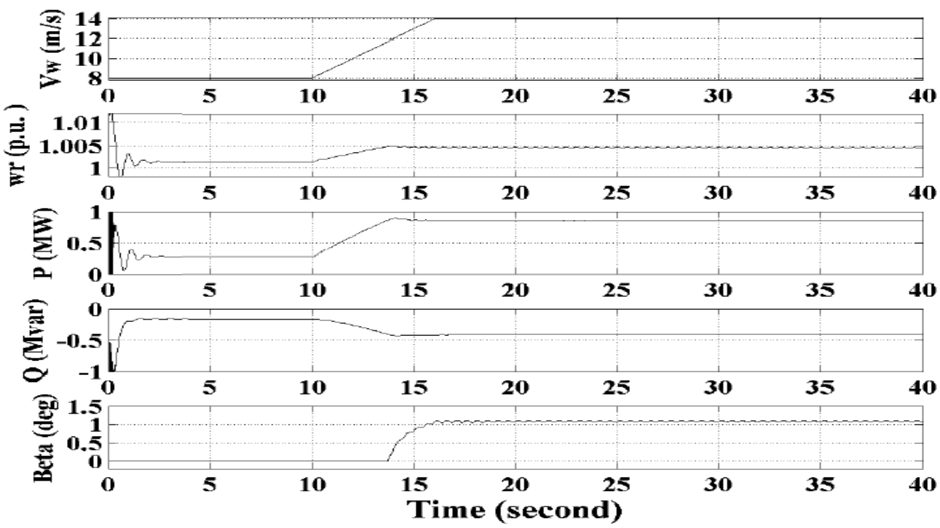

Figure 4.11: Pitch angle control for SCIG system[9]

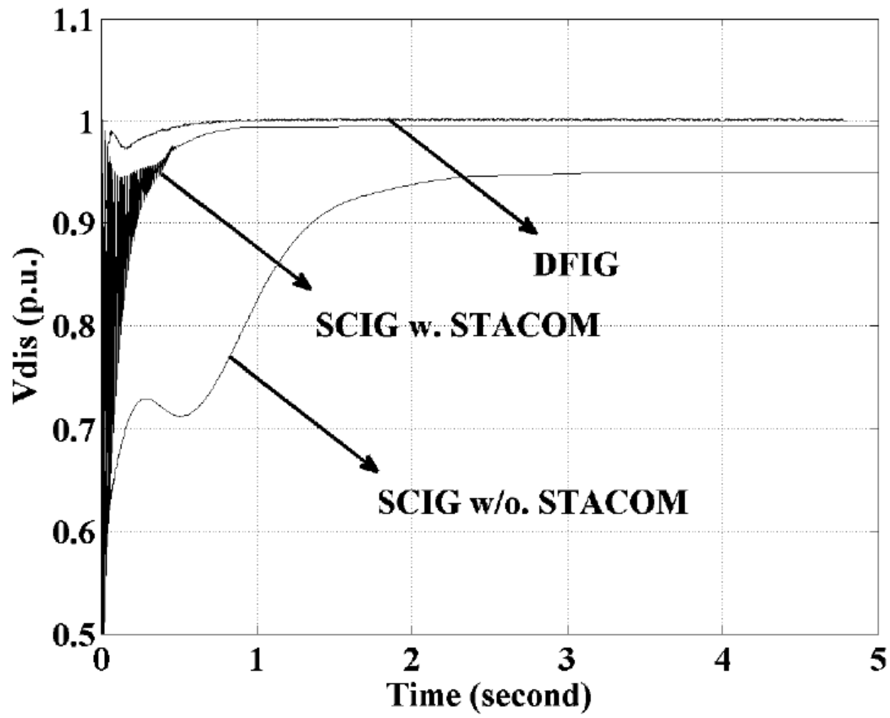

Figure 4.12: Grid voltages comparison between SCIG w/o. STACOM, SCIG w. STACOM and DFIG[9]

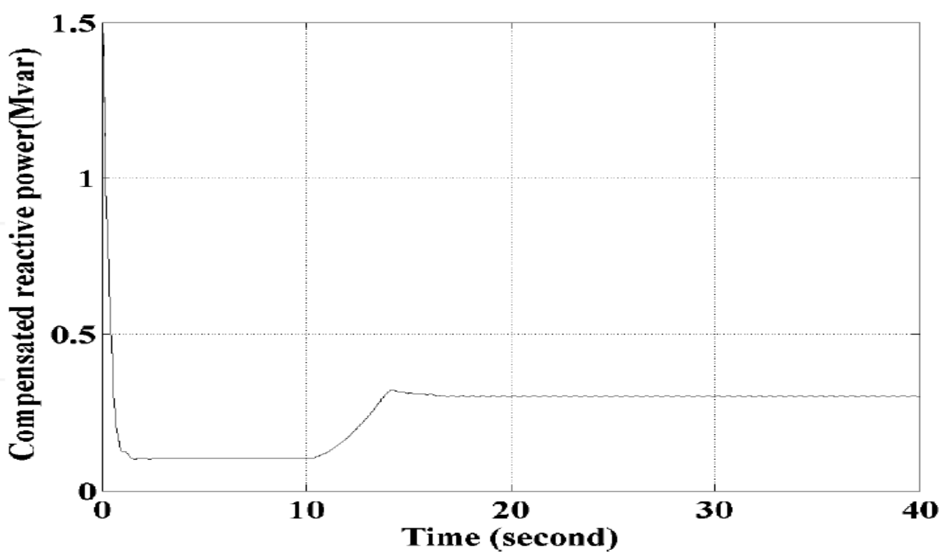

Figure 4.13: Compensated reactive power from STATCOM[9].

4.7 STATCOM Operation

STATCOM is a power electronics device based on the voltage source converter principle. The technology typically in use is a two level voltage source converter with a DC energy storage device, a coupling transformer connected in shunt with the power system, and DSP based control circuits. The main advantage of the STATCOM over thyristor type of static var compensators is that the compensating current does not depend on the voltage level of the connecting point and thus the compensating current is not lowered as the voltage drops. However, in the light of the new grid codes for wind generation, the most relevant feature of the STATCOM will be its inherent capability to increase the transient stability margin and thus contribute with ride through handling. STATCOM configuration is shown in the figure below :

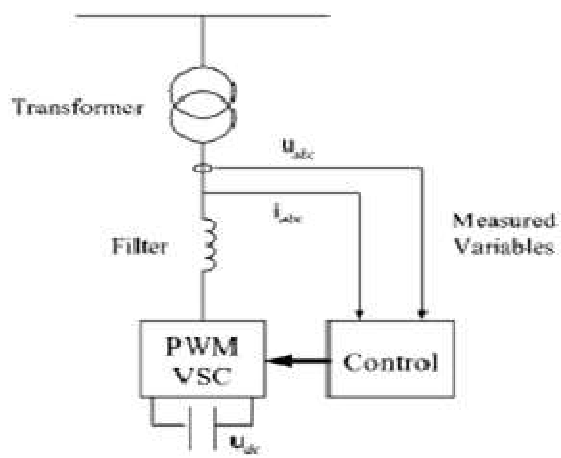

Figure 4.14: STATCOM configuration

It is the recent trend in reactive power control using voltage source PWM inverters. IT is the static realization of the synchronous condenser. Inductors are connected in series with AC supply. The inverters generate or absorb reactive power depending on its AC output voltage which in turn controlled to witching of IGBTs. The inverter produces a set of balanced voltages at the output terminals whose fundamental component VR is in phase with corresponding AC system voltage Vs. So only reactive power flows between the converter and system. When inverter output voltage VR is greater than AC system voltage VS, inverter acts as a capacitor generating lagging VAr. If VR < VS inverter acts as an inductor absorbing lagging VAr. In a practical inverter to supply inverter losses, the inverter output voltage VR is made to lag behind AC system voltage in case of capacitor operation and lead the AC system Voltage in case of inductor operation.

4.8 Generator control schemes in wind power systems

SCIG and DFIG are used almost exclusively in the energy conversion stage of the induction generator wind power system. The most commonly used system topologies are SCIG directly connected into the power grid and DFIG fed by back-to-back converter. The first topology implies a constant frequency and voltage of the SCIG that establishes a fixed-speed operation. In such system, the SCIG relies on the grid (or capacitor bank) to provide reactive power which is necessary to build electromagnetic excitation for rotary field. The generating mode of SCIG is triggered by driven torque which acts opposite to the generator speed within the super-synchronous speed operation region. Due to the absence of the power electronics interface, such system can only serve the grid support applications, wherein just limited control (pitch angle control) can be applied[4].

4.8.1 Pitch Angle Control

The system changes the pitch angle of the blades according to the variation of wind speed. As discussed earlier, with pitch control, it is possible to achieve a high efficiency by continuously aligning the blade in the direction of the relative wind.

On a pitch controlled machine, as the wind speed exceeds its rated speed, the blades are gradually turned about the longitudinal axis and out of the wind to increase the pitch angle. This reduces the aerodynamic efficiency of the rotor, and the rotor output power decreases. When the wind speed exceeds the safe limit for the system, the pitch angle is so changed that the power output reduces to zero and the machine shifts to the „stall" mode. After the gust passes, the pitch angle is reset to the normal position and the turbine is restarted. At normal wind speeds, the blade pitch angle should ideally settle to a value at which the output power equals the rated power.

The input variable to the pitch controller is the error signal arising from the difference between the output electrical power and the reference power. The pitch controller operates the blade actuator to alter the pitch angle. During operation below the rated speed, the control system endeavors to the pitch the blade at an angle that maximizes the rotor efficiency. The generator must be able to absorb the mechanical power output and deliver to the load. Hence, the generator output power needs to be simultaneously adjusted.

Figure 4.15: Typical power profiles for pitch control

4.8.2 Blade Pitch Control

If the rotor is able to control its blade pitch angle, it can be used not only for controlling rotor power and speed but also for smoothing out variations in loading and torque. Its efficiency as to the leveling of load peaks is, however, a question of response time, and this means the rate of blade pitching. Due to the inertia of the masses to be moved, and because

Overloading of the actuators is to be avoided, the blade pitch control mechanism is not able to react very rapidly to short-term fluctuations in wind speed. Load peaks which are consequences of longer and heavier gusts, however, will evoke responses and are partially absorbed (Fig.). In comparison with more recent rotors with active power control by aerodynamic stall, it is questionable, according to recent findings, whether blade pitch control is better for coping with dynamic loading due to wind turbulence.

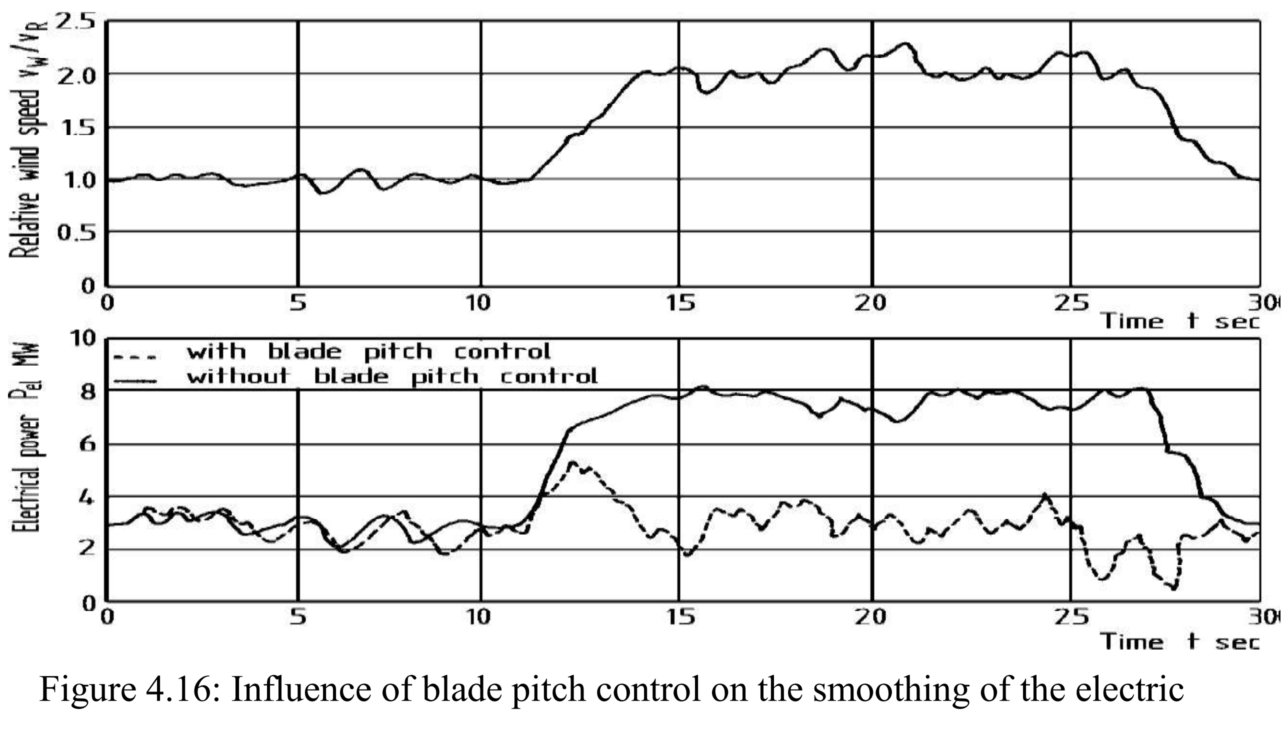

Figure 4.16: Influence of blade pitch control on the smoothing of the electric power output, using the Growian turbine as an example (without variable-speed operation

4.8.3 Blade Pitch Mechanism

Today nearly all, larger wind turbines have rotors equipped with blade pitch control .The mechanism required for this must basically fulfil two tasks. The primary task is to adjust the blade pitch angle for controlling the power and speed of the rotor. A pitching range of around 20 to 25 degrees is enough for this purpose. But apart from this main function, there is a second task which has considerable influence on the design of the blade pitch mechanism. To brake the rotor aerodynamically, it must be possible to pitch the rotor blades to the feathered position. This increases the pitching range to approximately 90°. The implementation of the blade pitch mechanics offers the designer possibilities for design creativity scarcely rivaled by any other system. The models implemented are accordingly varied and the proposals and patents are even more numerous.

4.8.4 Electrically Driven Blade Pitch Systems

In the beginning of modern wind turbine technology, electrical blade pitching used to be an exception in wind turbines. In principle, it is much more difficult to control electrical pitching drives. The speed and torque of common electric motors can only be controlled in practice by using frequency converters. Otherwise highly expensive direct-current units must be used. The ability to control the rate of pitch adjustment is essential in large turbines so that the loads on the rotor blades can be limited .Today, electronically-controlled pitch motors of very compact design are available which has led to the increasing use of electrical blade pitching drives by wind turbine manufacturers. The first one of these was Enercon where each rotor blade on their medium-sized range of turbines (E-40) has its own electric pitch motor. In recent years ,significant advances have been achieved in the field of electric blade pitch drives and their control systems. The suppliers have adapted themselves and are supplying the components as mass-produced articles.

Figure 4.17: Electrical blade pitch system inside the rotor hub (Rexroth)

4.8.5 Redundancy and Safety Issues

To prevent a runaway of the rotor when its load is suddenly lost, large wind turbines can only brake the rotor by adjusting the pitch of the rotor blades .Apart from structural strength, the second most vital safety feature of a wind turbine is, therefore, the reliability of the blade pitching mechanism .With this in mind, redundancy in the components and control circuits involved in rotor blade pitching is an indispensable requirement .A thorough “reliability and failure-mode analysis” of the blade pitch mechanism should, therefore. be required for all wind turbines. In order to assess the redundancy of the blade pitch adjustment mechanism in case of an emergency, three different functional areas must be considered:

– Sensor and release mechanism,
– Actuating elements,
– Power/pressure supplies.

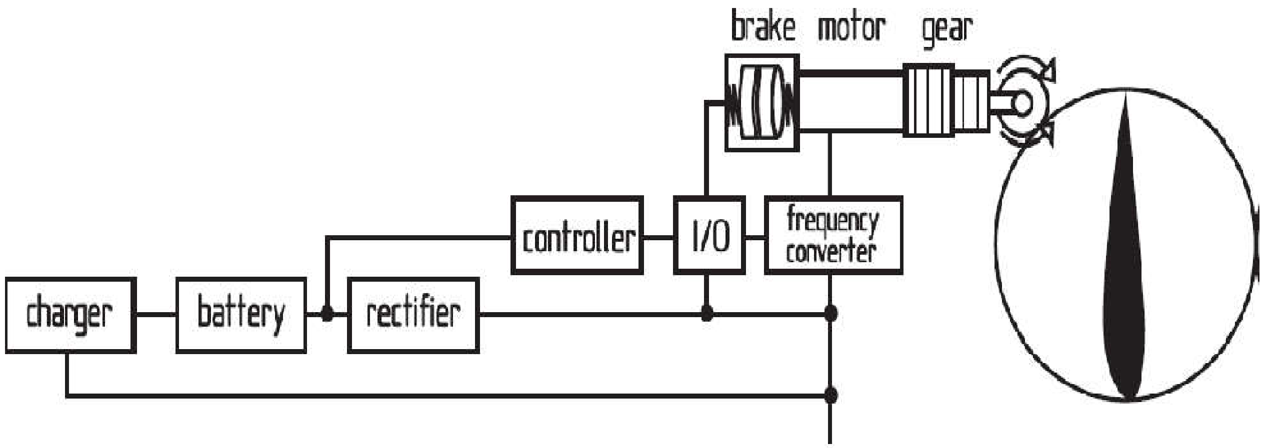

Figure4.18:Electrical power supply with batteries for emergency pitching in the case of electrical pitch control systems

4.9 Control Strategy

Different speed control strategies are required for the five different ranges of wind speed:

- Power is not generated by the machine below a cut-in speed. Rotation of the machine may start in this speed range if there is sufficient starting torque. But no power is generated and rotor rotates freely.

- Maximum power is extracted from the wind at normal wind speeds. This is achieved at a particular TSR value. Hence, for tracking maximum power point, rotational speed is changed continuously proportional to the wind speed.

- At high wind speeds, rotor speed is limited to a maximum value which depends on the design of the mechanical components. Here is lower than the maximum value. Power output is not proportional to the cube of the wind speed.

- At even higher wind speeds, output power is kept constant at the maximum value allowed by the electrical components.

- At cut-out or furling wind speed, the power generation is shut down and the rotation is stopped in order to protect the system components.

4.10 Induction Generator versus Synchronous Generator

Synchronous generators and induction generators have their own merits and limitations. The balance between the advantages and disadvantages of the two is situation specific. A cage induction machine is preferred for its ruggedness and low cost compared to a synchronous generator.

The induction machine, coupled to the utility system, finds favor for fixed-pitch, nearly constant speed wind turbines in order to provide damping for the wind turbine drive train when it faces fluctuation in the power input due to wind speed variations. An induction generator has no synchronization problem. It has relaxed stability criteria and is practically free form hunting owing to the presence of damping, given by the slope of the induction machine torque-slip curve. On the other hand, transient stability may be a serious problem with the grid-connected synchronous machine as it represents a stiff compliance in the dynamic model of the wind turbine drive train. Damping must be provided for either in the machine or mechanically in the drive train.

For symmetrical faults, an induction generator does not contribute any fault current to the network except instantaneous fault current, while for unbalanced faults the contribution is sustained. Whether it is balanced or unbalanced fault, a synchronous generator contributes fault current.

An induction generator demands lagging reactive VA of the order of 30% of its output kVA from the utility system and produces a current surge at the time of witching-in and during acceleration, both these adversely affecting the voltage of a network with a low fault level. Against this background, a synchronous generator has a low excitation demand, and its active and reactive power can be adjusted by pitch control and field control. In autonomous systems, voltage adjustment by field control is simple.

4.11 Conclusion

The SCIG system presents requires external reactive power source to support grid voltage and it can keep the output power at the nominal level by pitch control but cannot change the rotor speed to achieve maximum wind power capture at different wind speed.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main advantages of renewable are available, clean, low cost and continuous energy. The reasons for choosing induction generator in wind energy system are that its very reliable tends to be comparatively inexpensive, light weight, and low maintenance. The generator also has some mechanical properties which are useful for wind turbines. So, the induction generator is the most common generator in wind energy system applications due to its simplicity and ruggedness.

The Squirrel-Cage Induction Generator system presents requires external reactive power source to support grid voltage and it can keep the output power at the nominal level by pitch control but cannot change the rotor speed to achieve maximum wind power capture at different wind speed.

5.2 Recommendations

- Implementation a project a practically.
- Impalement economic Feasibility study.
- Implementation a project a Simulation.
- Design system to connect the wind generation station with electrical grid.
- Study the doubly feed induction generator systems ,and compare it with the squire cage induction generator .
- Study the effect of the connection of wind stations to the grid.

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APPENDIX A1

PITCH CONTROL ANALYSIS BY MATLAB

Explanation:

$$P_m = 0.5C_p(\lambda, \beta)\rho A V_w^3$$

Where:

Pm is mechanical output power of the wind turbine;

$C_p(\lambda,\beta)$ is the performance coefficient of the turbine;

ρ is the density of air in kg/m3;

A is the swept area of turbine;

Vw is the wind speed (m/s);

λ is the tip speed ratio;

β pitch angle of blade in degrees;

A basic equation used to model $C_p(\lambda,\beta)$.

$$C_p(\lambda, \beta) = C_1\left(\frac{C_2}{\lambda} - \beta C_3 - C_4\right)e^{\frac{C_5}{\lambda_i}} + C_6\lambda$$

And

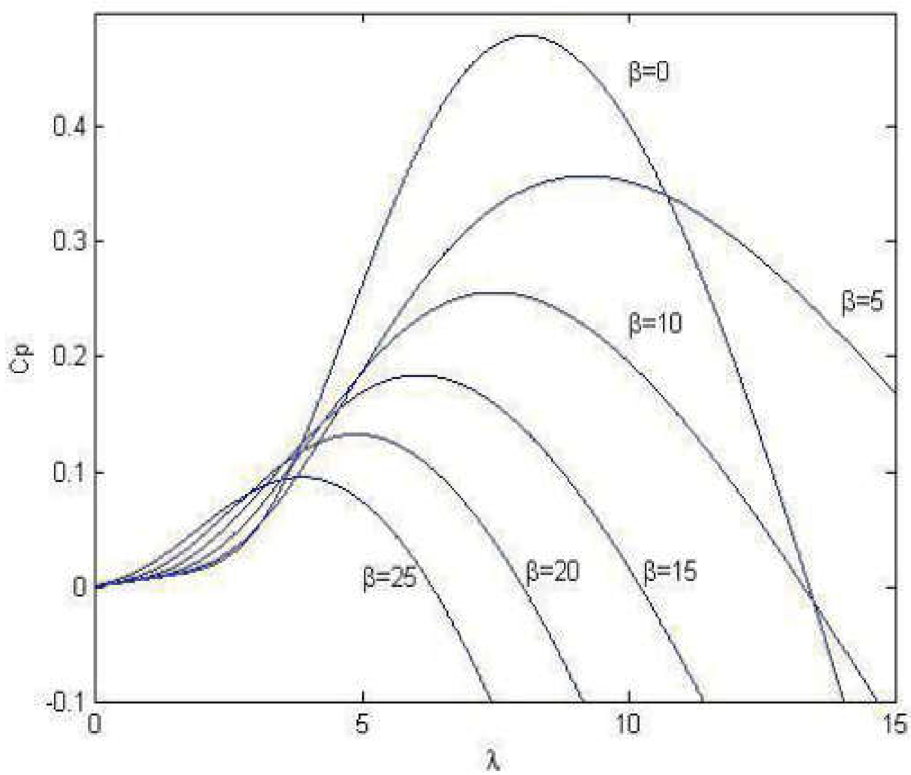
$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

The coefficients c1 to c6 are: c1 = 0.5176, c2 = 116, c3 = 0.4, c4 = 5, c5 = 21 and c6 = 0.0068. The Cp-λ characteristics, for different values of the pitch angle β, are illustrated below. The maximum value of Cp (Cpmax = 0.48) is achieved for β = 0 degree and for λ = 8.1. This particular value of λ is defined as the Nominal value (λ_nom).

PROGRAM:

```
L=0.01:0.1:15;

c1=0.5176;

c2=116;

c3=0.4;

c4=5;

c5=21;

c6=0.0068;

pitch=0:5:25;

for i=1:6

for p=1:length(L);

A(p)=1/(L(p)+0.08*pitch(i))-0.035/(pitch(i)^3+1);

C(p)=c1*(c2*A(p)-c3*pitch(i)-c4)*exp(-c5*A(p))+c6*L(p);

end

plot(A(p),C(p));
```

```
hold on;

end

axis ([0 15 -0.1 0.5]);

xlabel('\lambda'),ylabel('Cp');
```



APPENDIX B1

WIND TURBINE OUTPUT POWER VS. ROTATONAL SPEED, WITH WIND SPEED AS PARAMETER

PROGRAM:

```
c1=0.5176; c2=116; c3=0.4; c4=5; c5=21; c6=0.0068; r0=1.29; D=40;
A=pi*D^2/4;

L=0.01:0.1:15;

b=0;

V=[8,10,12,14,16,18,20];

for k=1:length(V)

for p=1:length(L);

AI(p)=1/(L(p))-0.035;

CP(p)=c1*(c2*AI(p)-c4)*exp(-c5*AI(p))+c6*L(p);

P(k,p)=(V(k)^3)*CP(p)*r0*A/2;

n(k,p)=(60/(pi*D))*AI(p)*V(k);

end;

hold on;

end;
```

```
M=max(P(6,:)); m=max(M); P=P/m; n1=length(L); n2=length(V);

for j=1:n1;

P(:,n1-j+1)=P(:,j);

end;

PR=P;

for q=1:n2;

plot(n(q,:), PR(q,:)); hold on

end;

grid; axis([0.1,1.45,-0.1,1.4]);

xlabel('rotational speed(relative units)'),ylabel('power (relative units)');
```