Chapter one
Introduction

1. Introduction

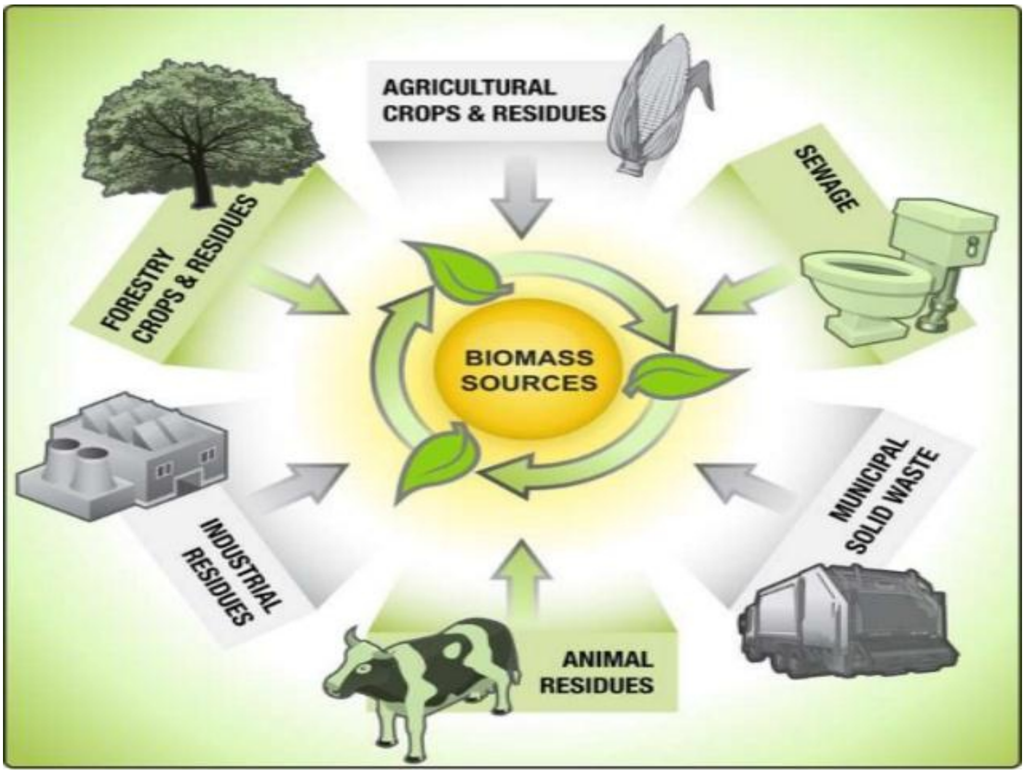
Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. Furthermore, they tend to be cyclical in nature, due to the effects of oligopoly in production and distribution. These traditional fossil fuel-based energy sources are facing increasing pressure on a host of environmental fronts, with perhaps the most serious challenge confronting the future use of coal being the Kyoto Protocol greenhouse gas (GHG) reduction targets. It is now clear that any effort to maintain atmospheric levels of CO2 below even 550 ppm cannot be based fundamentally on an oil and coal-powered global economy, barring radical carbon sequestration efforts.

The potential of renewable energy sources is enormous as they can in principle meet many times the world's energy demand. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources. A transition to renewables-based energy systems is looking increasingly likely as the costs of solar and wind power systems have dropped substantially in the past 30 years, and continue to decline, while the price of oil and gas continue to fluctuate. In fact, fossil fuel and renewable energy prices, social and environmental costs are heading in opposite directions. Furthermore, the economic and policy mechanisms needed to support the widespread dissemination and sustainable markets for renewable energy systems have also rapidly evolved. It is becoming clear that future growth in the energy sector is primarily in the new regime of renewable, and to some extent natural gas-based systems, and not in conventional oil and coal sources. Financial markets are awakening to the future growth potential of renewable and other new energy technologies, and this is a likely harbinger of the economic reality of truly competitive renewable energy systems.

In addition, renewable energy systems are usually founded on a small-scale, decentralized paradigm that is inherently conducive to, rather than at odds with, many electricity distribution, cogeneration (combined heat and power), environmental, and capital cost issues. As an alternative to custom, onsite construction of centralized power plants, renewable systems based on PV arrays, windmills, biomass or small hydropower, can be mass-produced "energy appliances" capable of being manufactured at low cost and tailored to meet specific energy loads and service conditions. These systems can have dramatically reduced as well as widely dispersed environmental impacts, rather than larger, more centralized impacts that in some cases are serious contributors to ambient air pollution, acid rain, and global climate change. Renewable energy sources currently supply somewhere between 15 percent and 20 percent of world's total energy demand. The supply is dominated by traditional biomass, mostly fuel wood used for cooking and heating, especially in developing countries in Africa, Asia and Latin America. A major contribution is also obtained from the use of large hydropower; with nearly 20 percent of the global electricity supply being provided by this source. New renewable energy sources (solar energy, wind energy, modern bio-energy, geothermal energy, and small hydropower) are currently contributing about two percent. A number of scenario studies have investigated the potential contribution of renewables to global energy supplies, indicating that in the second half of the 21st century their contribution might range from the present figure of nearly 20 percent to more than 50 percent with the right policies in place.

2. Type of Renewable Energy

1. Biomass Energy



Introduction

Biomass is the term used for all organic material originating from plants (including algae), trees and crops and is essentially the collection and storage of the sun's energy through photosynthesis. Biomass energy, or bioenergy, is the conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels. Biomass for bioenergy comes either directly from the land, as dedicated energy crops, or from residues generated in the processing of crops for food or other products such as pulp and paper from the wood industry. Another important contribution is from post-consumer residue streams such as construction and demolition wood, pallets used in transportation, and the clean fraction of municipal solid waste (MSW). The biomass to bioenergy system can be considered as the management of flow of solar generated materials, food, and fiber in our society. These interrelationships are shown in Figure 1, which presents the various resource types and applications, showing the flow of their harvest and residues to bioenergy applications. Not all biomass is directly used to produce energy but rather it can be converted into intermediate energy carriers called biofuels. This includes charcoal (higher energy density solid fuel), ethanol (liquid fuel), or producer-gas (from gasification of biomass).

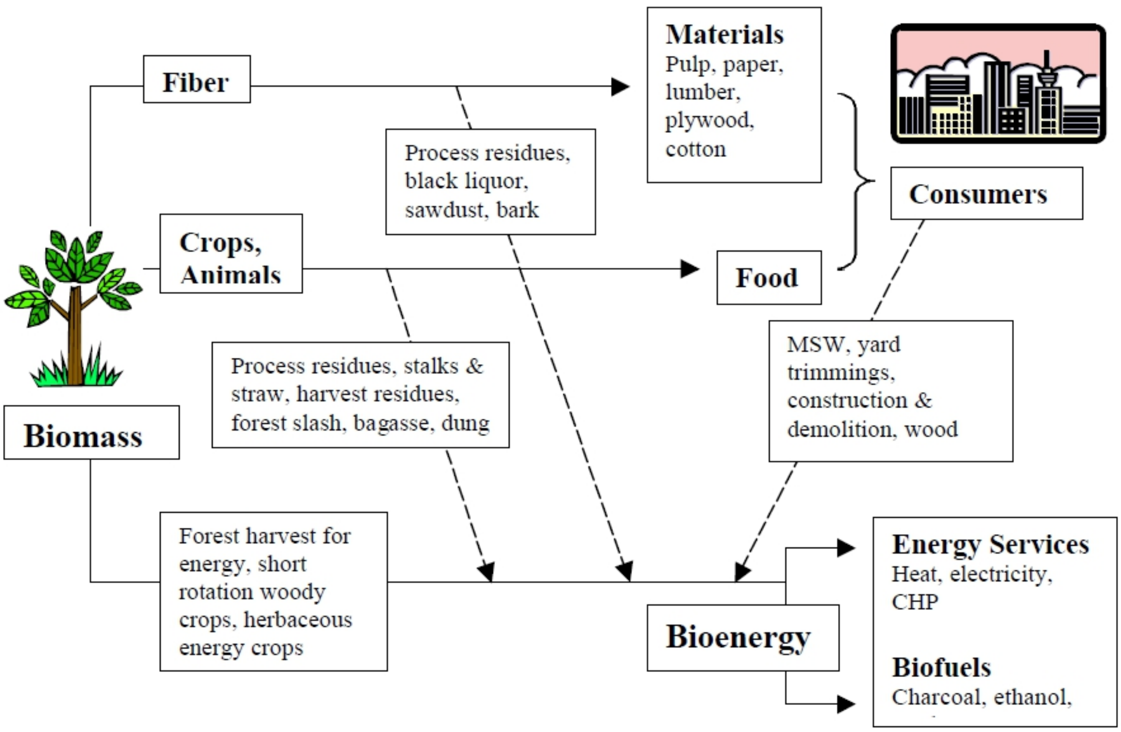


Figure 1. Biomass and bioenergy flow chart (Source: R.P. Over end, NREL, 2000)

Biomass was the first energy source harnessed by humans, and for nearly all of human history, wood has been our dominant energy source. Only during the last century, with the development of efficient techniques to extract and burn fossil fuels, have coal, oil, and natural gas, replaced wood as the industrialized world's primary fuel. Today some 40 to 55 exajoules (EJ = 1018 joules) per year of biomass is used for energy, out of about 450 EJ per year of total energy use, or an estimated 10-14 percent, making it the fourth largest source of energy behind oil (33 percent), coal (21 percent), and natural gas (19 percent). The precise amount is uncertain because the majority is used non-commercially in developing countries.

An Intergovernmental Panel on Climate Change (IPCC) study has explored five energy supply scenarios for satisfying the world's growing demand for energy services in the 21st century while limiting cumulative CO2 emissions between 1990 and 2100 to fewer than 500 gigatonnes of carbon. In all scenarios, a substantial contribution from carbon-neutral biomass energy as a fossil fuel substitute is included to help meet the CO2 emissions targets. When biomass is grown at the same average rate as it is harvested for energy, it is approximately carbon-neutral: carbon dioxide extracted from the atmosphere during growth is released back to the atmosphere during conversion to energy. Figure 2 shows the results for the IPCC's most biomass-intensive scenario where biomass energy contributes 180 EJ/year to global energy supply by 2050 – satisfying about one-third of the total global energy demand, and about half of total energy demand in developing countries. Roughly two-thirds of the global biomass supply in 2050 is assumed to be produced on high-yield energy plantations covering nearly 400 million hectares, or an area equivalent to one-quarter of present planted agricultural area. The other one-third comes from residues produced by agricultural and industrial activities.

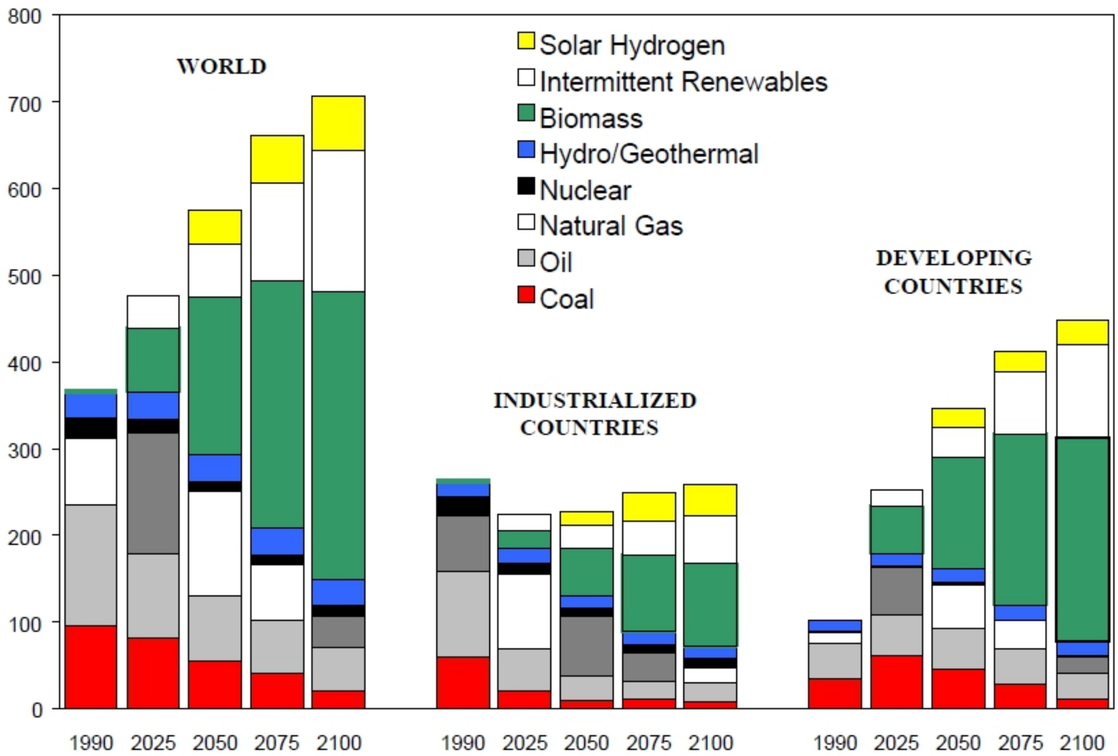


Figure 2. Primary commercial energy use by source for the biomass-intensive variant of the IPCC model (IPCC, 1996), shown for the world, for industrialized countries, and for developing countries (Source: Sivan, 2000)

Economic and Production Issues

A number of key areas can be identified which are essential for the successful development and implementation of sustainable, economically competitive bioenergy systems.

The main barrier is whether the energy carriers produced are competitive. This is particularly true when specially produced biomass is used. In many situations where cheap or negative cost biomass wastes and residues are available, the utilization of biomass is or could be competitive and future technology development should help further reduce the costs of bioenergy. In Sweden and Denmark, where a carbon and energy tax has been introduced, more expensive wood fuels and straw are now being used on a large scale. However, on a worldwide basis, the commercial production of energy crops is almost non-existent. Brazil is a major exception where subsidies have been introduced to make ethanol from sugarcane competitive with gasoline.

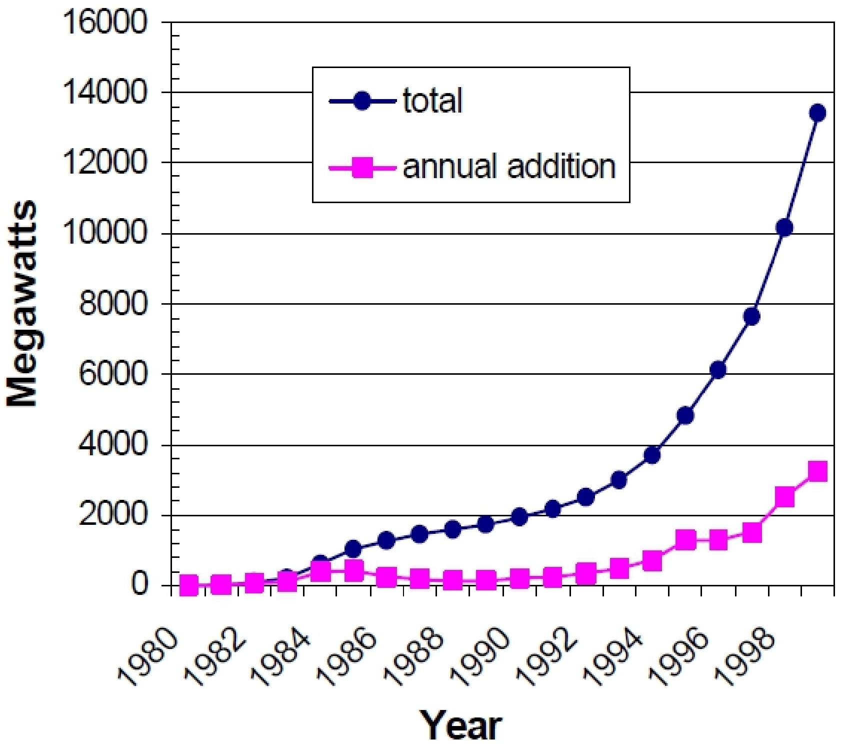
2.Wind Energy

Introduction

Wind has considerable potential as a global clean energy source, being both widely available, though diffuse, and producing no pollution during power generation. Wind energy has been one of humanity's primary energy sources for transporting goods, milling grain, and pumping water for several millennia. From windmills used in China, India and Persia over 2000 years ago to the generation of electricity in the early 20th century in Europe and North America wind energy has played an important part in our recorded history. As industrialization took place in Europe and then in America, wind power generation declined, first gradually as the use of petroleum and coal, both cheaper and more reliable energy sources, became widespread, and then more sharply as power transmission lines were extended into most rural areas of industrialized countries. The oil crises of the 70's, however, triggered renewed interest in wind energy technology for grid connected electricity production, water pumping, and power supply in remote areas, promoting the industry's rebirth.

This impetus prompted countries; notably Denmark and the United States, to establish government research and development (R&D) programs to improve wind turbine technology. In conjunction with private industry research this lead to a reemergence in the 1980's of wind energy in the United States and Europe, when the first modern grid-connected wind turbines were installed. In the 1990's this development accelerated, with wind becoming the fastest growing energy technology in the world developing into a commercially competitive global power generation industry. While in 1990 only about 2000 MW of grid-connected wind power was in operation worldwide by 1999 this figure had surpassed 10,000 MW, not including the over one million water-pumping wind turbines located in remote areas. Since 1990 the average annual growth rate in world wind generating capacity has been 24 percent, with rates of over 30 percent in the last two years. Today there is more than 13,000 MW of installed wind power, double the capacity that was in place just three years earlier (Figure 3). This dramatic growth rate in wind power has created one of the most rapidly expanding industries in the world, with sales of roughly $2 billion in 1998, and predictions of tenfold growth over the next decade. Most 2000 forecasts for installed capacity are being quickly eclipsed with wind power having already passed the 10,000 MW mark in early 1999.

Figure 3. World wind generating capacity, total and annual additions (Source: World watch Institute, 1999)



Economics of Wind Energy

Larger turbines, more efficient manufacturing, and careful siting of wind machines have brought wind power costs down precipitously from $2600 per kilowatt in 1981 to $800 per kilowatt in 1998. New wind farms in some areas have now reached economic parity with new coal-based power plants. And as the technology continues to improve, further cost declines are projected, which could make wind power the most economical source of electricity in some countries. Market growth, particularly in Europe, has been stimulated by a combination of favorable governmental policies, lower costs, improved technology (compared to wind turbines built in 1981, modern turbines generate 56 times the energy at only 9 times the cost), and concern over environmental impacts of energy use. Wind energy is currently one of the most cost-competitive renewable energy technologies. Worldwide, the cost of generating electricity from wind has fallen by more than 80 percent, from about 38 US cents in the early1980s to a current range of 3-6 UScents/kWh levelized over a plant's lifetime, and analysts forecast that costs will drop an additional 20-30 percent in the next five years. Consequently, in the not-too-distant future, analysts believe, wind energy costs could fall lower than most conventional fossil fuel generators, reaching a cost of 2.5 UScents/kWh (Figure 4).

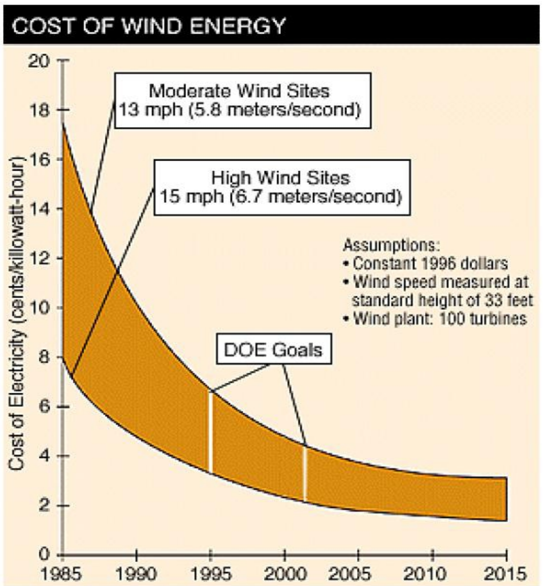


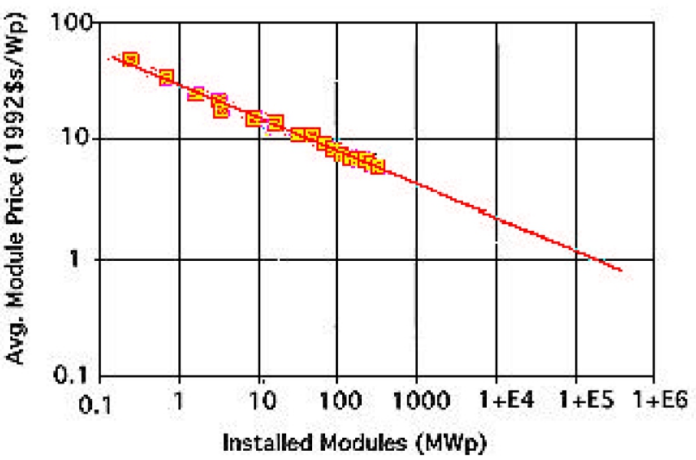
Figure 4. Trends in wind energy costs (Source: U.S. DOE, 1998; http://www.eren.doe.gov/wind/wttr.html)

3.Solar Photovoltaic and Solar Thermal Technologies

There are two basic categories of technologies that convert sunlight into useful forms of energy, aside from biomass-based systems that do this in a broader sense by using photosynthesis from plants as an intermediate step. First, solar photovoltaic (PV) modules convert sunlight directly into electricity. Second, solar thermal power systems use focused solar radiation to produce steam, which is then used to turn a turbine producing electricity. The following provides a brief overview of these technologies, along with their current commercial status.

1. Solar Photovoltaics

Solar PV modules are solid-state semiconductor devices with no moving parts that convert sunlight into direct-current electricity. The basic principle underlying the operation of PV modules dates back more than 150 years, but significant development really began following Bell Labs' invention of the silicon solar cell in 1954. The first major application of PV technology was to power satellites in the late 1950s, and this was an application where simplicity and reliability were paramount and cost was a secondary concern. Since that time, enormous progress has been made in PV performance and cost reduction, driven at first by the U.S. space program's needs and more recently through private/public sector collaborative efforts in the U.S., Europe, and Japan.



At present, annual global PV module production is over 150

MW, which translates into a more than $1 billion/year business. In addition to the ongoing use of PV technologies in space, their present-day cost and performance also make them suitable for many grid-isolated and even grid connected applications in both developed and developing parts of the world. PV technologies are potentially so useful that as their comparatively high initial cost is brought down another order of magnitude, it is very easy to imagine them becoming nearly ubiquitous late in the 21st century. PV systems would then likely be employed on many scales in vastly differing environments, from microscopic cells to 100 MW or larger 'central station' generating plants covering square kilometers on the earth's surface and in space. The technical and economic driving forces that favor the use of PV technologies in these widely diverse applications will be equally diverse. However, common among them will be the durability, high efficiency, quiet operation, and lack of moving parts that PV systems offer, and the fact that these attributes combine to provide a power source with minimum maintenance and unmatched reliability. PV system cost and performance have been steadily improving in recent years. PV manufacturing costs have fallen from about $30 per watt in 1976 to well under $10 per watt by the mid-1990s as can be seen in Figure 5. Installed PV system costs today are about $8.00 to $12.00 per watt, depending on the level of solar insolation at the site and other factors. These installed system costs are expected by some analysts to reach a range of from $3.00 to $6.00 perwatt by 2010, and if this is achieved PV systems could achieve a sales level of over 1,600 MW per year by that time.

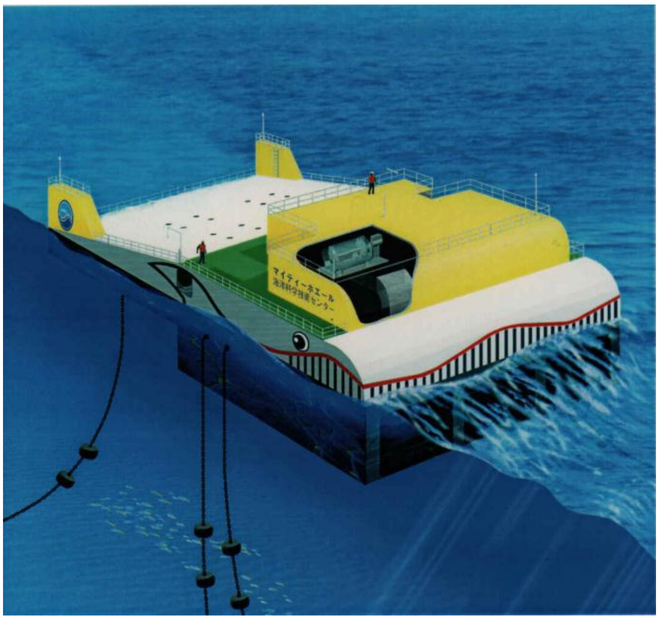
Figure 5. PV module price trend from 1976 to 1994 along 82 percent progress ratio (Source: U.S. DOE, 1997)

2. Solar Thermal Systems

Solar thermal power systems use various techniques to focus sunlight to heat an intermediary fluid, known as heat transfer fluid that then is used to generate steam.

The steam is then used in a conventional steam turbine to generate electricity. At present, there are three solar thermal power systems currently being developed: parabolic troughs, power towers, and dish/engine systems. Because these technologies involve a thermal intermediary, they can be readily hybridized with fossil fuels and in some cases adapted to utilize thermal storage. The primary advantage of hybridization and thermal storage is that the technologies can provide dispatch able power and operate during periods when solar energy is not available. Hybridization and thermal storage can enhance the economic value of the electricity produced, and reduce its average cost. Parabolic trough solar thermal systems are commercially available. These systems use parabolic trough-shaped mirrors to focus sunlight on thermally efficient receiver tubes that contain a heat transfer fluid. This fluid is heated to about 390° C. (734° F) and pumped through a series of heat exchangers to produce superheated steam that powers a conventional turbine generator to produce electricity. Nine of these parabolic trough systems, built in 1980s, are currently generating 354 MW in Southern California. These systems, sized between 14 and 80 MW, are hybridized with up to 25 percent natural gas in order to provide dispatch able power when solar energy is not available. Power tower solar thermal systems are in the demonstration and scale-up phase. They use a circular array of heliostats (large individually-tracking mirrors) to focus sunlight onto a central receiver mounted on top of a tower. The first power tower, Solar One, was built in Southern California and operated in the mid-1980s. This initial plant used a water/steam system to generate 10 MW of power. In 1992, a consortium of U.S. utilities joined together to retrofit Solar One to demonstrate a molten-salt receiver and thermal storage system. The addition of this thermal storage capability makes power towers unique among solar technologies by allowing dispatch able power to be provided at load factors of up to 65 percent. In this system, molten-salt is pumped from a “cold” tank at 288° C. (550° F) and then cycled through the receiver where it is heated to 565° C. (1,049° F) and finally returned to a “hot” tank. The hot salt can then be used to generate electricity when needed. Current designs allow storage ranging from 3 to 13 hours.

4. Hydropower



5.1. Introduction

Hydropower is the largest renewable resource used for electricity. It plays an essential role in many regions of the world with more than 150 countries generating hydroelectric power. A survey in 1997 by The International Journal on Hydropower & Dams found that hydro supplies at least 50 percent of national electricity production in 63 countries and at least 90 percent in 23 countries. About 10 countries obtain essentially all their commercial electricity from hydro, including Norway, several African nations, Bhutan and Paraguay. There is about 700 GW of hydro capacity in operation worldwide, generating 2600 TWh/year (about 19 percent of the world's electricity production). About half of this capacity and generation is in Europe and North America with Europe the largest at 32 percent of total hydro use and North America at 23 percent of the total. However, this proportion is declining as Asia and Latin America commission large amounts of new hydro capacity. Small, mini and micro hydro plants (usually defined as plants less than 10 MW, 2 MW and 100kW, respectively) also play a key role in many countries for rural electrification. An estimated 300 million people in China, for example, depend on small hydro.

Small Hydro

Small-scale hydro is mainly ‘run of river,’ so does not involve the construction of large dams and reservoirs. It also has the capacity to make a more immediate impact on the replacement of fossil fuels since, unlike other sources of renewable energy, it can generally produce some electricity on demand (at least at times of the year when an adequate flow of water is available) with no need for storage or backup systems. It is also in many cases cost competitive with fossil-fuel power stations, or for remote rural areas, diesel generated power. Small hydro has a large, and as yet untapped, potential in many parts of the world. It depends largely on already proven and developed technology with scope for further development and optimization. Least-cost hydro is generally high-head hydro since the higher the head, the less the flow of water required for a given power level, and so smaller and less costly equipment is needed. While this makes mountainous regions very attractive sites they also tend to be in areas of low population density and thus low electricity demand and long transmission distances often nullify the low cost advantage. Low-head hydro on the other hand is relatively common, and also tends to be found in or near concentrations of population where there is a demand for electricity. Unfortunately, the economics also tend to be less attractive unless there are policy incentives in place to encourage their development.

5. Geothermal Energy

Introduction

Geothermal energy, the natural heat within the earth, arises from the ancient heat remaining in the Earth's core, from friction where continental plates slide beneath each other, and from the decay of radioactive elements that occur naturally in small amounts in all rocks. For thousands of years, people have benefited from hot springs and steam vents, using them for bathing, cooking, and heating. During this century, technological advances have made it possible and economic to locate and drill into hydrothermal reservoirs, pipe the steam or hot water to the surface, and use the heat directly (for space heating, aquaculture, and industrial processes) or to convert the heat into electricity. The amount of geothermal energy is enormous. Scientists estimate that just 1 percent of the heat contained in just the uppermost 10 kilometers of the earth’s crust is equivalent to 500 times the energy contained in all of the earth's oil and gas resources. Yet, despite the fact that this heat is present in practically inexhaustible quantities, it is unevenly distributed, seldom concentrated and often at depths too great to be exploited industrially and economically.

Geothermal energy has been produced commercially for 70 years for both electricity generation and direct use. Its use has increased rapidly during the last three decades and from 1975 – 1995 the growth rate for electricity generation worldwide has been about 9 percent per year and for direct use of geothermal energy it has been about 6 percent per year. In 1997 geothermal resources had been identified in over 80 countries and there were quantified records of geothermal utilization in at least 46 countries.

Chapter two

Wind Energy

1. – Different wind turbine types: An overview

Today there are various types of wind turbines in operation, (fig. 1 gives an overview). The most common device is the horizontal axis wind turbine. This turbine consists of only a few aerodynamically optimised rotor blades, which for the purpose of regulation usually can be tumbled about their long axis (Pitch-regulation). Another cheaper way to regulate it, consists in designing the blades in such a way that the air streaming along the blades will go into turbulence at a certain speed (Stall-Regulation). These turbines can deliver power ranging from 10 kW to some MW. The largest turbine on the European

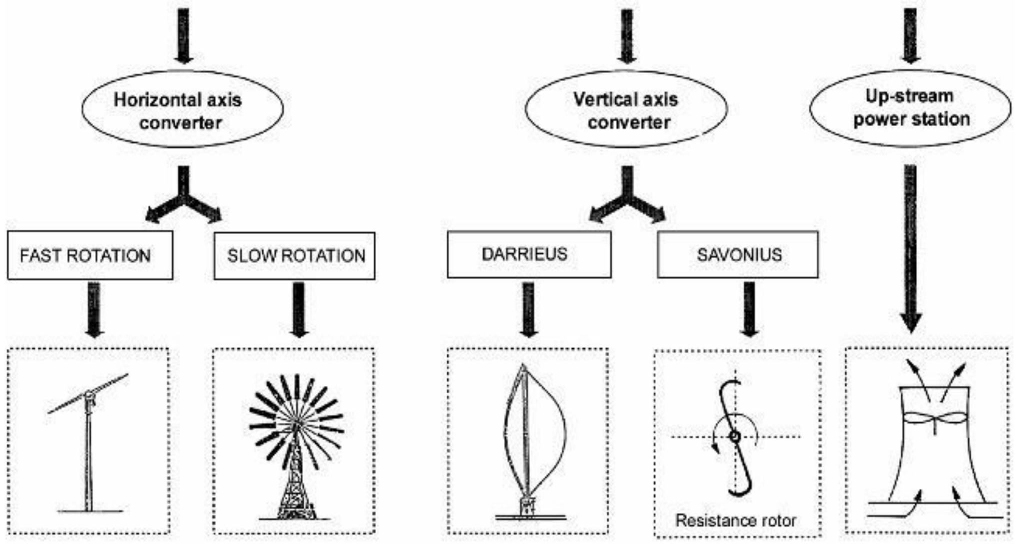


Fig. 1. – Overview of the different types of wind turbines.

market has a power of 3.6 MW, bigger machines are testing. The efficiency of this type of turbine is very high. Therefore, it is solely used for electricity generation which needs “high-speed engines” to keep the gear transmission and the generator small and cheap.

Another conventional (older) type of horizontal-axis rotor, is the multiblade wind turbine. It was first built about one hundred years ago. Such wind mills have a high starting torque which makes them suitable for driving mechanical water pumps. The number of rotations is low, and the blades are made from simple sheets with an easy geometry. For pumping water, a rotation regulating system is not necessary, but there is a mechanical safety system installed to protect the turbine against storm damage. By using a so-called wind-sheet in lee direction the rotor is turned in the direction of the wind. In order to increase the number of rotations, this type of turbine had been equipped with aerodynamically more efficient blades facilitating the production of electricity, here the area of a blade is smaller.

The mechanical stability of such “slow-speed turbines” is very high, some have had operation periods of more than fifty years.

A third type of turbine is known as DARRIEUS; a vertical-axis construction. Their advantage is that they do not depend on the direction of the wind. To start, they need the help of a generator working as motor or the help of a SAVONIUS rotor installed on top of the vertical axis. In the nineteen eighties a reasonable number of DARRIEUS turbines had been installed in California, but a further expansion into the higher power range and in the European markets has not taken place. One reason may be that they are noisier than horizontal-axis turbines. Another disadvantage is that wind velocity increases significantly with height, making horizontal-axis wheels on towers more eco-nomical. Nevertheless, there are some companies producing DARRIEUS turbines in the very low power range of a few kilowatts for decentralised electricity supply in areas without electrical grids, *e.g.*, in rural areas of developing countries.

The SAVONIUS rotor is only used for research activities, *e.g.* as a measurement device especially for wind velocity, it is not used for power production. Therefore it will not be discussed in detail in this paper.

The last technique to be dealt with is known as Up-Stream-Power-Station or thermal tower. In principle, it can be regarded as a mix between a wind turbine and a solar collector. In the top of a narrow, high tower is a wind wheel on a vertical axis driven by the rising warm air. A solar collector installed around the foot of the tower heats up the air. The design of the collector is simple; a transparent plastic foil is fixed over several metres on the ground in a circle around the tower. Therefore, the station needs a lot of space and the tower has to be very high. Such a system has a very poor efficiency, only about one percent. World wide there has only been one Up-Stream-Power- Station built so far, it was designed by a German company. For some years it worked satisfactorily at the location of Man arenas in Spain, but in the mid-eighties it was destroyed by bad weather. This station had an electrical power of 20 kW, the tower was about 200 m high, and the collector had a diameter of approximately the same size. A second Up-Stream-Power- Station with an electrical performance of 200 MW was discussed in Australia, but not realized. The tower height should be about 1000 m and the diameter of the collector area should be about 7000 m. No new Up-Stream-Power-Station has been designed and installed so far. Since there has been tremendous technical progress over the last ten years regarding solar farm stations as well as horizontal-axis wind turbines.

2. – Physical basics

2·1. *Energy content of the wind* . – The following section will be used to mathematically explain where the energy in the wind comes from and what factors it depends on.

Power is defined as

$$P = \frac{E}{t} = \frac{1}{2} \cdot A \cdot \rho_a \cdot v^3,$$

with

E: kinetic energy,
A: area,
ρ_a: specific density of the air, v: wind velocity.

Therefore, it is also proportional to the cube of the wind speed, v^3.

From fig. 2, it can be seen that the power output per m^2 of the rotor blade is not linearly proportional to the wind velocity, as proven in the theory above. This means that it is more profitable to place a wind turbine in a location with occasional high winds, than in a location where there is a constant low wind speed. Measurement at different places shows that the distribution of wind velocity over the year could be described by a We bull-equitation. That means that at least about 2/3 of the produced electricity will be earned by the upper third of wind velocity.

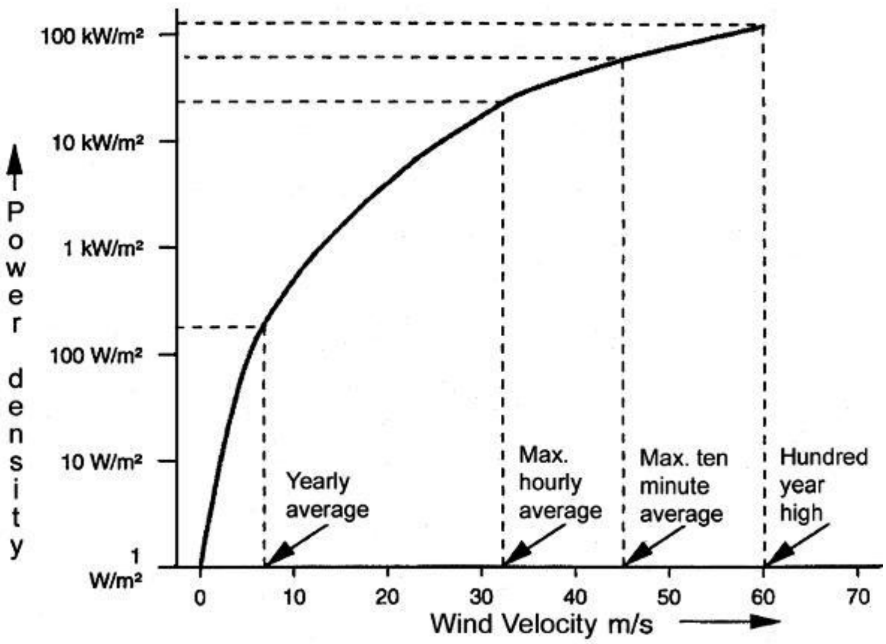


Fig. 2. – Relationship between wind velocity and power output (yearly average valid for Ger-many) ([1], p. 241 ff).

From a mechanical point of view, the power density range increases by one thousand for a wind speed change of just 10 m/s, thus producing a construction limit problem. Therefore, wind turbines are constructed to harness only the power from wind speeds in the upper regions.

2.2. *Power coefficients*. – There is now the question of how much of the energy in the wind can be transferred to the blade as mechanical energy.

Betz' law and c_p

Betz' law states that you can only convert a maximum of 59% of the kinetic energy in the wind to mechanical energy using a wind turbine. This is because the wind on the back side of the rotor must have a high enough velocity to move away and allow more wind through the plane of the rotor.

The relationship between the power of the rotor blade P_R and the maximum power $P_{R\max}$ is given by the power coefficient c_p:

$$P_R = P_1 - P_2 = c_p \cdot P_{R\max}. \tag{2.2}$$

The maximum power coefficient is determined through the ratio v_2/v_1 and setting the derivation to zero.

$$c_{p\,\max} = \frac{16}{17} = 0.593 \qquad \text{with} \qquad v_2 = \frac{1}{3} \cdot v_1, \tag{2.3}$$

Therefore, an ideal turbine will slow down the wind by 2/3 of its original speed (Betz' law).

The issues discussed in the theory can be summed up and related to the design of a wind energy turbine, by the so-called Cooking recipe:

"Cooking recipe" for the design of wind turbines.

1. A high aerofoil form ratio leads to a high Tip-speed ratio and therefore, a large power coefficient c_p.

⇒ Modern turbines with a good aerodynamic profile rotate quickly.

2. Simple profiles with smaller profile form ratios have a small Tip-speed ratio. Therefore, the area of the rotor radius that is occupied by blades must be increased in order to increase the power coefficient.

⇒ Slow rotating turbines have poor aerodynamic profiles and a high number of blades.

3. The profile form ratio and the tip-speed ratio have a considerably greater influence on the power coefficient than the number of blades.

⇒ The quality of an aerofoil in respect to a high-speed turbine, has an inferior significance.

3. – Technical design of wind turbines

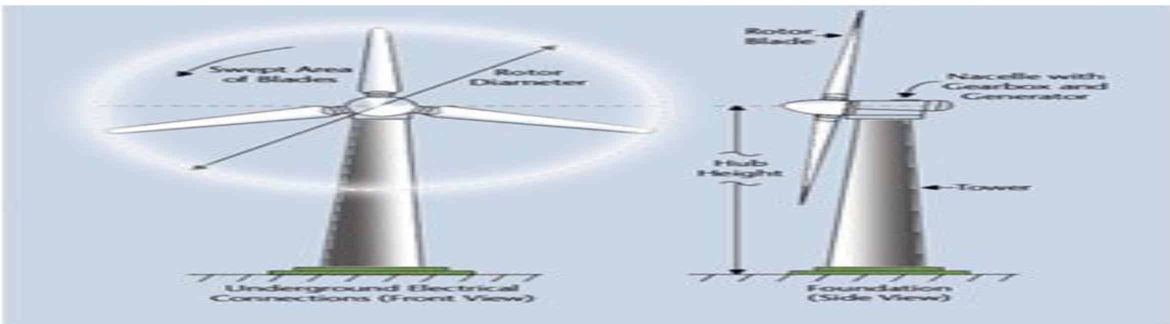
3.1. *The design with gearbox* . – The details of a design with gearbox are shown in fig. 3. The main aspect of the classic design is the split shaft system, where the main shaft turns slowly with the rotor blades and the torque is transmitted through a gearbox to the high-speed secondary shaft that drives the few-pole pair generator.

The transmission of torque to the generator is shut off by means of a large disk brake on the main shaft. A mechanical system controls the pitch of the blades, so pitch control can also be used to stop the operation of the turbine in *e.g.* storm conditions. The pitch mechanism is driven by a hydraulic system, with oil as the popular medium. This system needs almost yearly maintenance and constant pressure monitoring, along with the gear box which is lubricated with oil. For constructions without a main brake, each blade has its pitch angle controlled by a small electric motor.

To reduce weight generators with permanent magnets were developed. Some producers are equipping their converters as testing converters.

Wind speed and direction measuring apparatuses are located at the back of the hub head. A rack-and-pinion mechanism at the join of the hub and the tower, allows the hub to be rotated in to the wind direction, and out of it in storm conditions.

3.2. *The design without gearbox* . – Some companies, *e.g.* the German company Enercon, design another turbine type, without gearbox. The scheme of such a turbine is shown in fig. 4, where the main design aspects can be clearly seen.



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

Figure 2.2: HAWT wind turbine

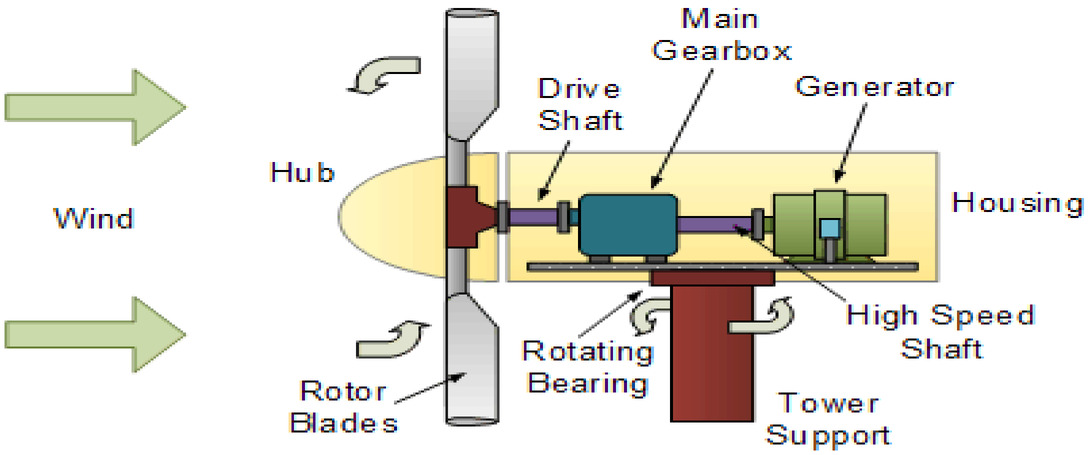


Fig. 4. – The design without gearbox (Enercon E-66).

This design has just one stationary shaft. The rotor blades and the generator are both mounted on this shaft. The generator is in the form of a large spoked wheel with *e.g.* forty-two pole pairs, around the outer circumference and stators mounted on a stationary arm around the wheel. The wheel is fixed to the blade apparatus, so it rotates slowly with the blades. Therefore, there is no need for a gearbox, rotating shafts or a disk brake. This minimising of mechanical parts simplifies the maintenance and production of the turbine.

The whole system is automated; pitch control and hub direction are controlled by a central computer, which operates the small directional motors.

3.3. *Aspects of design and development* . – There are several critical aspects of a wind turbine that need to be considered in the design phase, to ensure the turbine will be economic and durable.

The tower

In principle, the tower needs to be as tall as possible, because the wind speed increases with height. However, the height is limited by costing issues; an increase in tower height of 10 m costs an extra fifteen thousand dollars, and a tower height of over 100 m requires an aircraft-warning beacon, which is again so expensive.

Heat energy

Large turbines (> 1 MW), have an average generator efficiency of 98%. Heat is also generated in the mechanical parts of the machine including the bearings and the gear box. This means that around 40 kW of power are lost to the generator heating up during operation. This heat energy needs to be controlled to prevent damage to the machine parts. A large fan system is mounted in on the back side of the hub of a turbine and used to draw cool air through the hub and remove the heat energy emitted during operation.

Control and Monitoring

The following aspects of a wind turbine need to be controlled and monitored to ensure effective operation of a wind turbine within the legal limits:

– by large turbines; vibration levels,

– speed of rotation and the pitch angle of the rotor blades,

– the natural wind speed and direction,

– the voltage and frequency of the electricity produced,

– the output phase angle compared to the grid phase angle,

– the consistency of the electrical power output,

– the acquisition and storage of electrical signals,
– signal conversion equipment for the directional motors,

– rotational speed at night, to reduce the noise levels, because the noise is proportional to the blade-tip speed to the power six.

Mechanical stability

The following forces affect the stability of the mechanical system:

– gravity,

– centrifugal forces on the rotor blades,

– pressure changes on the blade due to the shadow effect the tower creates,

– stochastic power output of the turbine due to wind energy levels continually changing,

– resonance of the blades.

Wind direction set-up

A wind turbine can be designed to face in to the wind (windward), or away from it (leeward). A leeward turbine has the advantage of being self-orientating, but the diced-vantage of the tower disturbing the wind velocity profile, before the wind has reached the plane of the rotor blades. The pressure and speed differences experienced by the blade as it passes the tower, result in stresses on the hub, which need to be alleviated by use of an extra mechanism in the hub to allow the rotor blades to move out of their usual plane of rotation.

Table I. – *The technical figures of two diﬀerent multi-megawatt wind turbines for onshore.*

TABLE I. – *The technical figures of two different multi-megawatt wind turbines for onshore.*

	Enercon E-182 E3	REpower 3.2 MW
Design	without gearbox	with gearbox
Hub height	80–130 m (onshore)	100–130 m (onshore)
No. of blades	3	3
Rotor speed	6–18 rpm	6.7–12 rpm
Rotor diameter	82 m	114 m
Material of blade	Fibreglass (reinforced epoxy)	Fibreglass (reinforced epoxy)
Blade regulation	Pitch	Pitch
Rated power	3 MW	3.2 MW
Transmission ratio of gearbox	None	approx. 99
Generator	Multipole	Asynchronous, few poles
Grid connection	Via frequency converters	Via frequency converters

3.4. *Technical figures of two modern wind turbines*. –

The largest market introduced
machine up to the year 2012, is a 7.5MW turbine from the company Enercon.
Table I gives an idea of the technical data of wind turbines of the 3MW class. A design with and without gearbox have been chosen to show the different operation of their generators.

4. – Connection to the electrical grid

The main electrical grid has a constant frequency, *e.g.* of 50 Hz or 60 Hz, and a constant phase angle. Therefore, a wind turbine must produce electricity with the same constant values in order to be integrated into the main grid.
The input energy of a wind turbine is proportional to the wind speed, but the wind speed is never constant. Each wind speed has a corresponding rotor rotation speed, at which the maximum power is produced. This maximum occurs for different wind speedsat different rates of rotation. However, the rate of rotation must be held constant in order to achieve the required constant output frequency or the wind turbine has to be connected to the grid by doubly fed asynchronous generator or by electronic frequency converters.

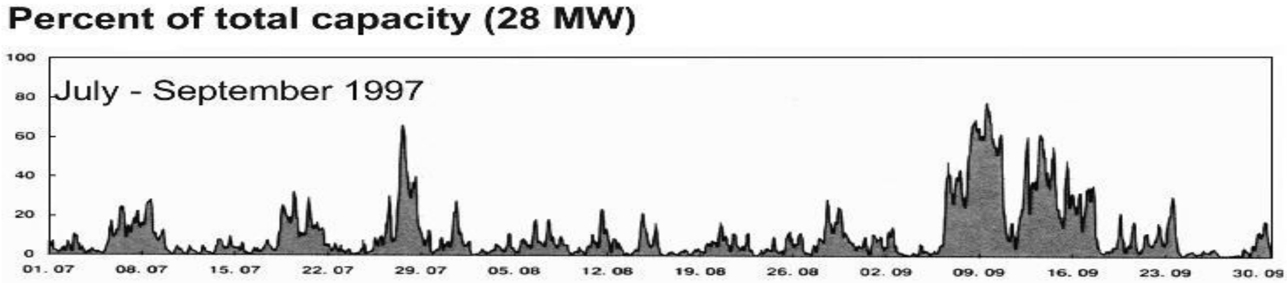
A small turbine can be connected directly into the grid network at 0.4 kV. When the wind turbine is integrated into the grid network, there must be no voltage change, voltage oscillation or flicker experienced in the homes on that network branch. The loss of voltage due to resistance in the cabling can be avoided by increasing the diameter of the cables. It is often required that a new network branch is constructed and linked to the transformer, in order to reduce the voltage disturbances. This increases the installation costs of the turbine.

Megawatt turbines cannot be connected to the grid at the 0.4 kV stage, but have to be connected in at 10–30 kV, which is the usual level of the city electricity share distribution. In remote areas, where a 30 kV connection is not established, the connection must be created and financed by the wind park developers. Wind parks with a lot of Megawatt turbines can also be connected into the electrical grid, *e.g.* at the 110 kV level in Germany.

As mentioned earlier the maximum power output is obtained only in few hours during the year. Figure 5 shows a typical load distribution, measured in Germany.

With larger wind energy installations in future this uneven distribution leads to the need of higher regulation capacities by conventional power systems. Grid connection of offshore wind farms poses a technical and economical challenge to wind turbine and grid operators. In the initial phase, the still quite limited capacity of early pilot farms enables using a conventional three-phase AC connection to the onshore grid system which is a well-known technology and inexpensive. This wind farms were also located near to the coast, the energy losses by using AC was therefore limited.

Greater capacities and remote offshore sites make it technically difficult to connect offshore wind farms to the mainland grid by using AC undersea cables. Losses, reactive power production and limited capacity of the sea cables may become important in the



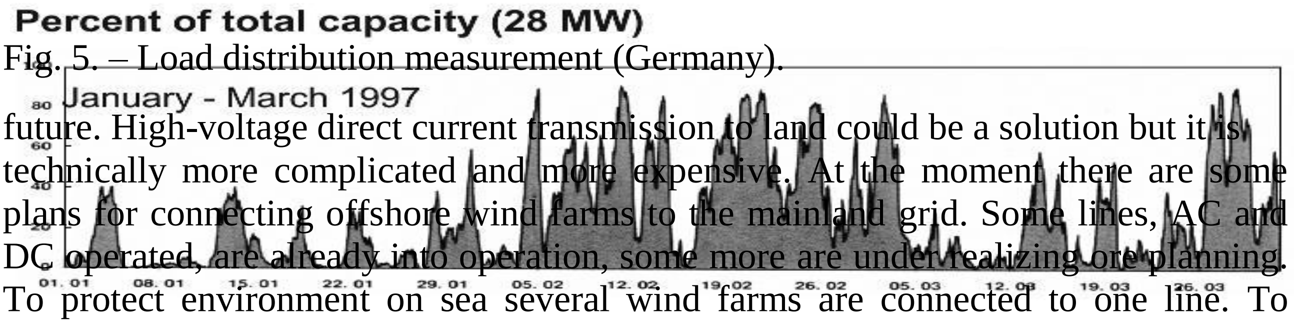


Fig. 5. – Load distribution measurement (Germany).

future. High-voltage direct current transmission to land could be a solution but it is technically more complicated and more expensive. At the moment there are some plans for connecting offshore wind farms to the mainland grid. Some lines, AC and DC operated, are already into operation, some more are under realizing ore planning. To protect environment on sea several wind farms are connected to one line. To connect the offshore wind farm to the onshore grid an internal grid is necessary. The produced power has to be fed to an offshore transformer substation. Wind turbines are connected to it via undersea cables by a voltage of about 30 kV. After stepping-up to the transmission line voltage, the power is conveyed to shore.

5. – Use of wind energy

5.1. *World-wide status*. –

In the nineteen eighties, it was the USA that took the lead in establishing wind farms. They set over 10000 turbines into operation, each generating between 80–200 kW. In Europe it was Denmark that was the main pioneers of wind energy. At the end of the twenty-first century, Germany has taken the world lead, producing about a third of the world's wind produced electricity until 2008. Many governments have began to produce initiative schemes to increase the economic feasibility of wind turbines. Some initiatives used include, paying more for wind produced electricity, and providing a proportion of the initial construction costs. Governments of industrial countries, or those with a high power consumption, are eager to promote wind

TABLE II. – *World wind power production* [2].

Land/Region	Total installed rated power up to the end of 2011 [GW]
China	63
USA	47
Germany	29
Spain	22
India	16
Italy	7
France	7
UK	7
Canada	5
Portugal	4
Remaining countries	32
Total	239

energy, because it is environmentally clean and sustainable and limits the need for fossil fuel usage (table II). The world total is about 239000MW. This is about 1% of the worldwide installed capacity of power stations (water, coal, natural gas, nuclear).

5.2. *Investment and operation costs*. –

The costs involved in installing a wind turbine vary depending on the design, size and chosen location of the new turbine. The infrastructure costs can be minimized by constructing wind parks, where a number of new turbines are installed on the same sight. An example of the investment costs for a wind park at land in Germany is shown in table III. The money invested in an average wind park on land depreciates over about a ten year period. During this period, the set-up and installation costs are high, along with the loan repayments and insurance costs. After this period, the costs then decrease. Over the next ten years, a financial return can then be made on the investment, when the price for the electricity per kilowatt hour is set at a high value by the government. This means it is economic to ensure the durability of the installed turbines, so maintenance costs after the ten year period are kept low and the investors can receive a good return on their investment. The above example of investment costs for wind parks on land in Germany is nontransferable to other countries. Especially the employee's wages and the structure of financing wind farms are quite different. Nevertheless power generating by wind turbines in developed countries with existing electrical grid and sufficient installed power, costs three to four times in comparison to power generation by conventional power stations.

TABLE III. – *The investment costs of Amesdorf and Wellen wind park in Germany, (status: Nov. 2001).*

	Invested costs (Million Euros)	Percent of total
Wind Park (ten 1.5 MW turbines) incl. transport, assembly, cabling, starting-up, grid connection and reinforcement, infrastructure.	15.8	83%
Technical planning, foundation soil analysis, survey, and grid connection fee.	2.0	10%
Commission, funding during phase of construction, interest risk.	0.1	1%
Compensatory measures during phase of construction.	0.3	1.3%
Raising of capital.	0.5	3%
Financial, contractual and fiscal consulting.	0.3	1.3%
Grand total	19	100%

Wind parks on sea need higher specific investments, although the wind offer is better on sea than on land. The costs of produced electricity are higher by an offshore wind park (status 2012). The expectation is that the cost could be reducing for new offshore wind parks in next years. A lot of countries are supporting the installation of wind converters by supporting programs.

5.3. *Environmental aspects*. –

Wind energy is a renewable energy source; therefore it holds many advantages over the fossil fuels, which have diminishing reserves. Wind energy is clean in regard to toxic emissions. Therefore, it does not add to Global warming or Acid rain problems. The wind turbines can affect the environment in aesthetic and human intrusive ways. This is because they must be sited in prominent locations and through the nature the rotation of their blades; they produce optical distortions *i.e.* flickering shadows, and a humming noise. The land required for the sighting of a wind park can be considered large, if all the access routes are also taken into consideration. However, they very rarely require the resettlement of communities, which is a problem associated with, *e.g.*, large Hydro-Electric-Power stations. The danger to birds of the rotating blades has been questioned, but it has been found that the birds change their flight paths to avoid the blades. It has also be questioned whether the reduced wind speed at ground level, affects the growth of flora. This is answered by the observation that many wind parks have animals grazing between the turbines.

6. – Research and development needs

The field of wind converter is connected with high technical development activities since a lot of years. According to the first report of the project "Wind Energy Thematic Network" founded by the European Commission, some aspects of the R&D needs are described below (facts are taken from [3]), which are also relevant in the year 2012:

1. *Environmental & Social Impacts* (*e.g.* enhancing local incentives by developing participation models)

– Methods to integrate wind turbines visually in to the landscape
– Reduction of noise impacts
– Mitigating impacts on bird populations, habitats and flight paths
– Turbine design regarding life cycle analysis
– Analyses social effects like local employment, investment, taxes etc.

2. *Wind Turbine & Component Design Issues* (*e.g.* basic research in aerodynamics, structural dynamics, structural design and control)

– New materials with higher strength like carbon fibre for the blades
– Feasibility studies of new wind turbines concepts and innovations
– Integration of demand site requirements in the design of turbine, *e.g.* electrical control system interaction with grid requirement

3. *Testing, Standardization, & Certification* (*e.g.* common accepted certification procedures
for wind turbines and wind farms)

– Identification of standards lacking, and initiation of appropriate actions for new standards
– Standards for service and maintenance concepts of offshore wind converters

4. *Grid Integration, Energy Systems & Resource Prediction* (*e.g.* forecast of wind resource)

– Development of scenarios for redesigning the grid system with high wind penetration
– Increasing both: power quality and consistency
– Energy management and storage systems for standalone applications

5. *Operation & Maintenance* (*e.g.* advanced condition monitoring)

– Development of early failure detection and condition systems
– Development in preventative maintenance

– Standardization of components for easy replacement– Certification of service and maintenance concepts
– Cold and icing climates resource assessment
6. *Offshore Wind Technology* (*e.g.* research into the control and efficiency of very large wind farms and more cost effective foundations, transport and installation techniques)
– Monitoring of environmental impacts (effects on birds, effects of noise and vibration on marine life especially by installation of wind converter etc.)
– Development of deep water foundation structures (fundamental wind turbine design research)
– offshore meteorology
– Special designs of systems and components for transportation, erection, access and maintenance of offshore wind turbines
– investigate the use of energy storage
– Improve corrosion protecting systems regarding the offshore conditions In addition to these aspects there have been done a lot of R&D needs by operating and market introduced wind turbines, *e.g.*:
– better state of knowledge of the dynamic forces on the drive train,
– improvement of the availability of gear boxes,
– optimization of control units and control systems,
– development of central lubrication systems.

- **Wind Energy Advantage**

1.Wind energy is cost competitive with other fuel sources.

Power purchase agreements are now being signed in the range of 5 to 6 cents per kilowatt-hour,[10] a price that is competitive with new gas-fired power plants.[11] Researchers expect continued cost reductions as the technology improves and the market develops.

2. Wind energy creates jobs.

Wind energy development creates thousands of long-term، high-paying jobs in fields such as wind turbine component manufacturing, construction and installation, maintenance and operations, legal and marketing services, transportation and logistical services, and more. In 2010, the wind sector invested $10 billion in the U.S. economy and employed ٧٥,٠٠٠workers. In the same year, 31 manufacturing facilities opened or were announced. According to the American Wind Energy Association, employment in the wind industry's manufacturing sector has increased from 2,500 jobs in ٢٠٠٤to 20,000 in 2010, with an estimated additional 14,000 manufacturing jobs planned.[12](Policy decisions will affect this number.[13]

3.Wind energy is an indigenous, homegrown energy source that helps to diversify the national energy portfolio.

The United States is the world's largest importer of oil and natural gas.[14] Our reliance on imports threatens our national economic security. Adding wind power to the energy mix diversifies the national energy portfolio and reduces America's reliance on imported fossil fuels. In addition to bolstering the security of our national energy supply, wind energy stabilizes the cost of electricity and reduces vulnerability to price spikes and supply disruptions. With the expanded use of electric and plug-in hybrid vehicles، wind energy can also reduce our dependence on imported transportation fuels.

4.Wind energy can provide income for rural farmers and ranchers, as well as economic benefits to depressed rural areas.

Wind projects provide revenue to the communities in which. they are located via lease payments to landowners, state and local tax revenues, and job creation. Even a utility-scale wind turbine has a small footprint, enabling farmers and ranchers who lease their land to developers to continue growing crops and grazing livestock. Achieving 20% wind energy by 2030 would provide significant economic benefits, including more than $8.8 billion in estimated property taxes and land lease payments between 2007 and 2030.[15] Rather than paying for energy imported from other states, this money stays in the community.

5.Wind energy is an inexhaustible renewable energy source.

Wind energy is plentiful and readily available, and capturing its power does not deplete our natural resources. The Great Plains and offshore areas have tremendous untapped wind energy potential.

6. Wind turbines do not consume water.

Most electric power plants require water to operate, and water use in drought-stricken areas like the western United States is a significant issue. Producing electricity from the wind does not require water. Achieving a 20% wind energy by 2030 scenario would reduce cumulative water use in the electric sector by 8%، or 4 trillion gallons.[16]

7. Wind energy is clean.

Electricity generated by wind turbines does not pollute thewater we drink or the air we breathe, so wind energy meansless smog, less acid rain, and fewer greenhouse gas emissions.A single 1-megawatt wind turbine can displace 1,800 tonsof carbon dioxide (CO_2) in 1 year (equivalent to planting square mile of forest).[17] Achieving 20% wind energy by2030would provide significant environmental benefits, suchas avoiding approximately 825 million metric tons of CO_2emissions in the electric sector.x Because it is a clean energy source, wind energy reduces health care and environmentalcosts associated with air pollution.

8.Wind energy systems have low operating costs.

Wind energy systems have low operating expenses because they have no fuel cost. When large amounts of wind energy are added to the grid, additional generation may be required to accommodate wind energy’s variability, but the Utility Wind Integration Group concluded that system operating cost increases from wind variability and uncertainty amounted to only about 10% or less of the wholesale value of the wind energy and that there are ways to reduce these costs.[18] The absence of fuel cost also protects consumers from fluctuating coal and natural gas costs.

9.Wind energy can be used in a variety of applications.

Wind turbines can be used in applications other than utilityscalewind farms. Community wind projects include turbines for schools, tribes, municipal utilities, and rural electriccooperatives. Small wind turbines, alone or as part of a hybridsystem, can power homes, businesses, farms, ranches, andschools. Wind energy is perfect for remote applications, suchas water pumping, ice making, powering telecommunications sites, and displacing diesel fuel in remote communities.

10.Wind energy is one of the most popular energy technologies.

Over the past 10 years, cumulative wind power capacity in the United States increased an average of 30% per year, slightly higher than the 28% growth rate inworldwide capacity.[19]Wind energy was the most frequently installed energy technology on a capacity basis of any technology in the United States in 2008 and 2009. [20] Because of all the benefits listed above and more, many opinion surveys show that the majority of people are in favor of wind energy. In Nebraska, a 2010 survey showed that 91% of respondents believe that the state should meet its electricity needs by using renewable energy such as wind power, and%٩٧ of respondents favor requiring electric utilities to use renewable energy resources for at least 20% of the electricity they generate.xiv Finally, a national survey conducted in 2010 revealed that 89% of respondents believe that increasing the amount of energy the nation gets from wind is a good idea.[21] Despite wind energy’s numerous benefits, wind development is not appropriate everywhere. Individuals and communities should make informed decisions on local wind development.

- ## <u>Disadvantage of Wind Energy</u>

1.It is Dependent on the Availability of Wind

Disadvantages of wind energy include the fact that it relies entirely on the availability of wind. As long as there is no wind no electricity will be produced. As such, this form of energy cannot be relied on in totality as it is bound to fail every now and then. Due to the fact that this form of energy is not reliable, electricity generators do not invest on it and as such, its technology is not improving. There is therefore a high likelihood that this form of energy will be done away with eventually as the technology of other forms of energy is improving with leaps and bounds.

2.Wind Turbines Kill Birds

Wind turbines are usually made of blades that rotate continuously and fiercely. Due to the fact that the blades are usually placed high up in the air, they are known to kill birds that fly over it. A research was done that showed that about 45,000 birds that flew over wind turbines have been killed over the past 20 years. The birds that are affected the most are the ones that usually migrate annually, these birds include; kestrels, golden eagles and tailed hawks. Attempts have been made to prevent more birds from dying as they paint the blades with conspicuous colors so that the birds can see and avoid them.

3.The Speed of the Blowing Wind Has to Be Right

So as to produce the right amounts of electric power, the wind turbines need to rotate at the right pace. The rotation should neither be too slow nor too fast. When the speed of the wind is extremely slow, it is not economical for the turbines to run. This is because the turbines are quite expensive to run. When there is too much wind that is blowing at a fast rate, it is mandatory that the turbines are shut down owing to concerns of safety as if the wind is so strong the turbines might get destroyed or might get detached and hurt people.

4.The Energy Density of Wind Is Low

Due to the fact that wind is diffuse and it is also spread over a wide area, so as to be able to produce large quantities of electricity it is mandatory that the number of turbines used cover a large area. Since many turbines have to be used, the costs of setting up a wind farm are so high. However, the production of other sources of energy faces the same problems.

5.This Form of Energy is Not Efficient

The system that is usually set up so as to turn wind energy into electric energy is not efficient. This happens to be one of the major disadvantages of this form of energy. The turbines do not have the ability to extract a hundred percent of the energy that is found in the blowing wind. Research shows that turbines extract only fifty nine percent of the wind energy that passes through them. This makes them very insufficient. The fact that experts in this field are not investing on making this system of power generation better means that the insufficiency is bound to continue.

6.The Energy that is Produced Can’t Be Stored in Large Scale

The energy that is produced cannot be stored in large scale. Considering the fact that it is impossible to have wind blowing daily, it is important that the energy storage of this system be sufficient. Seeing as it is not, this shortcoming contributes greatly to the insufficiency of wind energy. Needless to say, this problem is likely to be there for a very long time.

7.The Turbines are Noisy

One of the reason as to why most people avoid using this form is energy is that themachinery that is used for the production of electricity is very noisy. Although this form of energy is preferred as it does not pollute the environment, the noise that is usually produced in the process of producing electricity is too much: it can be a nuisance. As such, the system setups for this form of power cannot be placed in places that need to be quiet such as residential areas and places of works. This limits the number of places where the setups can be put up.

8.The Amount of Wind that Blows Is Unpredictable

The amount of wind that is likely to blow in a particular place at a particular time is impossible to predict. This is one of the major disadvantages of wind energy as one has to invest on other alternatives forms of energy. As such one has to incur double costs so as to ensure that they have enough electricity. The best alternatives of energy are geothermal and solar energy. As a result of this shortcoming, before setting up a wind farm, thorough research has to be done so as to make sure that the location is appropriate.

9.This Form of Energy is Suited to Be Set Up in Specific Places

Wind farms can only be set up on specific places. This limits the use of this form of energy to specific places. The best place to set up a wind farm is in the coastal regions. The reason as to why turbines are placed in the coastal region is due to the fact that coastal regions are always windy. This means that regions which are located hilly areas may not be able to benefit from this form of energy. The place where the turbines are placed ought to have a lot of wind blowing if any electricity is to be produced.

10.The Visual Impact that Turbines Have on the People

Many people are of the ideas that turbines are not appealing to the eye. There is however people who tend to think that they beautify the areas as they are appealing to the eyes. The different views have resulted into people filing petitions to bar the setting up of wind farms in areas that surround them. The fact that there are people who find turbines undesirable is a shortcoming of this form of energy as its use is limited to places where they are accepted.

11.Land Use

One of the main disadvantages of wind energy is that large tracks of land are needed to so that the appropriate number of turbines can be installed. One of the majorreason as to why the installation of turbines is considered to be a waste of time is because the electrical energy that is usually produced is too little to warrant the wastage of huge tracks of land. The fact that a safe area has to be around each farm contributes to wastage of land. A survey was done that showed that the installation of one turbine requires the use of 5 acres of land. However, I am not certain how true this is.

12.Poor Electricity Production

Many people wonder whether the little electricity produced is worth the costs that come with the buying of the turbines and towers. The amount of electricity that is produced is very little and not worth the cost of installing the wind farms. Also the fact that one may need to replace the turbines and towers after a while makes more expensive and therefore many people think it is not worth it. Although this form of energy is clean, the amount of electric energy produced ought to be enough to warrant the high.[22]

Outlook

The wind energy market has grown because of the environmental advantages of harnessing a clean and inexhaustible energy source and because of the economic incentives supplied by several governments. However, energy is required from other generation methods during the building phase of a new turbine, so in this period, Greenhouse gases and air pollution will be added to. If the life cycle of a wind turbine is looked at, more pollutants are saved on during operation, than are emitted during the building phase. A wind turbine is not a self-sustainable power station. This means that back-up power generation is needed at the times when the turbine is operational. This back-up is nowadays supplied by the established fossil fuel power stations. If the number of wind turbines increases, the need for extra investment in the back-up generation systems will arise, in order to maintain a stable electricity grid system. The challenges in this case are that existing power stations will deliver less electricity than before. Under this condition the electricity generation prices for new power stations are increasing due to smaller load duration time than before. For more information especially in respects to technological and ecological aspects (life time aspects) see [23]. These additional investments will need in some cases subsidies.
However, wind energy is still one of the most important renewable energy resources for the future, because it can be harnessed in a clean and inexhaustible manner, throughthe application of technically advanced and efficient machinery.

CHAPTER FOUR

DISCUSSION

&

result

Center tap transformar

The use of a center-tapped transformer as the output interface for a balanced current-output DAC offers several benefits. First, transformer coupling offers dc isolation between the DAC output and the final load. It can also aid in the rejection of common-mode signals present at the DAC output. Furthermore, transformer coupling can mitigate the even harmonics that result from an imbalance between the DAC outputs. Finally, all transformers have a limited bandwidth, which can be used to advantage for suppressing the Nyquist images that typically appear in a DAC output spectrum. The goal of this application note is two-fold. The first goal is to provide an explanation of the functionality of a balanced output in the context of a current-output DAC. The second goal is to provide formulas that relate the transformer turns ratio (N), the transformer load (RL), the DAC load resistors (RO), and the maximum DAC output current (IMAX).

Advantages

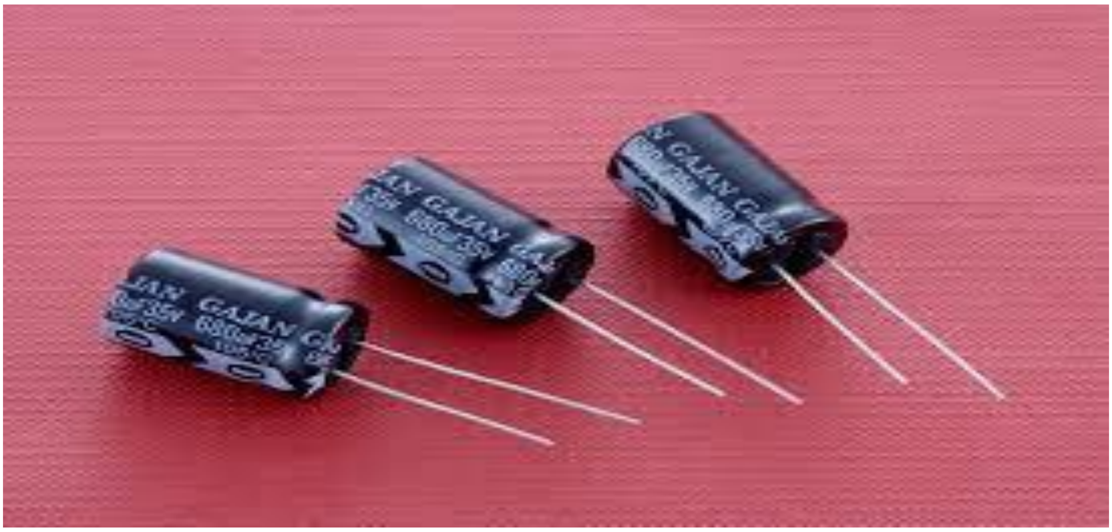
- Power rating of each winding is hallfed for the same output power.
- Nos of rectifier diodes saved for full wave rectifiction **.**

Dis advantage

- **More copper is needed than a single winding delivering the same power .**

Capacitor

A capacitor is a device which stores electric charge. Capacitors vary in shape and size, but the basic configuration is two conductors carrying equal but opposite charges (Figure 5.1.1). Capacitors have many important applications in electronics. Some examples include storing electric potential energy, delaying voltage changes when coupled with resistors, filtering out unwanted frequency signals, forming resonant circuits and making frequency-dependent and independent voltage dividers when combined with resistors. Some of these applications will be discussed in latter chapters.



Diode

A diode is a dispositive made of a semiconductor material, which has two terminals or electrodes (di-ode), that act like an on-off switch. When the diode is “on”, it acts as a short circuit and passes all current. When it is “off”, it behaves like an open circuit and passes no current. The two terminals are different and are marked as plus and minus in figure 1. If the polarity of the applied voltage matches that of the diode (forward bias), then the diode turns “on”. When the applied voltage polarity is opposite (reverse bias), it turns “off”. Of course this is the theoretical behaviour of an ideal diode, but it can be seen as a good approximation for a real diode. A diode is simply a pn junction (see ’Introduction into Semiconductor Physics’) with the following characteristics: • Under forward bias, it needs a small voltage to conduct. This voltage drop is maintained during conduction. • The maximum forward current is limited by heat-dissipation ability of the diode. Usually it is around 1000 mA. • There is a small reverse current.

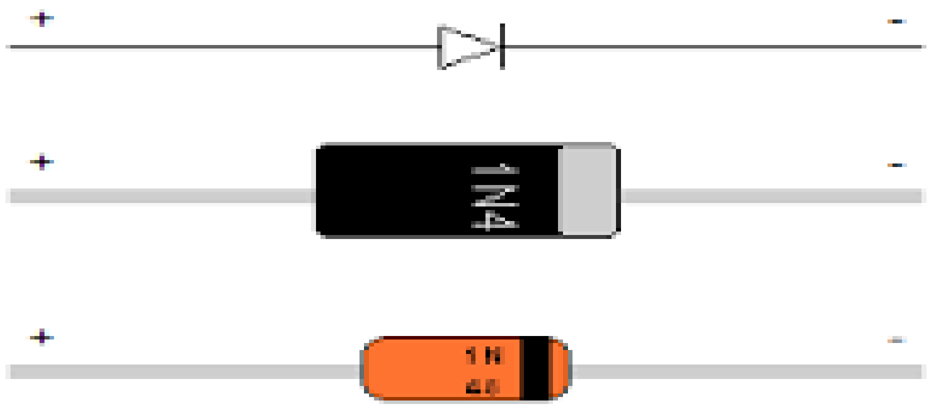


Figure 2: Orientation of diodes

Transistor 2N3055

There are two limitations on the power handling ability of a transistor: average junction temperature and second breakdown safe operating area curves indicate IC-VCE limits of the transistor that must be observed for reliable operation i.e., the transistor must not be subjected to greater dissipation than the curves indicate. The data of SOA curve is based on TJ(PK) = 200°C; TC is variable depending on conditions. Second breakdown pulse limits are valid for duty cycles to 10% provided TJ(PK)≤200°C. At high case temperatures, thermal limitation will reduce the power that can be handled to values less than the limitations imposed

Motor Dc D06D03E200

The traditional DC motor needs two current supplies, one through the stator windings to provide the magnetic field and the other through the rotor windings to interact with the magnetic field to generate the motive force. There are three ways of accomplishing this, each one resulting in unique characteristic motor performance. Because they all use wound rotors, they all need a commutator to feed the current into the rotor windings.

Speed is controlled by varying the rotor voltage and hence the rotor current, or by varying the magnetic flux in the air gap by changing the current in the field windings.

With access to both the field and rotor windings, all DC motors offer the facility of simple speed and torque control.

- **Series Wound**

The series wound motor has only one voltage supply to the motor and the field winding is connected in series with the rotor winding.

- **Characteristics**

The series motor has poor speed regulation. It delivers increasing torque with increased motor current but this is at the expense of speed which falls with increasing torque demands.

This motor has a very high starting torque because there is zero back EMF at zero speed however as the speed builds up so does the back EMF causing a reduction in torque.

Increasing the load on the motor tends to slow it down, but this in turn lowers back EMF and increases the torque to accommodate the load.

Speed control is possible by varying the supply voltage.

Under no load conditions the speed will accelerate to dangerous levels possibly causing destruction of the motor. The motor can be reversed by reversing the connections on either the field or the rotor windings but not both.

Regenerative braking is not possible since the field current needs to be maintained but it collapses when the rotor current passes through zero and reverses.

- **Applications**

  The series DC motor is an industry workhorse for both high and low power, fixed and variable speed electric drives.

  Applications range from cheap toys to automotive applications.

  They are inexpensive to manufacture and are used in variable speed household appliances such as sewing machines and power tools.

  Its high starting torque makes it particularly suitable for a wide range of traction applications.

- **Shunt Wound**

  The shunt wound motor also has only one voltage supply to the motor but in this case the field winding is connected in parallel with the rotor winding.

  - **Field Weakening**

    The speed of a shunt wound motor can be controlled to a limited extent without affecting the supply voltage, by "field weakening". A rheostat in series with the field winding can be used to reduce the field current. This in turn reduces the flux in the air gap and since the speed is inversely proportional to the flux, the motor will speed up. However the torque is directly proportional to the flux in the air gap so that the speed increase will be accompanied by a reduction in torque.

  Characteristics

  The shunt wound motor turns at almost constant speed if the voltage is fixed. The motor can deliver increasing torque, without an appreciable reduction in speed, by increasing the motor current.

  As with the series wound motor, the shunt wound motor can be reversed by reversing the connections on either the field or the rotor windings.

  Regenerative braking is possible. Self excitation maintains the field when the rotor current reverses.

  - **Applications**

    Fixed speed applications such as automotive windscreen wipers and fans.

- **Separately Excited**

The separately excited motor has independent voltage supplies to the field and rotor windings allowing more control over the motor performance.

- **Characteristics**

  The voltage on either the field or the rotor windings can be used to control the speed and torque of a separately excited motor.

- **Applications**

  Train and automotive traction applications.

Permanent Magnet Motors

As the name implies, these motors use permanent magnets rather than electromagnets to provide either the rotor or the stator field. They are used extensively in small DC motors and to an increasing extent in traction applications.

- **Rotor Magnets**

  These are by far the most common types of permanent magnet motors. They have no rotor windings but use permanent magnets to supply the rotor field and they behave like shunt wound DC motors with a fixed shunt current.
  Their major advantage is the elimination of the commutator.

- **Field Magnets**

  These motors have no field winding but use permanent magnets to provide the magnetic field. Current is still supplied to the rotor via a commutator as in other brushed motors and the speed can be controlled by varying the voltage on the rotor windings. In this way their behaviour is similar to a series wound DC motor.

Permanent magnet motors are explored in more depth in the section on Brushless DC and AC Motors

Universal Motors

In a series wound DC motor, reversing either the field winding leads or the rotor winding leads will reverse the direction of the motor. However, simply reversing the leads from the power supply will have no effect on the direction of rotation since it is equivalent to reversing the current through both the individual windings - in effect a double reversal. In other words the motor will turn in the same direction even though the current through the series windings is reversed. This means that the motor can run on alternating current as well as direct current since the direction of rotation is independent of the direction of the current through the series windings.

Universal motors are often used in power tools and household appliances such as vacuum cleaners and food mixers. See more about universal motors.

Resistors

The resistors that you would most likely see if you opened up a CD player, VCR, or other electronic device would look like the ones in Figure 2. • They basically look like little cylinders with colored lines painted on them. • The colored lines tell you the resistance and error range (tolerance) for a resistor according to the following rules and table of numbers. You do NOT have to memorize this table… it will be given to you if you need it. • To use the table you need to remember the following rules: 1. The first line is the first digit 2. The second line is the second digit 3. The third line is the multiplier 4. The last line (if any) is the tolerance • Some resistors may have additional colored bands, but we will ignore them here. • They usually have something to do with measuring things like failure rates or temperature coefficients


wiseGEEK

Maximum Ratings

Characteristic	Symbol	Rating	Unit
Collector-Emitter Voltage	V_{CEO}	60	V
Collector-Emitter Voltage	V_{CER}	70	
Collector-Base Voltage	V_{CBO}	100	
Emitter-Base Voltage	V_{EBO}	7.0	
Collector Current-Continuous	I_C	15	A
Base Current	I_B	7.0	
Total Power Dissipation at $T_C = 25°C$ Derate above 25°C	P_D	115 0.657	W W/°C
Operating and Storage Junction Temperature Range	T_J, T_{STG}	-65 to +200	°C

Blades turbo shape much like the shape of the aircraft wings was used by the sleek surface design means that the surface of the blade spins a little bit in a destination and be require in fact a PhD in mathematics or physics to understand it fully and design optimization of them.

Aerodynamics is not the only design in the design of wind turbine active consideration there are also things in size and lengths blades turbo it as far as can be derived turbine energy from the wind as much as possible to generate electricity ,in general , the double rotor diameter produces afour – fold increase in energy output in some cases in areas with wind speed is low with a smaller diameter rotor can end up more of the largest roundabout produce energy because if the configuration smaller will take power winds less energy to rotate the smaller generator so the turbine can reach full always the ability almost even height of the tower is a key factor in energy production also the Top turbine capable of taking more energy because the wind speed increase with increasing altitude and scientists speculate that each doubling to rise more than 12 percent of the wind speed

We have in our project that manufactures turbine blades locally using a tube made of strong light plastic weight diameter material (4 lang) and a length (1.35 meters)and we relied on measuring the length of the blade one o'clock =length flipper background for turbine.

The deviation is a diagonal angle and have been reling on our project angle (35) in order to play this angle streamlined air to plunge toward the bottom of the flipper by bending in the existing pipeline.

Note-we have designed and badminton and curvature toward the right in order to always spin to the right of any clockwise or spin in the opposite direction in order to cause the generation of reverse voltage.

4-2-2: The turbine blade base

An important part which the turbine blades to prove it and to link these blades birth of electricity generation and we have this rule manufacture of light thinks to the iron pluse (+) and length (25cm.)

Figure(28):The Turbine Blade base

4.2.3: Generating base

This part of the turbine and the job is to load generating DC power and installed it with the rudder (flipper background) of the turbine so that industry this rule of iron in the form of three –star and a length of half a meter of each hand to increase balance and build for the column installer them was the use of the main column measure (3inch) used in the construction of water transmission lines and of course all be iron

Figure (29):Generating base

4.2.4:Rudder (rear flipper)

An important part in the turbine industry and in our project, we manufacture this rudder to guide the turbine coming downwind from the point of emitted and in designer this have canceled spin control,which is a that control the turbine-mail device monitors the direction of emission of the wind through the sensors Air which in turn determine the direction of the wind and then there are the control panels you rotate the turbine downwind .

Figure (30):Rudder(rear flipper

4.2.5:The axisof rotation

To be a turbine that spins around himself and an angle of 360 degree heading towards the wind emission we have designed a mechanical part accurate is this function, avoiding any problems in connectors on this axis which is about rings made of copper material are for connecting electric you connect the output of the DC power generated by the panels storage.

The function of the rotation axis is to be a link between the stator and the rotor in order to preserve not cutting the wires when trying to guide the rudder fans leading to the top rotation in some cases , an enter cycle.

4.2.5.a: Conductor

An electrical conductor is a substance in which electrical change carriers, usually electrons, move easily from atom to atom with the application of voltage. Conductivity, in general, is capacity to transmit something, such as electricity or heat.

4.2.5.b:Electrode

An electrode is a conductor that passes an electrical current from one medium to another, usually from a power source to a device or material. It can take a number of different forms, including a wire, a plate, or a rod, and is most commonly made of metal, such as copper, silver, lead, or zinc, but can also be made of a non-metallic.

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Chapter three

Horizontal Axis Wind Turbine

Tubular towers (steel and concrete):

Steel tubular towers are the most common used solution. They are made of steel plates that are welded together. This type has a diameter from 4.5 meters at the bottom to 2 meters at the top, divided into 3 or 4 parts, where they are bolted together at the site where the wind farm is located. They can vary from 30 to 40 meters. The new steel towers are more than 100 meters with a base diameter of over 5 meters, which can be a problem since many
countries have a maximum transportable road size less than 4.9 meters. Unlike the lattice towers, they do not have bolted connections that need to be checked regularly for torque. Also, they have less of a visual effect than lattice towers. Concrete towers are used in countries where the price of steel is very high**.** They are made of smaller pieces put together at the site. They are easy to transport because they have smaller dimension of the components and it is easy to control the quality of the material, but they are heavy.

- **Lattice towers:** This type was common when turbines were smaller.

These types oftowers are very strong, not expensive to manufacture, easy to transport and erect. Their biggest problem is the visual impact and maintenance cost.

- **Guyed wind tower:** They take a scape because of the guy wires but

are very strong and most economical, but they are only used for small turbines.

- **Tilt up wind towers:** This type has a locking system making it easy to

take down for repair. They are mainly used for consumer wind energy.

- **Free standing towers:** Must to be used with cautions and for small

wind turbines.The effects that come from loading must be considered when it comes to bending and buckling. There are two types of loads that can effect a tower [5, p. 309]:

・**Steady:** steady tower loads happens from aerodynamically produced thrust and torque. There is also a load from the machine itself. There are two factors that the loading on the tower is estimated from.

1) Operating at rated power

2) Stationary at survival2 wind speed.

・**Dynamic:** can be a great source of loads on both soft3 and soft-soft4 towers.

A tower should be designed so the natural frequency does not collide with excitation frequency of the turbine, from either the rotor frequency or the blade passing frequency.

The excitation frequencies should not be within the 5 percent of the natural frequency when the turbine is fully operational. A dynamic magnification factor should be used to multiply the design loads when the structure of the turbine is being elevated, where the operation is intended in a region where the excitation frequencies are between 30 percent and 140 percent of the natural frequency of the tower [5, p. 310]:

3.2 Foundation

The foundation is not the first thing that comes to mind when thinking of a wind turbine.

The foundation is usually underground for most parts with diameters ranging from
approximately 15 – 21 meters [32]. Foundations are often underestimated but have to be a
reliable components of the wind turbine in order for it not to tilt and collapse. Critical
design factors include structural loads (extreme winds, normal operating winds and
fatigue), materials, construction, geotechnical parameters, tower flange dimensions, and
serviceability requirements (stiffness, settlement). Also, the mechanical and electrical
factors have to be considered [33].

A geological assessment has to be made after choosing a site for the wind turbine and/or
wind farms. Soil and rock characteristics are important issues when it comes to load factors
because it is important to have knowledge of how the soil behaves and how it supports the
wind turbine, and how it formed [32].

There are several types of foundations for wind turbines [32]:

・**Spread footing** is the most common foundation and best suited in low compressed
soil. 2 Maximum wind speed that a construction can withstand [94]

3 Soft tower: A soft tower has a natural frequency lower than the blade passing frequency but greater than the rotational frequency of the WT.

4 Soft-Soft Tower: A soft-soft tower has a natural frequency lower than the rotational frequency of the rotor.

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・**Patented caisson** is an embedded soil filled steel can mainly used in riverbeds and relies on skin friction of soil. It cannot be placed in all soil conditions due to movement of the soil.

・**Pile foundation** is best to use in very compressed soil where it is drilled deep down to support the wind turbine. They are expensive and cost a lot in labor. If there is a poor soil at the site, this foundation is well suited.

・**Rock socket or rock anchor** is attached to the rock. Rock socket foundation is more economical in shallow bedrocks rather than shallow spread foundations. Both types use less concrete and less steel. They cost less than other types but take longer to design, which is why investors rather choose spread footing foundation in order to keep schedule.
What has to be kept in mind is the bearing capacity of the soil has to be greater than the load, otherwise the foundation will sink and the system collapses. At some sites, the soil is very corrosive which has to be considered in cases where steel and concrete are being used.

3.3 Rotor

The rotor is a critical element of a wind turbine. The rotor consists of rotor blades and thehub, which will be presented in more detail in following sections. The power production is dependent on its interaction with the wind. The swept area, or surface area swept by the rotating blades, is the parameter that decides the size of the wind turbine. Equation 13, show the relationship between the swept area of the rotor and the diameter of the rotor [34, p. 3]:
□ □ 0.785□□ *(13)* There are two types of rotors in HAWT, upwind and downwind rotors [7, p. 80].

Downwind and upwind rotors are best suited for turbines with high capacity and operating at high tip speed ratio [7, p. 80]. Downwind rotors, have free yawing, which is easier to implement than active yawing used by upwind rotors. Also, the downwind position reduces
bending moment of the blade root flap. The main disadvantage is fatigue damage to the blades caused by periodic load leading to a wave on the generated electrical power. It is possible to decrease these effects by a teetering hub and individual pitching mechanism
[35].
The advantage of upwind rotors is reduced tower shading and because the air starts to bend
around the tower before it passes, the loss of power is less [36]. The main disadvantage is
the extended nacelle needed to put the rotor in the right position to avoid a blade strike.
Also, bad weather conditions may lead, to a stressed rotor hub by the blade [36].
TSR depends on the number of blades attached to the rotor. There are rotors with one or
two blades, but three blades is most common one is the three bladed rotor but maximum
capture of wind energy is only possible with large number of blades. The rotor must have
rotational speed according to its size, which means correct rotor diameter and the wind
speed. Or in other words, the rotor must have an efficient [7, p. 92]. Also, designers have
35

to keep in mind that by increasing the effective diameter of the rotor, the cost, weight,
tower structural complexity and noise level will also increase [7, p. 238].
Studies shows that the TSR for rotors with two blades is 2 to 4 percent less efficient than
the three blade rotor. There is even more drop when it comes to one blades rotor, or 6
percent less than the two bladed one. Also, is there an increase in cost and design
complexity as the number of blades increase [7, p. 102].
The rotor has to rotate faster in proportion to the number of blades. The one bladed rotor
has to rotate faster than three blades rotor to extract maximum power from the wind.
Which means more tip noise and erosion [35] [7, p. 103].
There is a connection between the reliability of the rotor, TSR and number of blades. High
speed ratio should have less blade area to be at optimum, than the rotor of a slower turbine.
If the TSR increases the chord and thickness decreases for any given number of blades.
This results in higher blade stresses. By reducing the number of blades, which means
higher TSR, the weight of the rotor can also be reduced [35].
Rotors found in wind turbines consist of airfoils that generate lift by virtue of the pressure
difference across the airfoil. The airfoil is a big influence in the performance of the rotor.

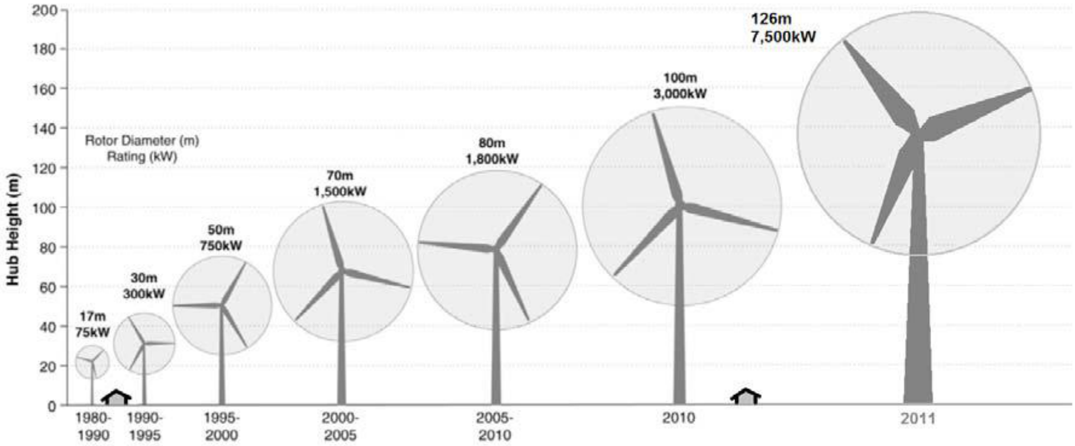
Improvement in performance depends on several factors, for example, high lift-to-drag ratio to improve rotor efficiency over a wide range of wind environments, characteristics of the stall, less noise, insensitivity to roughness and, optimum shape of the rotor for better performance [7, p. 104]. Behavior of the airfoil changes depending on Reynolds numbers, which must be available for analysis of a wind rotor system to take place [5, p. 112].

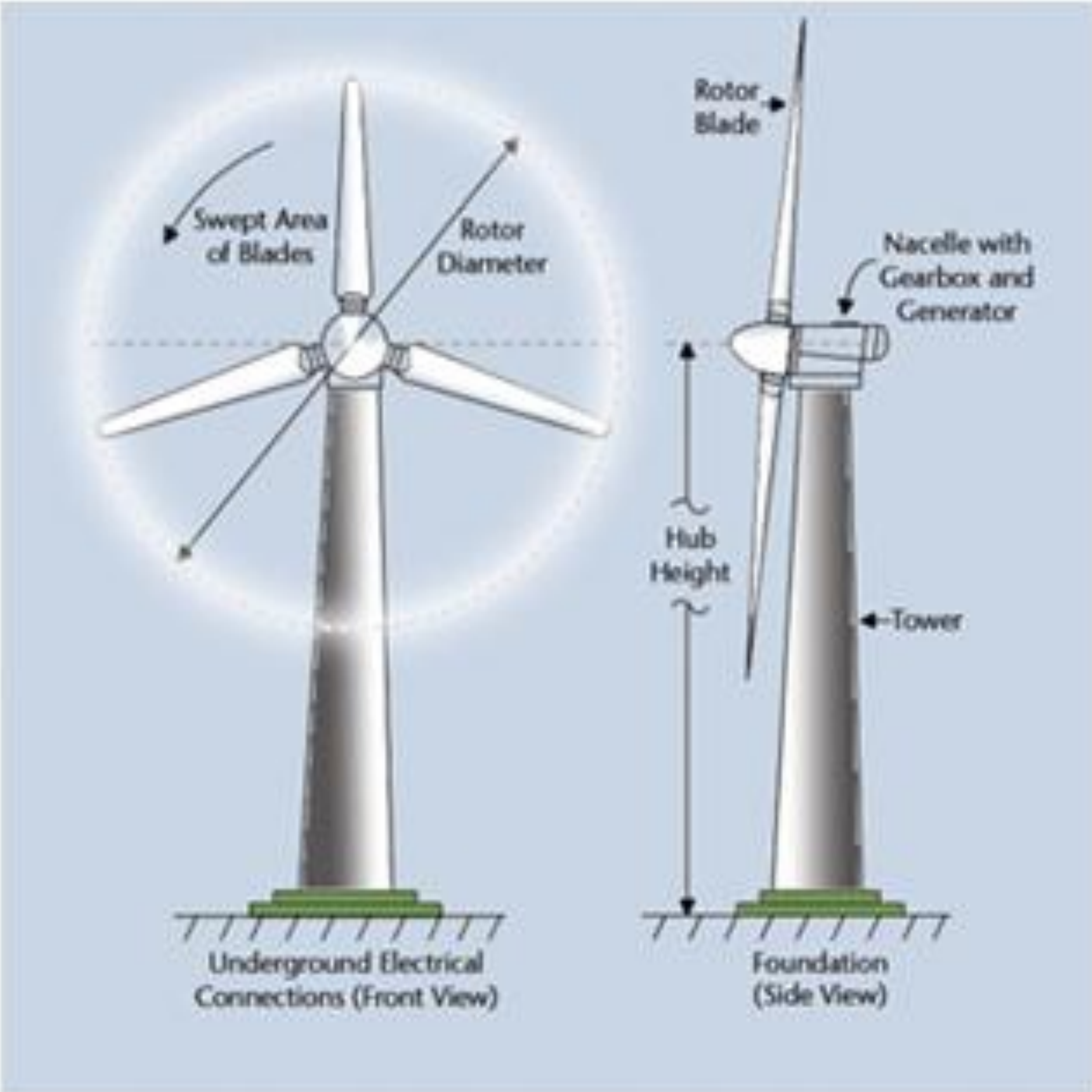
Hydrodynamic flows analysis, which influences the performance of the rotor, can be predicted regardless of the shape. This analysis can predict the air movement over a solitary spherical hill. This type of analysis is important in order to understand the theoretical aspects and operating principles of a wind turbine [7, p. 104].

The rotor has to operate continuously, so the rotor has to be designed with that in mind because maintenance is both expensive and time consuming [7

3.1 Tower

The height of an HAWT tower is very important when it comes to performance since wind speed increases with height [7, pp. 36-37].
The interaction between wind speed and installation height is complicated. The wind is affected by friction from turbulence around mountains, hills, trees, buildings etc. These influences decrease with increasing height. In short, wind speed increases with more height and friction while turbulence decreases. Higher towers therefore offer more wind speed and it is possible to use larger blades that increase the production of electrical power. Low wind speed and changes in wind speed as a function of height, called wind shear, can have a harmful influence on the performance of the turbine. When a reversal in temperature occurs in a calm wind environment, the wind speed can increase slightly between the ground and certain height of the tower and then start to decrease. Meaning the change in wind speed as a function of height is not constant [7, pp. 55-57].
In the case of HAWT the tower must be high enough for the blades to not touch the ground as they rotate. But generally, the height of the tower is 1 to 1.5 times the rotor diameter [5, p. 7] [25]. A wind turbine should be practical for the operation in question and the height of the tower should be based on an economic tradeoffs of increased energy capture versus increased cost and the characteristics of the site [5, p. 257]. Figure 5 shows how much the rated power increases with bigger blades, which require taller towers.


126m
7,500kW
100m
3,000kW
80m
1,800kW
70m
1,500kW
50m
750kW
30m
300kW
17m
75kW
Rotor Diameter (m)
Rating (kW)
Hub Height (m)
200
180
160
140
120
100
80
60
40
20
0
1980-1990
1990-1995
1995-2000
2000-2005
2005-2010
2010
2011



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

Figure 2.2: HAWT wind turbine

In order for a turbine to be defined as a HAWT, the rotor blades have to be connected to a horizontal shaft. These types of turbines are mainly for commercial usage. Critical components are the rotor, gearbox, anemometer, generator, yaw motor, control system and the foundation. The turbine can either be a rotor-upwind design or rotor-downwind design. An upwind rotor faces the wind while a downwind rotor enables the wind to pass the tower and nacelle before it hits the rotor. The rotor diameter, number and twist angle of rotor blades, tower height, rated electrical power, and control strategy are the main considerations in design. A huge factor regarding the efficiency is the height of the tower since more height means more wind power [7, p. 36]. According to Equation(***10***, the wind speed is in the third power meaning that more height equals more wind speed. Also, with increasing height, the turbine noise, rotor blades, and power output increases [7, p. 5]

Rotor diameter (D) is of equal importance because it determines the area (A) needed to

meet the output level which is needed in each case [7, pp. 33-37]. Upwind rotor design currently dominate the market [7, p. 36]. Even though the downwind rotor design adjusts automatically to wind direction, an important safety and operational feature, it does not adjust under abrupt or sudden changes in wind direction. This can be overcome with three-blade upwind rotor, making it more desirable than the downwind rotor [7, pp. 33-37] [5, pp. 3-5]. In order to optimize the power output performance, a selection of a ratio between the rotor diameter and the hub height has to be considered carefully. In order to avoid damage to the structure, the control system must ensure that the rated power output of a wind turbine does not exceed the maximum power allowed for the generator [7, pp. 33-37].

HAWT usually have two or three rotor blades. A turbine with two rotor blades is often in downwind installations where, the rotor is downwind on the tower. It is faster and cheaper, but it flickers more than the rotor with three blades and is less efficient. Three blade rotors operate more smoothly and are therefore less disturbing. HAWTs is lift based which means that they have blades designed as airfoils similar to aircraft wings. The apparent wind creates lift from a pressure differential between the upper and lower air surfaces [7, pp. 33-
37] [13].

The main advantages is high generating capacity, improved efficiency, variable pitch blade capacity, and tall tower to capture large amount of wind energy. There are also disadvantages such as consistent noise, killing of birds, interference with radio, TV transmission and radar, land use, maintenance worker hazards and visual impacts [7, p. 5].

MINISTRY OF HIGHER EDUCATION
AND SCIENTIFIC RESEARCH
UNIVERSITY OF DIYALA
ELECTRONIC
ENGINEERING DEPARTMENT

Design and Implementation Horizontal Wind Turbine

Submitted to the Electronic Department - College of Engineering - University of Diyalain Partial Fulfillment of the Requirements for theDegree of Bachelor in Electronic Engineering

By

SaadGadban
Ahmed Arkan

Supervisor
Asst. Lect. Omer Abood

2016-2015

الإهداء

الى من كان معي طول الطريق.............

الى أهلي والدي والدتي والى كل صديق.........

الى كل زملائي في الدراسة والى كل اصدقائي في طريق العلم.......

الى كل قريب وكل بعيد.........

الى كل من ساهم على وضع على طريق العلم..........

الى كل الذين ساعدوني في هذا البحث..........

الى كل من صبروا والى كل من طلبوا العلم............

الى اساتذتي الاعزاء..............

الى رئاسة القسم...............

بسم الله الرحمن الرحيم

﴿ اللَّهُ لاَ إِلَهَ إِلاَّ هُوَ الْحَيُّ الْقَيُّومُ لاَ تَأْخُذُهُ سِنَةٌ وَلاَ نَوْمٌ لَّهُ
مَا فِي السَّمَاوَاتِ وَمَا فِي الأَرْضِ مَن ذَا الَّذِي يَشْفَعُ
عِنْدَهُ إِلاَّ بِإِذْنِهِ يَعْلَمُ مَا بَيْنَ أَيْدِيهِمْ وَمَا خَلْفَهُمْ وَلاَ
يُحِيطُونَ بِشَيْءٍ مِّنْ عِلْمِهِ إِلاَّ بِمَا شَاء وَسِعَ كُرْسِيُّهُ
السَّمَاوَاتِ وَالأَرْضَ وَلاَ يَؤُودُهُ حِفْظُهُمَا وَهُوَ الْعَلِيُّ
الْعَظِيمُ ﴾

صدق الله العظيم

سورة البقرة الاية (255)

Supervisors Certification

I *certify that this project entitled (A multilevel Inverter Based On SHEPWM For Photovoltaic Application) was prepared under my supervision at the departments by of electronics engineering, College of engineering by* SaadGadban& Ahmed Arkan *as partial fulfillment of the requirements for the Degree of Bachelor in Electronics Engineering .*

Signature:**Asst.OmerAbood**

Name: Dr. Mohammed Salman

Title: Lecturer (ph.D)

(Head of The Department)

Date: / / 2016

ABSTRACT

Surface pressure data from the National Renewable Energy Laboratory's "Unsteady Aerodynamics Experiment" were analyzed to characterize the impact of threedimensionality, unsteadiness, and flow separation effects observed to occur on downwind horizontal axis wind turbines (HAWT). Surface pressure and strain gage data were collected from two rectangular planform blades with S809 airfoil crosssections, one flat and one twisted. Both blades were characterized by the maximum leading edge suction pressure and by the azimuth, velocity, and yaw at which it occurred. The occurrence of dynamic stall at all but the inboard station (30% span) shows good quantitative agreement with the theoretical limits on inflow velocity and yaw that should yield dynamic stall events. A full three-dimensional characterization of the surface pressure topographies combined with flow visualization data from surface mounted tufts offer key insights into the three-dimensional processes involved in the unsteady separation process and may help to explain the discrepancies observed with force measurements at 30% span. The results suggest that quasi-static separation and dynamic stall analysis methods relying on purely two-dimensional flow characterizations may not be capable of

simulating the complex three-dimensional flows observed with these data.