CHAPTER 1

HISTORY OF WINDMILLS

1.1 HISTORY OF WINDMILLS

Since the dawn of civilization mankind could have used wind power for various purposes, but according to documented history wind power has been in use since the year 5000 BC by the ancient Egyptians [1]. The Egyptians discovered that wind could be used as a source of energy for grinding corn, pumping water and other similar applications. The wind is a free, clean, and inexhaustible source of energy. It has served mankind well for many centuries. The first practical application of wind energy was witnessed in 4000 BC in the form of a single square sail on a sailing ship. This was done successfully on a trial basis to take advantage of the north wind up the River Nile against the river current. This idea was improved further by using many sails fixed to tall masts on ships as shown in figure 1.1. This allowed sailors to reef a sail thereby exposing a large surface area to harness all the available wind and propel the ship.

In 2500 BC, during the reign of the fifth dynasty of the Egyptian emperor, the people were allowed to travel out to sea by sail ships. This trail was carried on an exploration and trading trip around the horn of Africa and to the land of Punt without using muscle power. The immense potential of the inexhaustible wind flowing through the seas and continents was utilized to generate useful energy for humans. Indeed, wind was almost the only source of power for ships until Watt invented the steam engine in the 18th century. This concept of using wind as a source of energy was extended to land in the form of windmills.
Figure 1.1 First known sail ship
Windmills are machines that convert the power from wind into kinetic energy. They manifested in different forms to perform a variety of tasks like grinding grain, pumping water for farms, live stock, salt farms, timber milling, stone sharpener and ventilator for forging. Countries like Egypt, European countries, China, Persia, Netherlands, mid-west of America and Australia have been developing and deploying the technology for centuries. These early machines were, no doubt crude and mechanically inefficient, but they served their intended purposes well for many centuries.

Wind at very low speeds was enough to drive a winch motor and for transforming its kinetic energy into useful mechanical work. The type of windmill construction depended on the location, the kind of work, and the amount of work that it needed to perform. The architecture of these windmills as shown in figure 1.2 differed from one country or region to another. The Dutch even constructed a multi storiied tower with each floor allocated to grinding grain, removing chaff, storing grain and finally using the lowest floor as a residence for the windmill workers’ families. In the 1700 B.C, King Hammurabi[2] of Babylon used wind power for irrigation projects. This application became so common that all wind turbines were often called windmills, even when they actually pumped water or performed some other function. In 300 BC, horizontal axis windmills were invented in Egypt and Greece. These had 8 to 10 wooden beams rigged with sails and a rotor which turned perpendicular to the direction of wind. This specific type of windmill became popular in Portugal and Greece. Windmills began in India in 200 B.C as evidence by the famous Sanskrit classic “Arthasastra” by Kautilya[3]. It refer to windmills in Persia as invented by the Persians in 7 B.C.

In China water wheels were horizontal and was a critical power supply. However the vertical water wheels were also used for operating trip hammers for hulling rice and crushing ore. The Alternate source to windmills was the watermills and used for the same work as the windmills do. The watermills were first put to use in 31 BC and not preferred because of the dependence on tides. Water powered wheels were employed in ancient China in 2nd century BC.
Fig. 1.2 Wind operated stone grain grinder
The Chinese engineer Tu Shih[4] invented a water powered reciprocator for casting of agricultural implementation. Smelters and Casters were used this technology for operating their billows as shown in figure 1.3. In 4th century AD, watermills were employed at Bardegal near Arles in Southern France and used a flour mill employing 16 water wheels.

The power of wind, harnessed and directed by machines of many designs, freed the serfs of the middle ages from some backbreaking tasks. In Holland, the windmill allowed lowland reclamation, pumping water up from land that could be made fertile and productive. In other countries, the growth of wind power meant irrigation, sawing timber, or milling grain. Many developments of watermills were carried out and were deployed in various operations till 41 AD. An Engineer of the Augustan period called Vitruvius [5] has written many volumes on Roman engineering. The vertical watermill was widely used but was limited to the rivers, where water current exists. The Romans were not much interested in finding out alternate sources of energy, since abandoned cheap slave labour was available in the region. Till the 13 century AD technological innovations in water mills were slowly introduced in the east and the west through central Asia, slowly exported by sea.

The Greek engineer Heron[6] of Alexandria in the 1st century AD used a wind driven wheel to power a machine. A type of wind driven wheel was used by Tibet and Chinese since the 4th Century AD. Iran and Afghanistan windmills were used in the 7th Century AD. Vertical axis windmill with long vertical drive shafts see figure 1.4 fitted with 6 to 12 rectangular sails covered with reed matting or cloth were used for grinding corn, pumping water and by the sugarcane industries. The Chinese used windmills in addition to water mills for grinding corn especially during winter. In the mid 8th Century AD, wind powered statues and palace complex were turned around in Baghdad. Vertical axis wind pumps were extensively used in China for many centuries and these still exist along the eastern coast north of the Yangtze River, near Tientsin for lifting salt making farms. figure 1.5 shows a square-pallet wooden chain pump driven by windmill, which were employed by the Chinese.
Fig. 1.3  Reciprocating Stone grain grinder
Figure 1. 4 Vertical axis wind operated mill
a) Bevel gear  B) Anemometer  c) Blades  d) Yawing mechanism  e) Vertical drive shaft
f) Rotating grinding stone  g) Stationary grinding stone.
Figure 30. Square wooden enclosed chain-type water pump

Fig1.5 Square wooden chain driven water mill
A Greek mathematician named Hero born in Alexandria in 10th Century AD invented the first small windmill application in the form of wind powered organ as shown figure 1.6. He had many inventions, one of them being the first steam engine invented in 60th Century AD. He also invented a windmill and a water pressure device which could open and close doors. His inventions find mention in his book titled “Pneumatica”.

Persia is believed to be the birthplace of windmills with vertical axis sometime between 600 and 800 AD. These windmills were slowly deployed across the Middle East, Central Asia, China and India. The horizontal axis windmills were extensively used in the North-western Europe to grind flour in the 1180 AD. Around this period windmills were used to pump sea water in China and Sicily.

The towers which were traditionally made of wood were for the first time constructed using stone by Weedley and Yorkshire in the year 1185 AD. This technology became popular and was used at various locations. The horizontal windmills used in Europe were of different design from the vertical axis windmill used in Afghanistan used during this period. The drawback of the horizontal axis windmill depicted in figure 1.7 was that the entire windmill had to be turned manually and to stop the windmills the blades had to be stopped by hand since there was no braking system. In the latter part of the 12th Century AD, horizontal axis windmills grew in popularity and were installed along the coastline of the Mediterranean Sea in Europe. During this period the Egyptians and Persians replaced their vertical axis windmills with horizontal windmills.

In 1350, Holland started development of horizontal axis windmills mainly for draining marshes. There windmills were larger in dimensions with 4 blades. These windmills deliver higher output power, which was considered necessary for pumping out water from low lying area. Later in 1368, during the reign of the Ming dynasty[7], the Chinese switched from the vertical axis over from their old vertical axis windmill to the horizontal axis windmill to take advantage of the horizontal axis design in terms of the power output.
Figure 1.6 First wind powered music instrument invented by “Hero”
Figure 1.7 First Greek sail rotor water pump

Figure 6. Greek sail rotor water pump
Windmills were in use in China for many years before the first documentation were prepared by Chinese Statesman Yehlu Chhu-Tshai[8] in 1219. These windmills were small vertical axis windmills of the Persian design and were employed for small application.

In 14th Century AD, The Dutch used their windmills to drain areas of the Rhine River delta as Holland was below the sea level and hence floor prone. These windmills figure 1.8 were extensively used till a proper flood control system was installed. The windmills designed for draining flood water were called “WIP MILLS” which were a significant improvement of the European “POSTMILLS”. This system consists of a tail-pole luffing device with a frame work of removable sail boats and a breaking system of the Danish design built with a rope encircling a break wheel. This novel design soon spread to other countries like Europe, America, Canada and Japan in the Far East. The first wind turbine for grinding corn was built in Holland in 1439. A typical American windmill was far smaller in dimension than the European design. The blades of the American windmills were tightly packed into a smooth circle and looking like a pinwheel.

The smock mill evolved from the post mill and was named thus for using cloth on sails by “Smocking”. The smock mills were mainly found in the Netherlands this windmills consisted of a fixed wooden body for holding the milling machinery, together with a rotatable table, which held the roof, the sails, the wind shaft and the brake wheel. The smock mill only rotates its rotatable table. This design allowed for much larger and taller mills than the “post mill”. The advantage of the design was that the taller mills allowed an extra length of sails to increase the power output. The sails were mostly octagonal in shape. By the end of the 14 century, the smock mill was replaced by the tower mill design as depicted in figure 1.9.

The wing design was improvised and the wooden body was changed to either brick or stone structure. The materials used for the design were more weather proof and stronger than the wooden structure including, raising tower for increased power output. The smock mill and the post mill had to be rotated manually and the sails had to be adjusted by a wind-smith for extracting maximum power. This type of mill was used for many decades with some in existence till this day. figure.1.9A, B, C, D.
Figure 1.8  Wind operated water pump used for irrigation
Figure 1.9 First concrete floor windmill
Figure 1.9A  Ancient Wind Mills still Existing Kinderdijk, Netherlands
Figure 1.9B Ancient Wind Mills still Existing Kinderdijk, Netherlands
Figure 1.9C  Ancient Wind Mills still Existing Kinderdijk, Netherlands
Figure 1.9D  Ancient Wind Mills still Existing Kinderdijk, Netherlands
The English were the first to introduce windmills in America in the 16th century. These windmills were installed at Jamestown, Virginia settlement. The post mills were developed with lot of improvements in design and introduced as a tower mill. The turret of this windmill was raised higher and the grinding machinery transferred all machine from the top of the existing wooden structure including the gearing. The disadvantages of turning such a heavy post mill with all its grinding machinery and stock of grain or flour was found. The beam which turned the post mill was first affixed to the cap of the fixed tower, where the caps alone turned to keep the sails filled by the wind. The tower mill had a fixed supporting tower with a rotatable cap which carried the wind rotor. The tower was usually built of brick in a cylindrical shape, but was sometimes built of wood, and polygonal in cross section. In one style, the cap had a support or tail extending out and down to the ground level. A circle of posts surrounded the tower where the support touched the ground. The miller would check the direction of the prevailing wind and rotate the cap and rotor into the wind with a winch attached between the tail and one of the posts. The tail would then be tied to a post to hold the rotor in the proper direction. This process would be repeated when the wind direction changed. Protection from high winds was accomplished by turning the rotor out of the wind. This was installed in the northwest of the United States founded by French Canadians in 1683. The interior arrangement of this windmill was redesigned with better amenities for a living. This type of mill was used for many decades with some in existence and in use till this day in Kindirdijik, Netherlands.

In the middle of 17th century, the Persians were using wind turbines extensively. These were vertical axis machines with a number of radially-mounted sails. These early machines were crude and mechanically inefficient, but they served their intended purpose well. They were made from local materials and cheap labor. Many people were employed in maintenance work, due to its crude construction of the machine. Their sizes were determined by the materials locally available. A need for more power was met by building more wind turbines rather than larger ones. In 1745 Edmund Lee [9] of Brock Mill near Wigan, provided the solution which would be applied to windmills and even wind turbines and a patent was granted figure 1.10.
Fig 1.10 Wooden frame fan blades
In 1704, Antoine Parent[10] suggested that the efficiency of an undershot waterwheel turbine at one third of the velocity of the stream was about 15 percent when compared with a perfect one which ought to be able to pump back again to the original height the water which drove it. Parent realised there must be a connection between an incompressible fluid, water, and a compressible fluid, air and that it ought to be possible to determine the power of a windmill from the speed of the wind. The relationship between air and water was further explored by Belidor[11] in the year 1730. Parent published his calculations in 1713 showing that the wind force on the sails was proportional to the square of its speed and the square of the sine of the angle, with which it hit the sails. His calculations were to form the basis on which subsequent engineers worked for the next fifty years both on the Continent and in England. W. Emerson[12], in England followed Parent but by the time his book named “Principles of Mechanics” was published in 1754, it was realised that Parent had neglected the effect of rotation on the inclination or angle of incidence of the blades. Emerson used the angle of incidence quoted above as the best angle for starting a mill and pointed out that this would always be so, if the wind struck them in the same angle when moving as, when at rest. Emerson has not advanced in theory or calculations.

The Dutch brought the windmills to their settlements in New Amsterdam (Manhattan Island, New York) and New England. Mr. Leupold Jacob[13] in Europe introduced in 1724, a self regulating wind turbine with 8 blades that drove a single piston operating pump with a crankshaft and a tie rod. This was an ingenious design as each blade is connected with a spring, adjusting itself the wing length depending on the speed of the wind. This technique was quite safe to avoid damage during galewind. In the year 1745, Edmund Lee invented the tail fan for the windmill, to turn the windmill automatically according to the direction of wind. This system became popular in England, Germany, and Denmark. Johann Ernst Elias Bessler[14] was the first to attempt to build a horizontal windmill of the Savonius type, in the town of Furstenburg in Germany in 1745. He fell to his death whilst construction was under way. It was never completed but the building still exists.
In 1759, John Smeaton [15] published his paper in the Royal Society by comparing the models of Mr.Rouse of Harborough, Leicestershire and Mr.B.Robins[16]. He the critically analysed the work done by Maclaurin and Parent. Smeaton was noted for his theory, based on the windmill experiment carried out on a hydraulic test rig with which he was able to wind. He felt the required volume of air and the velocity cannot be generated. So he placed the test rig in a room with connection to the sails outside the room by an arm protruding 1.54m long, a pendulum for wind direction and manually operated by a rope wound around the shaft drum figure 10A.

Smeaton carried out 19 experiments on at least 6 different types of sails which could be set at different angles of inclination. He had only one choice of sail and did not know that other type of sails would work with the same principles for comparison. He took great care in working to overcome friction in the windmills and thus experimented in an oil mill constructed by him. He documented that the theoretical observations made by Parent and Maclaurin were wrong. While Parent’s value of 35 deg for the angle of inclination between the plane of the sail and the plane of rotation of the whip gave the greatest force, the speed was too slow for useful work. [17]

Smeaton found out half this angle would gave an increase of 50 percent in the product of the load at the maximum number of revolutions. Smeaton experiment concluded that the best shape would be convex on the windward side but the Dutchman confirmed the concave form would be better. The tip to be nearly parallel to the plane of rotation in order to avoid creating back pressure when the sail passed in front of the body of the mill into the areas lifted off the supporting framework, causing it to flap. Not only did this weaken and damage the cloth but it caused rain on the sail to be flung against the body of the mill. Smeaton found the velocity of the tip of the sail was nearly in direct proportion to the velocity of the wind. Therefore, while increasing the area of sail at the extremities of the arms would give greater leverage and power, there was little benefit in extending the radius because the
Figure 1.10A Smeaton laboratory apparatus for testing windmills
revolutions would have to fall to maintain the tip speed ratio. He found the best sails were rectangular with the surface on the driving side. He employed a maximum of 4 blades for most of his experiments [18].

He documented his findings as follows: The effect or output was governed by the following rules. First, the velocity of the sail varied as the velocity of the wind so that the peripheral speed of a sail was nearly proportional to wind velocity (V). Second, the load or maximum effect at a given time varied as the velocity of the wind multiplied by the velocity of the sail, so it varied as the square of the velocity of the wind (V²). The effect, that is the power developed, at the maximum, was nearly proportional to the cube of the velocity of the wind (V³).

The windmill “smoke jack” was developed into a form of windmill by Erasmus Darwin [17], who wrote about it to the Society of Arts in 1768. He penned many of his inventions and after 21 years, his later research on his inventions were made as drawings and included in one of his books, Phytologia. Stephen Hooper secured four patents between 1776 and 1806. The important one was that patented in 1777 which reads as below:

“A straight or arbour G which is put in motion by the wind on a number of flyers fastened at an angle to arms on arbour G, within the shutters H and I; these shutters open to an angle, by which means the wind is conveyed to the flyers; the shutters are regulated by the wind to shut or let open in proportion to the strength of the same”

Hooper’s first patent was also concerned with pumping water and shows a bucket and chain pump driven by a horizontal shaft. The horses were kept standby during the ‘no wind’ period. He built a corn mill on his own property at Margate on top of a two-storey building. The rotor was contained in a tall, slightly tapering tower about 28ft in diameter and 40ft tall. The vertical shaft drove five pairs of stones through gearing. The mill was working in 1825 and stopped working due to the damage after severe storms. Stephen Hooper moved to London in the year 1801 and
he patented a new design in 1803, similar in principle to Darwin’s windmill. He further patented his findings and developments in the year 1806.

In 1750, Scottish Andrew Meikle reached an important milestone by introducing a small auxiliary mill at right angle with the vanes, in order to rotate with the sails automatically. In this way there was no necessity to turn the windmill table intermittently. In the same year John Smeaton who was the first scientist in the field of windmill used modern techniques in developing and redesigning windmills to improve the efficiency. He closely studied velocity and pressure of objects in air to determine efficiency of old windmills. He found that windmill blades should be given a twist in order to improve the efficiency [20]. In the year 1759, he published a technical paper titled “An Experimental Inquiry concerning the Natural Powers of Water and Wind to turn Mills and other Machines depending on Circular Motion”. He presented his findings with respect to the design changes for increasing windmill blades from 3 to around 5 to 8 sails to achieve higher efficiency. Attempts to combine tests on windmills with measurements of the wind speed were made in Holland, when a new type of scoop wheel for draining their polders was being evaluated. The inventor, a Dutchman, Anthoine George Eckhart, who was a member of the Society of Haarlem and also a fellow of the Royal Society in England, had erected two mills with his new wheels which were compared with two conventional mills under the supervision of a committee of Christian Brunings, Dirk Klinkenberg and Johannes van der Wall between 1774 and 1776 [22].

Brunings designed anemometers, which were built by the instrument maker J.Paauw of Leiden, with pressure plates to measure the wind force at a height of about 30 feet. Although the instruments were treated with great care and were read systematically, neither Brunings nor his contemporaries succeeded in discovering the fundamental relationship between the readings and the power of the mills. In 1788, Hooper built a horizontal axis windmill for the master Hodgson, on part of the site of Bolingbroke House at Battersea, then in Surrey. The tower height was maintained at 140 ft, with taper from 54 ft diameter at the top and 45 ft diameter at the bottom. It was carrying 96 movable shutters of 80 ft long and 9 inches wide. It was designated
for grinding linseed and later to grind malt for a distillery. The upkeep of the windmill was heavy and thus stopped working since 1849. But in 1787, Mead, Rennie and Hooper successfully developed the distance alteration with respect to the wind force of the windmill for grinding automatically by using centrifugal governors.

In the latest version of the Beaufort scale, force 3 is given as 4.4 m/sec. (10 m.p.h) and force 6 is given as 12.6 m/sec (28 m.p.h). These are roughly the limits between which the traditional windmill will work and with only three steps in the scale, it is too coarse for practical use [25].

The air has mass, which is low because the density of air is low. When this mass (m) moves, the resulting wind has kinetic energy which is proportional to \( \frac{1}{2} mV^2 \). If then density equals the mass per unit volume of air, or its density, and A the area through which the wind is passing, the mass of air passing in unit time is density x A x V and the kinetic energy becomes \( \frac{1}{2} m x V^2 \). If \( \rho \) equals the mass per unit volume of air, or its density and the area through which the wind is passing, the mass of air passing in unit time is \( \rho AV \) and the total kinetic energy available becomes \( \frac{1}{2} \rho AV^3 \). But Betz has shown with his experiment that from the total power, only 0.593 could be extracted by an ideal wind-motor. This was further proved by J.A.Griffiths that the highest efficiency was 25 percent in a 3.13 m/sec (7 m.p.h) wind [22].

The wind energy calculation shows increase in energy available in strong winds because the potential is increasing by the cube of the velocity. The Herne mill in Kent showed only 1.79 h.p from a wind speed of 2.24 m/sec and a massive output of 919.98 h.p if the wind speed increased to 17.88 m/s. Another problem with the wind mills was to start the windmills at light winds. The wind must be strong enough to overcome the inertia and frictions exerted by the bearings / gears. One of the considerations at the design stage of a windmill was to consider start at a lowest wind speed as low as 1.8m/s but however the average wind speed would be much higher during the running of the windmill.
The horizontal axis rotor design was used widely by the Greeks. This was adapted by Thailand and China for wind pumps because of its high starting torque, low stalling speed, low weight and cost. It easily adjusts to the higher wind velocities. The development organizations in countries like Sri-lanka, India, Ethiopia employed this design for areas with limited resources of materials and skill. In India a 10 m diameter sail windmill with eight triangular cloth sails of the Greek configuration was constructed in India by Madurai windmill committee for irrigation by tapping into the low speed winds prevalent in Southern India.

The design shown in figure 1.11 was built using local materials and skills to make it affordable to the farming community. The eight sails of khaki canvas were fitted to spars of bamboo and an oxcart wheel was used as a hub. A steel crankshaft with ball bearing fitted at the lower end transferring the reciprocating movement with the help of a wooden connecting rod, making a variable stroke lever arm to a 10 cm bore piston pump. The stroke was maintained 30cm with lift 10 m height and this could lift 6000 L of water per hour, with a wind velocity of 16 km/hr. The base was a welded steel turntable resting on a steel truck tyre rim bolted to the tower with the support of 6 eight meters long teak wood poles. The construction cost of this windmill was 400 USD.

In the 18th century, windmills were used to pump water for salt making on the islands of Bermuda and on Cape Cod during the American Revolution. In 1805 Admiral Sir Francis Beaufort, hydrographer to the British navy, introduced his Beaufort scale in 1805, when commanding the frigate woolwich. He wanted to devise a concise and repeatable method of reporting wind conditions in the ship’s log for Admiralty records and based his scale on the performance of his ship in different winds, thus it was a force scale and not a speed measurement. In 1807, William Cubitt used a series of weights and pulleys to stall shutters on windmill sails. He also introduced a self regulating windmill sails, by using chords tied to the mill vane edges. These vane edges fold inwards during high wind speeds and regulate the speed of the windmill. The French man named Leonard Euler and Jean L.d’Alembert continued theoretical work on the angle of the sails but he wasn't as successful as John smeaton.
Figure 8. Madurai prototype sail rotor water pump

Fig1.11 Madurai prototype sail rotor water pump
In 1846, Dr. Thomas Romney Robinson of Armagh Observatory invented a form of anemometer which became the most widely used type. This was a form of horizontal windmill with three or four hemispherical cups mounted on horizontal arms. The wind is caught in the hollow of one cup and turns the rotor while the streamlined outer surface of another cup moves against the wind. The inertia of the instrument and, in cold weather, the drag of the lubricating oil, may cause the anemometer to fail to record sudden gusts, but its simplicity and the fact that it could record winds from any angle have ensured its continuing popularity. By the year 1850, Holland had installed over 9000 working windmill. In 1854 Daniel Halladay installed the first windmill with four wooden blades for fan wings. He further developed using thin wooden sheets nailed to form a frame with tails figure 1.12, to turn them into the direction of the wind. Speed controls were introduced by hinging section of blades, which eventually fold back in high winds like an umbrella and reduces thrust.

The self-governing wind pump was patented by Daniel Halladay. The custom grinding windmills in Illinois were actually constructed by German immigrants, with the aid of local farmers and Dutch craftsmen, incorporating some elements from European windmills. In 1854, John Burnham invented the small and light windmill motor an “American style” windmill motor which moves with a wind speed of 8 Km per hour. He invented this by his studies on sailboats’ construction. The boat’s sail or canvas used, dragged all the way to its desired direction that established his confidence in constructing light windmill on a concrete foundation with a metallic tower of 11.3 m diameter and 100 thin metal vane blades. The blades were placed in between double rings to strengthen them to withstand high wind speeds.
Fig 1.12 Self regulating wind mill patented on 9\textsuperscript{th} Dec 1745
The farmers in the plains of Argentina, west of USA and Australia used these windmills since it was of great use for cultivation and irrigation. For example in Nebraska abundant water was available but was located in the subsoil at such a depth, it could not help farmers. In addition rain was scarce in the region but wind in the valley was strong and constantly available. This helped farmers use windmills to develop and convert deserts into fertile farm land. Wheat was cultivated in tons from this converted farm land and it was a great success for the farming community. In addition to the irrigation wind mills were also used for grinding and chopping cattle feed. Many windmills were produced in America from the 1860’s onwards. In fact one such windmill was patented in Brooklyn, New York figure1.13 and commercialized. Among the first were D.Strunk, Janesville, Wisconsin who patented a design in the year 1866. In the same year J.C.Fay from New York patented his new design. Large scale commercial production started in the year 1880 and reached its peak before the turn of the century. Rollason’s Wind Motor Company in England was making horizontal windmills from 1890s

1.1 Windmills powered electricity generation.

Denmark was the first country to use the wind for generation of electricity. Different Scientific principles apply to windmills and sail boats. The use of many vanes on a windmill makes the difference in dispersion of wind, varying resistance and hence the speed. In 1870 the multi vane windmill design of Europe conquered the American continent but not locally. This design later became popular in Europe as “American Wind Mill”. Poul La Cour found the error of John Burnham style of windmill construction and hence devised a much lower number of vanes restricting to 4 on a single windmill. The vanes were 7 m in length and 2.3 m wide which would sweep an area of 73 square meters sufficient enough to drive a 12 horse power dynamo.
Fig 1.13 Patented circular vane sail in 1855 by Frank G. Johnson and Francis Peabody
In 1870, the wooden blades were replaced by thin aerodynamically shaped metal blades. It was observed the light weight metal sails were rotating at higher speed and needed a gear box to match the machine speed. Between 1850 and 1900, American Midwest installed six million small windmills on farms for operating irrigation pumps [21]. The Danes were using a 23 m diameter wind turbine in 1890 to generate electricity. Star, Eclipse, Fairbanks-Morse and Aerometer companies became famous suppliers in North and South America. In the 19th century electric generators were used on the Sailing ship “Chance” New Zealand. A significant source of industrial power in Netherlands was met by this type of wind mill. There were about 2500 windmills in Denmark by the end of the 19th century employed for mechanical loads like pumps with the mills generating about 30 MW. The Americans even constructed a 5 mast sail ship with 40,000 square feet of canvas as sails for harnessing the wind, for a case study on “increasing the speed of the sail boats” and found it to be a success.

Charles F.Brush made history when he established his own electric company in son Francisco in 1879. He supplied electricity from a power plant to a major city. He also constructed the country's first hydroelectric plant at St. Anthony Falls near Minneapolis, MN. Brush retired to Cleveland, where he built a mansion. It was the first successful automatic wind turbine, in his first home in Cleveland to run on electricity. His turbine gained much attention in America and the Scientific American published a full article on it in the publication [24].

The areas around coasts are always the most windy, and in Britain with the prevailing south westerlie’s. The measurements for wind velocity taken in Britian were found to be in the range of 8 to 22 miles per hour. The first known windmill for electricity production was vertical axis windmill built in July 1887 by Scottish Prof.James Blyth of Anderson’s College, in Glasgow, Scotland. The 33 feet (10mtrs) high, 17mtrs rotor, cloth-sailed wind turbine of 12 kw capacities were installed at Maykirk in Kincardineshire and was employed for charging accumulators developed by Camille Alphonse Faure, to power the lighting of a cottage. This made the first house in the world to have its electricity supplied by wind power and the excess
power was offered to the people of Maykirk for lighting the main street. The Maykirk people turned down the offer as they thought the electricity was “the work of the devil”. Although Prof. Blyth later built a wind machine to supply emergency power, the invention never caught on as technology, as it was not economically viable. In 1880 Sir Benjamin Baker, who received a knighthood for the construction of the Forth Bridge carried out a series of experiments for two years on wind forces, using three pressure plates. The largest was 300 sq.ft and the two others 1.5 sq.ft. each. But even with reliable anemometers, it was still very difficult to measure the wind speeds actually hitting the rotor of a windmill. An anemometer mounted on a tower close to a windmill might not record the same winds as those reaching the mill itself.

Some investigations were carried out in India in 1880 but it was felt that the wind in most areas was too uncertain and too variable. The investigation and trails were carried out with an aero motor 4.88 m diameter windmill mounted on a 21.33 m tower with a 20.32 pump lifting water 9.84 m high at Madras. Gearing between the rotor and pump was 3½ to 1. Several days’ observation was carried on the trail of the anemometer fixed to the windmill tower. It was proved that when the wind velocity exceeded 1.34 m/sec, a certain amount of work was done but a steady breeze of 3.23 m/sec was needed to keep the mill in continuous motion. It was also noted that this wind pump would be capable of irrigating 10 acres when the water had to be raised 7.62 m. Considering the capital cost of the windmill, depreciation and interest, a monthly maintenance charge of Rs.25 was found to be economical comparing the cost of 2 pair of cattle used to tap the same amount of water requires Rs.67. So the windmill proved to be more economical. The problem with windmills was getting them to start under light wind conditions. A strong wind force is required to overcome the friction and to keep the blades moving sufficiently to carry out work. This shows the low density of wind will stall the moment of the blades.
In the year 1888, Charles F. Brush designed and constructed a larger and heavily engineered machine **figure 1.14**, in the backyard of his Cleveland mansion, Ohio. The wind turbine had a rotor of 56 feet (17mtrs) diameter with a tower height of 60 ft (18mtrs) and was only rated at 12 kW. It turned very slowly since it had 144 blades and was used to charge a bank of batteries, to operate up to 100 incandescent light bulbs along with arc lamps and various motors in Brush’s laboratory. This machine was abandoned in 1908, when electricity was available from Cleveland’s central stations. With the development of electric power in larger capacity, windmills were deployed for lighting building from centrally generated power houses in remote areas. He sold his company in 1891 which was later renamed as Edison’s General Electric Company [25].

In the year 1888, One of the windmill manufacturing companies called Butler in Indiana established its production in wooden and steel wheel mills. It initially manufactured solid wooden wheel models and later started Single Gear mill. A large number of these windmills did not survive, as the world war began in Europe. The improved model with double gear open back geared steel pumping mill of 6 inches to 16 inches diameters was very familiar in the Midwest and was supplied abroad. The special feature of this windmill is that the bearings were used either of Babbitt material or oil-less bronze bearings.

Danish Professor and scientist, Poul La Cour, was supported by the Denmark Government in 1890 for 17 years, to carry out detailed scientific study on windmills. He constructed a wind turbine to generate electricity that was used to produce hydrogen for experiments and to light the local high school. It later became the local power plant of the village Askov. Poul La Cour no doubt perfected the generation of electricity and was the best person selected to look into this by the Danish government. He generated electricity and stored it in batteries as reserve for future use.
Figure 1.14 Charles Brush’s First power generation wind mill
The only problem he was facing was absence of wind for some period of
the year. The windmills were used to elevate water to a higher level as reserve for
irrigation. He studied the American style of windmill, but found it to be less efficient.
He had been carrying out various studies by constructing many models of windmill
pilot projects. During the “no wind period” the workers in the factory were idle and
the overall cost like labour wages, factory rent and capital interest used for the
windmills were higher. He had successive studies done on the laws of governing the
wind force and windmill design to achieve most for humanity. He established the
first electrician society. He had many technologies for developments of wind mills
and one such development was to use sail design. He believed that windmills could
be useful to generate electricity with the aid of unique sail design to power about 25
to 35 kW. However, fossil-fuel steam plants were still favoured for their greater
efficiency and inexpensive way of energy production when compared with wind
generated electricity.

By 1910, several hundred units with capacities ranging from 5 to 25 kW
were in operation in Denmark. The period between 1900 and 1973 witnessed many
wind generators made by individuals that competed with fossil fuel based generation
plants. The oil price crisis had led to a rethink on non fossil fuel energy sources. In
Denmark wind energy was a part of a decentralized electrification plan. By 1908,
many wind driven electric generators ranging from 5 to 25 kW were introduced. The
largest machine was developed during this period with a 75 foot diameter (23 meters)
rotor with four blades and on a 79 foot (24mtrs) tower.

Prof. Poul La Cour introduced Mr. Sorensen of Denmark, an innovative
capable man to his followers before his death to fulfil his imaginations and
experiments. Sorensen constructed the first dream project of Prof. Poul with four
vanes but it was a “conical wind motor” since they were curved vanes. This design
of windmill increased the efficiency to 50 percent, when compared to German wind
mills. The German and Dutch windmills are constructed with large vanes to fit the
windmill mechanism with speeds ranging from 9 to 13 km per hour. The city of
Wittke, Schleswig in Germany was illuminated with this class of motor generating 30 horse power at a speed of 12.5 km per hour.

In 1901, Capt. Robert Falcon Scott installed a windmill in a ship called “Discovery” figure 1.15, when he made his first trip to the Antarctic. The windmill was connected to a small dynamo for generating and moving electrical equipment of the steamer to save a small amount of fuel the ship had loaded. The system did not work much of the time as the steamer was stuck in a bad storm and the windmill was damaged.

Sigurd J. Savonius a Finnish engineer invented the Savonius wind turbine in 1922. They were simple turbines, aerodynamic and drag type devices and in the shape of a letter ‘S’ looking from the top. The shape of the curvature experienced less drag when moving against the wind than when moving with the wind. This differential drag caused the wind turbine to spin. Savonius turbines were selected for the cost effectiveness or reliability but the efficiency was lower compared to other types of vertical axis turbines. It was not required to turn its position in the wind direction like the horizontal axis turbines.

Alternative energy enthusiasts often built this turbine from used oil barrels by cutting the barrels in half lengthwise and welding the two halves back together offset from one another to catch the wind. A picture of such a turbine is shown in figure 1.16. This was developed at Kansas State University, Manhattan, Kansas. The tower of the KSU Savonius was 11 m high and 6 m wide. Each rotor was 3 m high by 1.75 m in diameter. The rotors were connected together and drove a single 5 kW, three-phase, permanent magnet generator. At the rated wind speed of 12 m/s, the rotor speed was 103 rpm and the generator speed was 1800 rpm with a frequency of 60 Hz. The Output voltage and frequency was varied due to the constant wind speed and load changes. This means that this particular turbine could not be directly paralleled with the utility grid. This asynchronous electricity are limited to electric heating and driving three-phase induction motors in situations, which can withstand variable speed operation.
Fig 1.15 First windmill installed sail ship in 1901 by Capt Robert Falcon Scott
Figure 1.16 Kansas State University Savonius, rated at 5 kW in a 12-m/s wind.
These include heat pumps, some water pumps, and fans. Asynchronous systems do not require complex blade pitch, voltage, and frequency controls making it less expensive. The main advantages of the Savonius are a very high starting torque and simple construction. The disadvantages are weight of materials and the difficulty of designing the rotor to withstand high wind speeds and a comparison in efficiency is shown in figure 1.17

The French, Germens and Italians had developed many variants of Vertical-axis wind turbines. They are indifferent to wind direction, and veering winds do not create yaw loads. Another advantage is the gearing and generator is close to the ground. This experimental VAWT was tested at Sandia, using extruded aluminium blades of airfoil section, though blades of symmetrical section also work well.

Darrieus wind turbine was patented in 1931 by a French aeronautical engineer Georges Jean Marie Darrieus in USA. It had a vertical axis with many design combinations. The blades were shaped and called troposkein, from the Greek word for turning rope. Since the blade operates in almost pure tension, a relatively light, inexpensive blade was sufficient. It was placed at the ground level along with the generator and gearbox. This was no requirement for directional adjustments; all these attributes lowered the manufacturing as well as the maintenance cost of the windmill. The main disadvantage with the Darrieus wind turbine is that, as a result of its installation at the ground level, the extraction of useful energy gets reduced due to low wind speeds at the ground level.

A vertical axis wind turbine (VAWT) is shown in figure 1.18, which converts force into torque on a rotating shaft. It used to convert the wind force into torque on a rotating shaft. The diameter swept by the blades of this machine is 55 feet, and the power fed to utility lines is rated at 60 kilowatts. The cost of energy was calculated to be around 4 cents a kilowatt hour. One disadvantage of the Darrieus is that it is not normally self starting.
Figur e 1.17  A typical wind turbine performance chart
Fig 1.18 VAWT–Darrieus Vertical axis wind turbine being tested at New Mexico
That is, if the turbine has stopped during a period of low wind speeds, it will not re-start when the wind speed increases. The normal starting is usually supported by an induction motor connected to the local utility network. This is not necessarily a major disadvantage because the same induction motor can be used as an induction generator to supply power to the utility network, when the turbine is at operating speed. Induction machines are simple, rugged, and inexpensive, requiring essentially no controls other than a contactor to connect the machine to the utility network [28].

The first large Darrieus constructed was a 230-kW machine on Magdalen Island, Quebec, Canada in May, 1977 by Dominion Aluminium Fabricators, Limited of Ontario, Canada. The average power output of this machine was 100 kW in the first year of operation which was reasonably good. Then a noise was observed in the gearbox hence the machine was stopped for inspection. The brakes were removed, under the pretext of being safe, because the turbine would not be able to self start. Unfortunately, on July 6, 1978, the turbine started, without load and means of stopping it, went well over the design speed of 38 r/min. The spoiler did not activate properly, and when the turbine reached 68 r/min a guy wire broke, and the turbine crashed to the ground. This proved that Darrieus could sometimes start under unusual gust conditions and hence that braking systems need to be designed to suit this mechanism.

In 1925, commercial wind-electric plants using two- and three-bladed propellers appeared on the American market. The most common brands were Wincharger (200 to 1200W) and Jacobs (1.5 to 3 kW). These were used on farms to charge storage batteries which were then used to operate radios, lights, and small appliances with voltage ratings of 12, 32, or 110 volts. A good selection of 32 V DC appliances was developed by the industry to meet this demand. In 1927 the Jacob brothers, opened a factory named ‘Jacobs wind’ in Minneapolis to produce wind turbine generators for farm use. This was intended for use in lighting or battery charging for farms that were in remote areas where electricity was not able deliverable from the normal central station. In 30 years the firm produced about 30,000 small wind turbines, which ran successfully for many years in remote locations in Africa and in the Richard Evelyn Byrd expedition to Antarctica. Later
many other manufacturers produced small wind turbines for the same market like Wincharger, Miller Airlite, Universal Aero-electric, Paris Dunn, Airline and Winpower.

During the 1930’s the speed of the windmill was controlled by introducing a coiled governing spring to the top of the vane by varying the surface area of the blades with that of the wind. The turning of the windmill was carried at the floor level manually, using for this purpose a steel wire around the base of the mill and by pulling it as required and using band type friction brake to prevent it from rotating back. The American style windmill was introduced in the year 1930[29]. The windmill was connected to a water pump, consisting of a cylinder and a piston and a delivery valve was installed for raising the water up all the way high to a tank on top of a farm house. The discharge pressure by this pump was noticed to be around 5 kg/cm2. The gravity flow of water from high tank drove a hydraulic wheel and a dynamo which generated small current to light up 20 electrical lights. When this current was in excess, it was used to charge a storage battery for use during “no wind period”. From the 1930s to the late 1950s, many large prototype wind-electric generators, the largest of which was rated at 1,250 kW, were constructed and tested in a number of countries, including Denmark, the United Kingdom, France, Germany, the USSR and the United States of America. Although technically successful, they were not generally adopted because they were not cost competitive with large-scale fossil-fueled generation. Russia developed a modern horizontal axis wind generator called WIME-3D in Balaklava near Yalta, USSR in 1931. This was a 100kW generator mounted on a 100 foot (30mtrs) tower, connected to the local grid. It had a 30mtrs rotor with three blades. It had an annual load factor of 32 percent which is close to the present day wind machines. The type shown in the figure1.19 was used for a long period for water pumping. It is a high speed propeller type rotor and can be used for centrifugal pumps. These rotors are characterized by high starting velocity, speed and low starting torque. The rotors are carved from wood and can be used for
Figure 15. Thai high-speed rotor water pump — wooden mounting assembly

Figure 1. 19 High speed rotor water pump – wooden mounted assembly
centrifugal pumps, chain driven square pallet pumps and with slight modification to the centre shaft it can be used to drive a reciprocating pump. The windmills were used to generate electricity for the use in farms, where there was no electricity supply from the central power generation station. They were used to charge batteries from a few hundred watts to several kilowatts and for cathodic protection of electrifying bridge structures to prevent corrosion. During this period high tensile steel found to be cheap and hence prefabricated of towers were used for installation of windmills.

The famous American wind generators were two bladed horizontal axis machine manufactured by the Wincharger Corporation in 1930 with a peak output of 200 watts. The blade speed was regulated using curved air brakes near the hub and it is still being manufactured [29].

The Dutch windmill “Prinsenmolen” was being modernized in the year 1935 and was considered to be exceptionally suitable for scientific investigation due to its closeness to a large lake in an area free from obstructions. Between 1936 and 1970 the Dunlite Corporation of Australia built many small wind generators to provide power to rural postal service stations and farms. In 1938, the Elektro Company in Switzerland established and manufactured a large range of DC wind electric generators. These highly reliable windmills were used around the world in all extremes of climate to supply power for communication relay stations and navigational aids.

After 1940, the cost of utility generated electricity continued to fall, dipping under 3 cents per kWh. This was accomplished by using larger and more efficient conventional generating plants. In 1934 Palmer Putnam plunged into an effort to develop a giant wind-turbine generator to be synchronized with New England utility companies’ power station. This way, power from the wind could be fed into the local utility grid.

The idea attracted considerable support, including the backing of the S. Morgan Smith Company assisted by some of the best technical designers and engineers of the time. The Smith-Putnam wind turbine was the first partially
successful effort to extract utility-scale alternating current from the wind. Located on a Vermont hilltop called Grandpa’s Knob, it was rated at 1.25 megawatts, and operated intermittently for several years. It was a remarkable test machine and, except for escalating costs, could have paved the way for improved versions. Only recently were its records surpassed by turbines using newer materials and processes [30].

On October 19th 1941 mid-autumn, testing began with engineers turned the windmill over to a chill 24-m.p.h. wind. The giant blades turned faster and faster, the generator cut in, and wind produced electricity flowed from the Grandpa’s knob into the utility grid. Similar though less ambitious events had occurred in other countries, but for the United States, this was a first, and for the world, it was the maximum electricity ever generated by a single wind turbine. Palmer Putnam had long since gone to Washington to help in the war effort. But the Smith- Putnam wind-turbine project continued. The machine generated power until a bearing failed in 1943 and no replacement was available due to wartime priorities. It was to be nearly two years before Grandpa's Knob saw the turbine operate again. When it did, time and long time disuse had took their toll. Tiny cracks had appeared in the blades and in March 1945, shortly after the project started up with a new bearing installed, one blade flew free. That was the end. The Smith Company had invested about $1.25 million of the company funds into the project. While wind turbines were proved technically feasible, the costs were too much. It would be more than thirty years later, in a time of oil embargoes, skyrocketing inflation, and energy shortage, before a larger turbine would feel the wind in its blades and generate more electricity than the Smith-Putnam machine on Grandpa's Knob.

The Smith-Putnam machine had a tower which was 34 m high and a rotor 53 m in diameter. The rotor had a chord (the distance from the leading to the trailing edge) of 3.45 m. Each of the two blades was made with stainless steel ribs covered by a stainless steel skin and weighed 7300 kg. The blade pitch (the angle at which the blade passes through the air) was adjustable to maintain a constant rotor speed of 28.7 r/min. This rotational speed was maintained in wind speeds as high as 32 m/s.
At higher wind speeds, the blades were struck in a wide open position and thus the machine stopped. The rotor turned an ac synchronous generator that produced 1250 kW of electrical power at wind speeds above 13 m/s.

In 1941-1943, the Smith company in Denmark manufactured twelve 60 kW and six 70 kW DC wind electric generators which supplied a local electricity grid for about 10 years. During the Second World War, German boats used small wind generators to re-charge submarine batteries. In 1946 the lighthouse and residences on the island Insel Neuwerk were partly powered by 15mtrs diameter wind turbine delivering 18 kW power. Percy H. Thomas, an Engineer, estimated the capital costs for his machine at US$75 per installed kW. This was low enough to be of interest so the Federal Power Commission approached Congress for funding a prototype of this machine. It was in 1951 when the Korean War was starting, that the Congress chose not to fund the prototype. The project was later cancelled. This basically marked the end of American wind power research for over twenty years until fuel supplies became a problem again. Other countries continued wind research for a longer period of time. Denmark built their Gedser wind turbine in 1957. This machine produced 200 kW in a 15 m/s wind. It was connected to the Danish public power system and produced approximately 400,000 kWh per year. The tower was 26 m high and the rotor was 24 m in diameter. The generator was located in housing on the top of the tower. The installation cost of this system was approximately $250/kW. This wind turbine ran until 1968 when it was stopped.

Johannes Juul from “Electricity Producers of Sealand, Inc.” had developed another Bogo-mill in 1953 and Gedser-mill started running in 1957. Both windmills used three blades, a moderate revolving speed with stall regulation, directly coupled with an asynchronous generator and an active yawing system - a concept which was based on common sense and practical experiences, and which later became to make up the backbone of the Danish windmill industry. France operated an experimental 800 KVA wind turbine at Nogent-Le-Roi between 1955 and 1966. Germany too built a 100 kW machine by Dr. Ulrich Hutter in 1957. It reached its rated power output at a wind speed of 8 m/s, which is substantially lower than the machines mentioned
earlier. This machine used lightweight, 35 m diameter fiberglass blades with a simple hollow pipe tower supported by guy wires. The blade pitch would change at higher wind speeds to keep the propeller angular velocity constant. Dr. Hutter obtained over 4000 hours of full rated power operation over the next 11 years, a substantial amount for an experimental machine, which contributed to the design of larger wind turbines for the future.

The world’s first alternating current wind turbines appeared in the 1957, pioneered by Poul La Cour’s former student Johannes Juul. This was a 24 m diameter wind turbine at Gedser and ran for 10 years till 1967 with a three bladed, horizontal axis turbine similar to those now running for commercial wind power development. In the early 1960s, the NEYRPIC organization of France, constructed a 1,000 kW and 3,000 V asynchronous AC wind electric generator which supplied a maximum output of 220,000 kWh. They were heavy duty machines, many of which exist today.

Hydro-Québec Research and Natural Resources Canada installed experimental vertical axis wind turbines in the year 1970. However, it does not exist anymore as the horizontal axis wind turbines are more efficient in power production. In response to the increase in oil price after the 1973 oil crisis, NASA set up a research council to look into utility scale wind turbines. The Danish Academy of Technical Science re-examined the possibilities of large-scale wind-electric generation in 1974 and concluded that wind energy could supply 10 per cent of the country’s electricity requirement. Large Darrieus rotors supported on icosahedron frames were proposed as an appropriate design.

The Federal Wind Energy Program had its beginning in 1972 when a joint Solar Energy Panel of the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) recommended that wind energy be developed to broaden the Nation’s energy options for new energy sources. In 1973, NSF was given the responsibility for the Federal Solar Energy Program, of which wind energy was a part. The Lewis Research Center, a Federal Laboratory controlled
by NASA, was selected to manage the technology development and initial deployment of large wind turbines. Early in 1974, NASA was funded by NSF to design, build, and operate a wind turbine for research purposes, designated the MOD-0, initiate studies of wind turbines for utility application, and to undertake a program of supporting research and technology development for wind turbines. In 1975, the responsibility within the Federal government for wind turbine development was assigned to the newly created Energy Research and Development Administration (ERDA). ERDA was then absorbed by the Department of Energy (DOE) in 1977. The NASA Lewis Research Center continued to direct the technology development of large turbines during this period.

The MOD-0 figure 1.20 were designed with the rotor turning at a constant speed of 40 rpm except when starting up or shutting down. A gear box assists the rotational speed to increase to 1800 r/min driving a synchronous generator, connected to a utility network. The starting is accomplished by activating a control to align the wind turbine with the wind. The blade pitch was controlled by hydraulic at a programmed rate and the rotor speed is brought to about 40 rpm. At this time an automatic synchronizer is activated to synchronize with the utility network. If the wind speed drops below the set value of 40 rpm, the generator is disconnected from the utility grid, the blades are feathered (pitched so no power output is possible) and the rotor is allowed to a stop. All these steps of starting up, synchronization, power control, and shutting down are controlled by a microprocessor automatically. This design was further improved with many additions to increase the efficiency of the windmill.

The research council of NASA built a first prototype wind turbine with a capacity of 100kW in Sandusky Ohio funded by the National Science Foundation and Energy Research Development Administration. This was a light weight 2-bladed wind turbine and delivering the same output as the three blades thus decreasing the capital cost and the weight of a wind turbine. The speed was enhanced with a higher
Fig 1.20 MOD-O Model wind generator general view and super structure
gear ratio to reduce the damaging stress of the blades. NASA which invited many to partner with the development and research activities finally operated the Danish 3-bladed wind turbine at Gedser during 1977 and 1979 as a model to build larger wind turbines. The concept of using the same 3 blade wind turbine set up in 1957 was redesigned by Johannes Juul and was successfully running for 11 years from 1957 to 1969 generating 200 kW [30]. The data was used in carrying out further research in the aerodynamic, electrical and mechanical characteristics of the 3-bladed wind turbine.

A large change took place in 1978, when a large multi megawatt wind turbine was constructed and it was the first of its kind. The shaft, gearbox and generator were bought second hand and the frequency converter control box was put together by Professor Ulrich Krabbe of Denmark’s Technical University and his students. It was used for converting the varying frequency of the generator, so that the mill could deliver power to the power grid. Computer control and supervision systems were developed with long assembly language programs were written for the Z80-computer. Large cranes were used for erecting this windmill. The complete construction was carried out as per the recommendation of the academy for Technical Sciences using this as a practical and research project in wind energy.

1.2 DEVELOPMENT IN WIND ENERGY GENERATION

In 1980s most of the wind turbines were relatively small units in the range of 25kW rating. NASA carried out research on scaling large wind turbines for economic production of electricity by the manufacturers to create low cost electricity. The development of American windmill using steel blades with lighter material and efficient design shapes to optimize output power proved well above expectations. The speed was higher than expected which required slow down gear boxes to meet the required output.

The Danish commercial wind power development improved in capacity and efficiency based on the serial number of turbines production primarily based on theoretical and practical approach. The extensive wind turbine manufacturing for
commercial use advanced the technology for producing high power wind turbine
with higher efficiency. In mid 1980’s the United States government took initiative to
work along with the industry to develop large turbines commercially. NASA
developed wind turbine industry in the USA with investments from National Science
Foundation and later by Department of Energy. This research helped to develop the
technologies of many present big turbines. The material, structure and various
design aspects were given importance during the research activities for furthering the
development of shore based wind energy [34]. This has led to the world records of
large diameter rotors and power output. In 1988, a close look at Egypt’s coastal
zones of Suez Canal and Red Sea indicated existence of high wind energy potential.
This tapped by erecting a wind farm with a capacity of 400 kW in Ras Ghareb.

In the year 1981, three large turbines with a combined output of 7.5 MW
were developed. The largest single wind turbine built in the world, MOD-5B, with
rotor diameter 100mtrs and was rated at 3.2MW. This turbine had a two bladed rotor
and a successful variable speed drive train. The turbine output of 4 MW was
recorded as the highest for over many years. This was available and sold commercially. Most of the wind turbine manufacturers left the business, when fossil
constructed the 65kW Kuujjuaq Wind Turbine, as a demonstration project, it was
found successful.

In 1984, Darrieus (vertical axis) type wind turbine was constructed as the
world's largest turbine on the Gaspé Peninsula, on Project Éole. The $35-million,
110-metre high turbine is a joint venture between Hydro-Quebec and the National
Research Council of Canada. In the year 1987, the Boeing Engineering and
Construction Company which commercially sold large turbines, stopped
manufacturing and left the market. Wind energy was found to be uneconomical
compared with that of the energy generated from fossil fuel. In the year 1980 the
state of California has provided tax relief for wind power and this gesture gathered
momentum for setting up large wind farms such as Altamont Pass.
In the 1990’s durability and aesthetics were considered as important issues and the turbines were placed atop steel tubular or reinforced concrete towers. Small generators were connected to the top and the tower raised into position. Large generators were hoisted into position atop the tower to a ladder placed inside the tower to help and assist technicians to maintain the generators and also protect from the weather. The Cowley Ridge wind plant, Canada’s first commercial wind farm, was constructed in southern Alberta in 1994. Since then, all of Canada’s provinces have adopted wind energy.

In 1990, Egypt with rich oil fields decided to have a relook at its old invention of windmills for development and installation. This happened due to a large demand and consumption of fossil fuel around the world including the homeland. Particularly during the last two decades, wind energy technologies for electricity generation developed tremendously and reached a remarkable state of technical maturity. Wind power was used in large scale wind farms for national electrical grids as well as in small individual units for providing electricity to rural residences or grid-isolated locations. The capacity development in wind turbine from 300 kW /500 kW in 1980s and was replaced with a new capacity of 600kW/750kW in 1990 [37]. In1986 New and Renewable Energy Authority (NREA) were formed in Egypt to look into large commercial scale wind turbine manufacturing and installation. In 1994, the Cowley Ridge wind plant, near Pincher Creek, Alberta was completed thus becoming the first commercial wind farm in Canada.

During the period 1992-1995 a pilot wind farm with total power 5.2 MW was erected in a place called Hurgada in Egypt. This farm was connected to the local city grid in 1993 and to the national electricity grid in 1998. The International Energy Agency (IEA) estimated the world’s total demand for electricity to be 12,500 TWh in 1993 projected a higher figure of 20,907 TWh by the year 2010. It is felt that this demand can be easily met as the available resource of wind energy around the world is abundant. The potential of tapping and harnessing clean energy at locations offshore and in land with less populated rural areas is still available. Developing countries like India and China have increased the generation of clean energy to
compete with the industrialized countries. Even, countries like Egypt and Cape Verde have shown interest in developing wind energy, which could increase the world wind energy generation. The volume of wind energy demand in the world by 2020 would be more than double the installed generation of 6.1 GW in 1996. It is felt that the climate change phenomena will compel wind energy generation to increase to meet the proposed generation of 375 GW by 2020 with a calculated growth rate of 25 percent a year.

1.3 CONCLUSION

From the fore going, the following observations can be made about the development of windmills over the centuries.

- The windmill is perhaps one of the few man-made devices that have evolved over the centuries to serve man kind in various ways.

- The evolution process has been in spurts spread over several eras.

- After experimenting with both the horizontal axis as well as vertical axis machines for ages, mankind seems to have settled for the horizontal axis machines because of the advantages it offers over the vertical axis machines. However even today, in the 21st century efforts are still on to see if the vertical axis machines could be suitably developed for use as generators.

- The modern day horizontal axis windmill is a highly optimized version of the very first windmill in history, with all the high-tech safety features to enhance its operational life.
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