On some of the design aspects of wind energy conversion systems

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Abstract

In the overall process of utilizing wind power, two essential components of technical data, i.e. one related to the engineering or performance characteristics of commercially available wind turbine generators, and the other related to the availability of wind resources, are needed. The performance of wind energy conversion systems (WECs) depends upon subsystems like wind turbine (aerodynamic), gears (mechanical), and generator (electrical). The availability of wind resources is governed by the climatic conditions of the region, for which the wind survey is extremely important to exploit wind energy. In this paper, design aspects, such as factors affecting wind power, siting requirements for WECs, problems related with grid connections, classification of wind electric generation schemes, criteria for selection of equipment for WECs, choice of generators, three basic design philosophies, main considerations in wind turbine design, choice between two and three blade rotors, weight and size considerations and environmental aspects related with WECs have been presented.

\textbf{Keywords:} Constant speed constant frequency; Variable speed constant frequency; Variable speed variable frequency; Wind energy conversion systems; Self-excited induction generator
1. Introduction

Wind powered systems have been widely used since the tenth century for water pumping, grinding grain and other low power applications. There were several early attempts to build large scale wind powered systems to generate electricity. In 1931, the Russians built a large windmill with a 100 ft (30.5 m) diameter blade, but it had a very low conversion efficiency and was abandoned. In 1945, a Vermont utility built a large wind powered generator to produce electricity. This system costed $1.25 million and had an electrical power output of 1.25 MW. This unit lasted for 23 days before one of the blades failed due to fatigue, and the project was abandoned.

The National Aeronautics and Space Administration (NASA), in conjunction with the Energy Research and Development Administration (ERDA), has built and tested a large number of large wind powered generators. The first machine was a 100 kW unit built at Sandusky, Ohio, for around a million dollars. A number of other machines with power up to 2.5 MW and rotor diameter up to 350 ft (107 m) have been constructed. During the 1980s, it became popular to invest money in wind systems because of the tax benefits. Consequently, a number of wind farms were built, particularly in the mountain passes of California. In 1985, about half of the world’s wind generated electricity was produced in the Altamont Pass area of California. This area has 6700 turbines with a total rated capacity of 630 MW [1]. Among the renewable sources of energy available today for generation of electrical power, wind energy stands foremost because of the relatively low capital cost involved and the short gestation period required. The world has obtained the installed wind capacity of 13400 MW by the end of 1999 [2].

The design and successful operation of large scale wind powered generators face a number of formidable problems. If the system is designed to produce a.c. power, a constant angular velocity and force is desirable. Unfortunately, the wind velocity is neither constant in magnitude or direction nor is it constant from the top to bottom of a large rotor. This imposes severe cyclic loads on the turbine blades, creating fatigue problems. This problem is compounded if a downwind rotor system is used because the shadow of the support tower unloads the blade. This effect also produces a noticeable popping noise, which can be objectionable.

The available wind resource is governed by the climatology of the region concerned and has a large variability from one location to the other and also from season to season at any fixed location. A wind survey is extremely important to exploit wind energy. A lot of development has taken place in the design of wind energy conversion systems. Modern wind turbines are highly sophisticated machines built, on the aerodynamic principles developed from the aerospace industry, incorporating advanced materials and electronics and are designed to deliver energy across a wide range of speeds. In this paper, WECs related aspects, such as factors affecting wind power, siting requirements for WECs, problems related with grid connections, classification of wind electric generation schemes, criteria for selection of equipment for WECs, choice of generators, three basic design philosophies, main considerations in wind turbine design, choice between two and three blade rotors, weight and size considerations and environmental aspects related with WECs have been presented.
2. Factors affecting wind power

One of the most important tools in working with the wind, whether designing a wind turbine or using one, is the firm understanding of the factors affecting the wind power. Following are the important factors that must be considered:

2.1. Power in the wind

The total power that is available to a wind turbine is equal to the product of the mass flow rate of the wind \( m_w \) and \( V^2 \). Assuming constant area or ducted flow, the continuity equation states that \( m_w = qAV \), where \( q \) is the density of the air in kg/m\(^3\), \( A \) is the exposed area in m\(^2\), and \( V \) is the velocity in m/s. Thus, the total wind power becomes

\[
\text{Total wind power } P_w = \frac{(m_w V^2)}{2} = qAV \frac{1}{2} = \frac{1}{2} WP
\]

The density is a function of pressure, temperature and relative humidity. It is seen from Eq. (1) that the wind power varies as the cube of the wind velocity. Unfortunately, the total wind energy cannot be recovered in a wind turbine because the output wind velocity cannot be reduced to zero, otherwise there would be no flow through the turbine [1]. If the inlet wind velocity is \( V_i \) and the output velocity is \( V_o \), the mass flow rate through the system is approximately \( qAV_{ave} \), where the average velocity is \( \frac{V_i + V_o}{2} \), and the power recovered from the wind is equal to the rate of change in the kinetic energy, or

\[
\dot{P}_{out} = m_w (V_i^2 - V_o^2)/2 = \frac{(pA/4)(V_i + V_o)(V_i^2 - V_o^2)}{2} = \frac{(P_w/2)(1 + x - x^2 - x^3)}{2}
\]

where \( x = V_o/V_i \). Differentiating Eq. (2) with respect to \( x \) and setting it to zero gives the optimum value of \( x \) for maximum power output:

\[
\frac{dP_{out}}{dx} = 0 = (1 - 2x - 3x^2)
\]

and solving the quadratic equation

\[
x_{max} = 1 = 3
\]

Substituting the value of \( x_{max} \) in Eq. (2), the maximum power recovered is

\[
\dot{P}_{out max} = 16 = 27P_w = 0.593P_w
\]

Thus, the maximum power that can be realized from a wind system is 59.3 percent of the total wind power. The power in the wind is converted to mechanical power with an efficiency (coefficient of performance) \( c_p \), which is transmitted to the generator through a mechanical transmission with efficiency \( g_m \) and which is converted to electricity with an efficiency \( g_g \) [3]. The electrical power output is then

\[
P_e = c_p g_m g_g P_w \ W
\]

Optimistic values for these coefficients are \( c_p = 0.45 \), \( g_m = 0.95 \) and \( g_g = 0.9 \), which give an overall efficiency of 38%. Actual values will probably lie between 25% and 30%. This will vary with wind speed, with the type of turbine and with the nature of load. For a given system, \( P_w \)
and $P_e$ will vary with wind speed. As the wind increases from a low value, the turbine is able to overcome all mechanical and electrical losses and start delivering electrical power to the load at cut-in speed $V_C$. The rated power output of the generator is reached at rated wind speed $V_R$. Above $V_R$, some wind power is spilled to maintain constant power output. At the furling speed $V_F$, the machine is shut down to protect it from high winds.

2.2. **Wind statistics**

Wind is a highly variable power source, and there are several methods of characterizing this variability. The most common method is the power duration curve [4]. This is a good concept but is not easily used to select $V_C$ and $V_R$ for a given wind site, which is an important design requirement. Another method is to use a statistical representation, particularly a Weibull function [3].

2.3. **Load factor**

There are at least two major objectives in wind turbine design. One is to maximize the average power output. The other is to meet the necessary load factor (which is the ratio of average electrical power to the rated electrical power) requirement of the load. Load factor is not of major concern if the wind electric generator (WEG) is acting as a fuel saver on the electric network. But if the generator is pumping irrigation water in asynchronous mode, for example, the load factor is very important [5].

2.4. **Seasonal and diurnal variation of wind power**

Seasonal and diurnal variations have significant effects on wind [6]. Load duration data are required to judge the appropriate effects. Diurnal variation is less with increased height. Average power may vary from about 80% of the long term annual average power in the early morning hours to about 120% of the long term average power in the early afternoon hours.

2.5. **Effect of height**

Wind speed increases with height because of friction at the earth surface [7]. The rate of increase of wind speed is given by

$$V = V_O = \delta Z = Z \beta^{1/7}$$

where $V$ is the predicted wind speed at height $Z$ and $V_O$ is the wind speed at height $Z_O$. This translates into a substantial increase in power at greater heights.

2.6. **Variation with time**

For most applications of wind power, it is more important to know about the continuity of supply than the total amount of energy available in a year. In practice, when the wind blows strongly, e.g. more than 12 m/s, there is no shortage of power, and often, the generated power has to be dumped [7]. Difficulties appear, however, if there are extended periods of light or zero winds.
A rule of thumb for electricity generation is that sites with average wind speed less than 5 m/s will have unacceptably long periods without generation, and the sites of average 8 m/s or above will be considered very good. In all the cases it will be necessary to match carefully the machine characteristic to the local wind regime to give the type of supply required.

3. Siting requirements for WECs

In addition to adequate availability of wind resources (a minimum of 18 km/h or 5 m/s wind speed) the following factors have to be considered while locating a WEG:

- availability of land,
- availability of power grid (for a grid connected system),
- accessibility of site,
- terrain and soil,
- frequency of lightning strokes.

Once the wind resource at a particular site has been established, the next factor to be considered is the availability of land [8,9]. The area of land required depends upon the size of wind farm. The optimum spacing in a row is 8-12 times the rotor diameter in the wind directions and 1.5-3 times the rotor diameter in cross wind directions [10]. As a rule of thumb, 10 ha/MW can be taken as the land requirement of wind farms, including infrastructure. In order to optimize the power output from a given site, additional information is needed, such as wind rose, wind speeds, vegetation, topography, ground roughness etc., besides the configuration of a set of wind turbines, which can be altered for reaching best array efficiencies and highest generation. Factors such as convenient access to the wind farm site, load bearing capacity of the soil, frequency of cyclones, earthquakes etc., also require consideration before siting the wind farm.

4. Problems related with grid connections

For grid connected systems, there must be a reliable power grid/transmission network near the site so that the wind generated power can be fed into the grid. Normally, the wind turbine generates power at 400 V, which is stepped up to 11-110 kV, depending upon the power capacity of the wind system. If the wind power capacity is up to 6 MW, the voltage level is stepped up to 11/22 kV; for capacity of 6-10 MW, the voltage level is increased up to 33 kV; and for capacity higher than 10 MW, it is preferred to locate a 66 or 110 kV substation at the wind farm site [9]. Non-availability of a reliable grid may have the following problems:

4.1. Poor grid stability

For economic exploitation of wind energy, a reliable grid is as important as the availability of strong winds. The loss of generation for want of a stable grid can be 10-20%, and this deficiency
may perhaps be the main reason for low actual energy output of WEGs compared to the predicted output in known windy areas with adequate wind data [11].

4.2. Low frequency operation

Low frequency operation affects the output of WEGs in two ways. Many WEGs do not get cut-in, when the frequency is less than 48 Hz (for a standard frequency of 50 Hz), although wind conditions are favorable, with consequent loss in output. This deficiency apart, the output of WEGs at low frequency operation is considerably reduced, due to the reduced speed of the rotor. The loss in output could be about 5-10% on account of low frequency operation.

4.3. Impact of low power factor

WEGs fitted with induction generators need reactive power for magnetization. Normally in conventional energy systems, generators apart from supplying active power will be supplying a reactive power, but in the case of WEGs fitted with induction generators, instead of supplying reactive power to the grid, they absorb reactive power from grid, which undoubtedly is a strain on the grid. Suitable reactive power compensation [12] may be required to reduce the reactive power burden on the grid.

5. Classification of wind electric generation schemes

Wind electric conversion systems can be broadly classified as:

5.1. According to the size of useful electrical power output [13]:

(i) Small size (up to 2 kW): These may be used for remote applications, or at places requiring relatively low power.
(ii) Medium size (2-100 kW): These turbines may be used to supply less than 100 kW rated capacity to several residences or local use.
(iii) Large size (100 kW and up): They are used to generate power for distribution in central power grids.

5.2. According to the rotational speed of the aeroturbines [14,15]:

1. constant speed constant frequency (CSCF),
2. variable speed constant frequency (VSCF),
3. variable speed variable frequency (VSVF).

5.2.1. Constant speed constant frequency

In the CSCF scheme, the rotor is held constant by continuously adjusting the blade pitch and/or generator characteristics. For synchronous generators, the requirement of constant speed is very rigid and only minor fluctuations of about 1% for short durations could be allowed [4]. As the wind
fluctuates, a control mechanism becomes necessary to vary the pitch of the rotor so that the power derived from the wind system is held fairly constant. Such a control is necessary since wind power varies with the cube of the wind velocity. During gusty periods, the machine is subjected to rapid changes in the input power. The control mechanism must be sensitive enough to damp out these transients so that the machine output does not become unstable. Such a mechanism is expensive and adds complexity to the system. Induction generators with small negative slip can also be considered as constant speed. An induction generator can operate on an infinite bus bar at a slip of 1-5% above the synchronous speed. Induction generators are simpler than synchronous generators. They are easier to operate, control and maintain, have no synchronization problem and are economical. The CSCF schemes that mostly employ synchronous generators [4] tend to be more expensive because of the precise blade pitch control mechanisms required on the wind turbine to maintain constant speed, as the synchronous generators run at constant speed, and hence, require costly speed controls. However, synchronous generators can supply reactive power to the system. If the electric power derived from wind is significant compared with the capacity of the grid system, synchronous machines stability becomes a serious problem.

5.2.2. Variable speed constant frequency

The variable speed operation of a wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines (VAWT) exhibit this gain under variable speed operation. The VSVF scheme mostly employs an induction generator. In this scheme, the need for a costly blade control mechanism is avoided. An induction generator requires reactive power, but induction generators are low in initial cost, leading to an overall reduction of 5-10% in total system capital cost, and are maintenance free and most reliable. Generation schemes involving variable speed rotors are more complicated than constant speed systems. Variable frequency power must be converted to constant frequency power, and this can be done by using thyristors [14-17].

5.2.3. Variable speed variable frequency

Generally, resistive heating loads are less frequency sensitive. Synchronous generators can be affected at variable speed, corresponding to the changing drive speed [18-21]. For this purpose, self-excited induction generators (SEIG) can be conveniently used. This scheme is gaining importance for stand alone wind power applications.

5.3. According to the orientation of turbines:

There are two classes of wind turbines, horizontal axis and vertical axis machines [6,7]:

5.3.1. Horizontal axis

In horizontal axis wind turbines (HAWT), the axis of rotation is parallel to the direction of the wind. There may be many designs of horizontal axis wind mills. Depending upon the number of blades, these may be classified as single bladed, double bladed, three bladed, multi bladed and bicycle bladed [1,6]. Depending upon the orientation of the blades with respect to wind direction these may be classified as up wind and down wind type. As the wind changes direction, all horizontal axis wind machines have some means for keeping the rotor into the wind, e.g. powered
yaw system. On smaller wind machines, such as the farm windmill, the tail vane keeps the rotor pointed into the wind, regardless of changes in wind direction. Both tail vanes and fan tails use forces in the wind itself to orient the rotor upwind of the tower.

5.3.2. Vertical axis

In VAWT, the axis of rotation is perpendicular to the direction of the wind. These machines are also called cross wind axis machines. The main designs of vertical axis machines are the Savonious rotor and Darrieus rotor. The principal advantages of VAWT over conventional HAWT are that VAWT are omni-directional, i.e. they accept the wind from any direction. This simplifies their design and eliminates the problem imposed by gyroscopic forces on the rotor of conventional machines as the turbines yaw into the wind. The vertical axis rotation also permits mounting the generator and gear at the ground level [13]. On the negative side, the VAWT requires guy wires attached to the top for support, which may limit its application, particularly for offshore sites.

6. Selection of equipment

It has been observed that the main criterion for selection of the size of a WEG has been the availability of commercially available equipment of proven design and performance. The technology for grid connected wind turbines has been growing fast. Though it started in the range of 55-100 kW, the commercial and technical viability of higher ratings in the range of 225-1000 kW has now been established and in fact standardized. The wind turbines that are most popular are either pitch or stall regulated and have two to three fiber glass reinforced polyester blades. In order to ensure the quality of WEGs, it is suggested to have test standards based on those already existing in Denmark (RISO), Netherlands (ECN) etc., suitably modified to conform with the environmental condition of that country where the WEGs are to be installed.

7. Choice of generators

There are mainly the following three classes of generators [11]:

7.1. DC generators

DC generators are relatively unusual in wind/micro-hydro turbine applications because they are expensive and require regular maintenance [22]. Nowadays, for most d.c. applications, for example, it is more common to employ an a.c. generator to generate a.c., which is then converted to d.c. with simple solid state rectifiers.

7.2. Synchronous generator

The major advantage of synchronous generator is that its reactive power characteristic can be controlled, and therefore such machines can be used to supply reactive power to other items of
power systems that require reactive power. It is normal for a stand alone wind-Diesel system to have a synchronous generator, usually connected to the Diesel engine. Synchronous generators, when fitted to a wind turbine, must be controlled carefully to prevent the rotor speed accelerating through synchronous speed especially during turbulent winds. Moreover, it requires a flexible coupling in the drive train, or to mount the gearbox assembly on springs or dampers to absorb turbulence [22]. Synchronous generators are costlier than induction generators, particularly in smaller size ranges. Synchronous generators are more prone to failures.

7.3. Induction generators

An induction generator offers many advantages over a conventional synchronous generator as a source of isolated power supply. Reduced unit cost, ruggedness, brushless (in squirrel cage construction), reduced size, absence of separate DC source and ease of maintenance, self-protection against severe overloads and short circuits are the main advantages [18-21]. Further, induction generators are loosely coupled devices, i.e. they are heavily damped and, therefore, have the ability to absorb slight changes in rotor speed, and drive train transients to some extent, can, therefore, be absorbed, whereas synchronous generators are closely coupled devices and when used in wind turbines, are subjected to turbulence and require additional damping devices, such as flexible couplings in the drive train or mounting the gearbox assembly on springs and dampers. Reactive power consumption and poor voltage regulation under varying speed are the major drawbacks of the induction generators, but the development of static power converters has facilitated control of the output of voltage of the induction generator, within limits.

8. Three basic design philosophies

Designs for wind turbines have been driven by three basic design philosophies for handling wind loads, i.e. (i) withstanding the loads, (ii) shedding or avoiding of loads and (iii) managing loads mechanically and/or electrically [23]. The classic Danish configuration, based on the first design philosophy, was originally developed by Paul La Com in 1890. Important characteristics of such designs are optimization for reliability, high solidity but non-optimum blade pitch, low tip speed ratio (TSR) and three or more blades. Turbines based on the second design philosophy (Hutter design) have design criteria like optimization for performance, low solidity, optimum blade pitch, high TSR, etc. Designs based on the third philosophy (Smith Putnam), designed to manage the load mechanically and/or electrically, have design considerations like optimization for control, two or three blades, moderate TSR, mechanical and electrical innovations (flapping or hinged blades, variable speed/low speed generators). The second and third designs, based on shedding or avoiding of loads and managing loads mechanically and/or electrically, have been relatively later developments and are now becoming predominant. The third design utilizes direct mechanical or electrical intervention to mitigate turbine loads. This design is associated with utility projects or projects developed specifically to satisfy high utility power quality requirements.
Table 1

Increasing size of commercial wind turbines since 1980

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Year</th>
<th>Capacity (kW)</th>
<th>Rotor diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1980-1982</td>
<td>55</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>1983-1985</td>
<td>75</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>1986-1988</td>
<td>120</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>1989-1991</td>
<td>250</td>
<td>27</td>
</tr>
<tr>
<td>5</td>
<td>1992-1994</td>
<td>500</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>1995-1997</td>
<td>750</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>1998-2000</td>
<td>2000</td>
<td>66</td>
</tr>
</tbody>
</table>

9. Main considerations in wind turbine design

A wind turbine is composed of a number of subsystems: rotor, power train, control and safety system, nacelle structure, tower, foundations etc. Modern wind turbine manufacturers must weigh many factors before selecting a final configuration for development. The intended wind environment is the most important consideration. Turbines designed for high wind or for use at highly fluctuating wind sites will generally have rotors of smaller diameter and more robust than turbines for lower wind sites. The design criteria specified by the International Electrotechnical Commission (IEC) base the design loads on the mean wind speed and the turbulence level. Minimizing cost is the next most important design criterion. In fact, cost is probably the key force that drives the designers towards increased innovation and diversity. Electricity generated by wind is still more expensive than power from conventional power plants, unless the environmental benefits of wind power are taken into account. If the cost of wind energy could be cut by an additional 30-50%, then it would be globally competitive. The goal to achieve this 30-50% reduction has inspired designers to look for cost reduction by increasing size, tailoring turbines for specific sites, exploring new structural dynamic concepts, developing custom generators and power electronics, as well as implementing modern control system strategies [24]. Table 1 shows the increase in the size and corresponding diameters of commercially available wind turbines since 1980.

10. Choice between two and three blade rotors

Blades are one of the most critical components of a wind turbine rotor. Initially, blades were made from wood. Wooden blades were replaced by galvanized steel blades. Later, steel blades were also replaced by aluminium, which is lighter and stronger. In recent years, fiber glass as rotor blades is becoming very popular [6]. Light weight, highly flexible turbines are usually two bladed and have a teeter hinge, coming hinges or flex beams to allow blade motion to relieve the flap load, whereas structurally stiff and robust turbines are usually the three blade, upwind yaw driven type. The structural dynamic difference between two and three blades is the rotor moment of inertia. The three bladed rotor mass movement has polar symmetry, whereas the two bladed rotor mass movements do not have the same, so the structural dynamic equations for the two bladed turbine system are significantly more complex and have periodic coefficients [23]. The three bladed system governing equations have constant coefficients making them easier to solve and most importantly making the cause-and-effect relationship easier to understand. Often visual aesthetics, lower noise
and polar symmetry are reasons for using three blade designs. However, the greater weight and higher cost of the three blades provide a compelling reason for designers to explore the possibilities of two blade rotors more thoroughly.

11. Weight and size considerations

Towers are as integral to the performance of the wind system as the wind turbine itself. The tower must be strong enough to withstand the thrust on the wind turbine and the thrust on the tower. The tower must also support the weight of the wind turbine. Tall towers are preferred as they minimize the turbulence induced. Tall towers allow more flexibility in siting. The most important factor is the ability of a tower to withstand the forces acting on it in high winds. Towers are rated by the thrust load they can endure without buckling. The thrust on the tower at high speeds depends on the rotor diameter of the wind turbine and its mode of operation under such conditions.

As the turbine weight increases, the initial cost also increases. However initial turbine cost alone does not determine the cost per kilowatt hour of electrical output. The cost of operation and maintenance (O&M) and the cost of major overhauls and repairs must be included. To be cost effective, a turbine must have high availability and low O&M costs [23]. This leads to different design perspectives. Designers of heavier weight and robust turbines argue that such designs have high availability and low maintenance and reducing weight excessively will increase O&M costs. Lightweight turbines, while reducing initial cost and weight must have low O&M costs. This technical challenge requires a thorough understanding of the dynamic behavior of the lightweight turbines and how to control the structure responses. The variation in tower top weight is 20-30 kg/m$^2$ for an increase in rotor diameter from 30 to 60 m [13]. The weight of the tower increases with the number of blades. Pitch controlled turbines are somewhat lighter than stall regulated turbines with increase in the size, the cost increases, but with the increase in tower height, the energy capture is more, which negates such high cost.

12. Environmental aspects

12.1. Audible noise

The wind turbine is generally quiet. It poses no objectionable noise disturbance in the surrounding area. The wind turbine manufacturers generally supply the noise level data in dB versus the distance from the tower. A typical 600 kW wind turbine may produce 55 dB noise at 50 m distance from the turbine and 40 dB at a 250 m distance [10]. This noise is, however, a steady state noise. The wind turbine makes loud noise while yawing under changing wind direction. Local noise ordinances must be satisfied before installing wind turbines.

12.2. Electromagnetic interference

Any stationary or moving structure in the proximity of a radio or TV station interferes with the signals. The wind turbine towers can cause objectionable electromagnetic interference (EMI) on the performance of the nearby transmitters or receivers [10].
In other aspects, the visual impact of the wind farm can be of concern to some one. The breeding and feeding patterns of birds may be disturbed [6]. They may even be injured and even killed if they collide with the blades.

13. Conclusions

The design of wind energy conversion systems is a very complex task and requires interdisciplinary skills, e.g. civil, mechanical, electrical and electronics, geography, aerospace, environmental etc. An attempt has been made to discuss the important design aspects of WECs. In this paper, design aspects, such as factors affecting wind power, siting requirements for WECs, problems related with grid connections, classification of wind electric generation schemes, criteria for selection of equipment for WECs, choice of generators, three basic design philosophies, main considerations in wind turbine design, choice between two and three blade rotors, weight and size considerations and environmentally related aspects with WECs, have been critically discussed.

References