International Journal of Emerging Electric Power Systems

Volume 3, *Issue* 2 | 2005 | *Article* 1070

Some Issues Related to Power Generation Using Wind Energy Conversion Systems: An Overview

Dr. R. C. Bansal, *Birla Institute of Technology & Science, Pilani*
Dr. Ahmed F. Zobaa, *Cairo University, Egypt*
Dr. R. K. Saket, *Department of Electrical Engg., Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal (India)*

Recommended Citation:
Bansal, Dr. R. C.; Zobaa, Dr. Ahmed F.; and Saket, Dr. R. K. (2005) "Some Issues Related to Power Generation Using Wind Energy Conversion Systems: An Overview ," *International Journal of Emerging Electric Power Systems*: Vol. 3: Iss. 2, Article 1070.
DOI: 10.2202/1553-779X.1070

Some Issues Related to Power Generation Using Wind Energy Conversion Systems: An Overview

Dr. R. C. Bansal, Dr. Ahmed F. Zobaa, and Dr. R. K. Saket

Abstract

Design and successful operation of wind energy conversion systems (WECs) is a very complex task and requires the skills of many interdisciplinary skills, e.g., civil, mechanical, electrical and electronics, geography, aerospace, environmental etc. Performance of WECs depends upon subsystems like wind turbine (aerodynamic), gears (mechanical), generator (electrical); whereas the availability of wind resources are governed by the climatic conditions of the region concerned for which wind survey is extremely important to exploit wind energy. This paper presents a number of issues related to the power generation from WECs e.g. factors affecting wind power, their classification, choice of generators, main design considerations in wind turbine design, problems related with grid connections, wind-diesel autonomous hybrid power systems, reactive power control of wind system, environmental aspects of power generation, economics of wind power generation, and latest trend of wind power generation from off shore sites.

KEYWORDS: Doubly Fed Induction Generator, off shore wind power system, Wind Energy Conversion Systems (WECs), Self-Excited Induction Generator (SEIG)

1 Introduction

Among the renewable sources of energy available today for generation of electrical power, wind energy stands foremost because of the no pollution, relatively low capital cost involved and the short gestation period required. 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. The National Aeronautics and Space Administration (NASA), in conjunction with the Energy Research Development Agency (ERDA), has built and tested a large number of large wind-powered generators. The first machine was 100 kW unit built at Sandusky, Ohio, for around a million dollars. Recently Enercon constructed a wind turbine of 4.5 MW and rotor diameter of more than 112.8 metres [1].

Today wind energy is the fastest growing energy source. Presently wind power meets the electricity needs of more than 35 million people. Globally the wind power industry employs around 70000 people and has the worth more than $5 billion. According to Global Wind Energy Council (GWEC), Global wind power capacity has increased from 7600 MW at the end of 1997 to 47337 MW by Feb 2005. Main countries producing electricity from wind are Germany, Spain, US, Denmark, and India having their installed capacities (MW) 16629, 8263, 6470, 3117, and 3000 respectively by Feb. 2005. Today wind power accounts for about 0.4% of world's electricity demand. An analysis by European Wind Energy Association (EWEA) shows that there are no technical, economic or resource limitation that prevent wind power from developing to nearly 12% of the world's electricity supply by 2020, but with strong political commitment worldwide wind energy industry could install an estimated 1200, 000 MW by 2020 [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 ac power, a constant angular velocity and force is desirable. Unfortunately, the wind velocity is neither constant in magnitude and direction nor it is constant from the top to bottom of a large rotor.

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. Wind survey is extremely important to exploit wind energy. Lot of development has been 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. Following Sections discuss number of issues related to power generation from wind systems.

2 Factors affecting wind power

One of the most important tool in the 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, which must be considered:

2.1 Power in the wind

The total power that is available to a wind is given as

Total wind power in Watts, $P_w = (m_w V^2)/2 = (\rho A V^3)/2$ (1)

where $m_w = \rho A V$, where ρ 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. The density is a function of pressure, temperature, and relative humidity. It is seen from equation (1) that 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 [3, 4]. If the inlet wind velocity is V_i and the output velocity is V_o, the mass flow rate through the system is approximately $\rho A V_{ave}$, where the average velocity is $(V_i + V_o)/2$, and the power recovered from the wind is equal to the mass rate times the change in the kinetic energy, or:

$$P_{out} = m_w (V^2_i - V^2_o)/2 = (\rho A/4)(V_i + V_o)(V^2_i - V^2_o)$$
$$= (P_w/2)(1 + x - x^2 - x^3) \qquad (2)$$

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

$$d(P_{out})/dx = 0 = (1 - 2x - 3x^2) \qquad (3)$$

and using the quadratic equation

$$x_{max\ P} = 1/3 \qquad (4)$$

Substituting the value of $x_{max\ P}$ in equation (2), the maximum power recovered is:

$$P_{out\ max} = 16/27\ P_w = 0.593\ P_w \qquad (5)$$

Thus the maximum power that can be realized from a wind system is 59.3 % of the total wind power. The power in the wind is converted to mechanical power with an efficiency (coefficient of performance) c_p, and transmitted to the generator through a mechanical transmission with efficiency n_m, and further converted to electricity with an efficiency n_g . The electrical power output is then

$$P_e = c_p\, n_m\, n_g\, P_w \qquad (6)$$

Optimistic values for these coefficients are $c_p = 0.4$, $n_m = 0.9$ and $n_g = 0.9$, which give an overall efficiency of 32%. Actual values will probably lie between 25% to 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 highly variable power source and there are several methods of characterizing this variability. Most common is the power duration curve [5-9]. 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 Weibull function.

2.3 Load factor

There are at least two major constraints on 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 is acting as a fuel saver on the electric network. But if the generator is pumping irrigation water in asynchronous mode, for example, load factor is very important [10].

2.4 Seasonal and diurnal variation of wind power

Seasonal and diurnal variation has significant effect on wind [7,8]. 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 the height because of friction at earth surface [7,8]. The rate of increase is given by

$$V/V_O = (Z/Z_O)^{1/7} \tag{7}$$

Where V is the predicted wind speed at height Z and V_O is the wind speed at height Z_O. This translates into 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-generated power has to be dumped [9]. 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 carefully match the machine characteristic to the local wind regime to give the type of supply required.

3 Classifications of wind energy conversion systems (WECs)

There are number of ways of classifying of WECs. Following are the main types of classifications of WECs:

3.1 According to size of useful electrical power output [10]:

(i) Small size (up to 2kW): 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.

3.2 According to rotational speed of aero turbines [11-13]:

(i) ***Fixed Speed Generators***

In fixed speed generators wind energy is transformed into electrical energy using a simple squirrel-cage induction machine directly connected to a three-phase power grid. The rotor of the wind turbine is coupled to the generator shaft with a fixed-ratio gearbox. Some induction generators use pole-adjustable winding configurations to enable operation at different synchronous speeds. However, at any given operating point, the turbine basically has to operate at constant speed.

The construction and performance of fixed-speed wind turbines very much depends on the characteristics of mechanical subcircuits, e.g., pitch control time constants, main breaker maximum switching rate, etc. The response time of some of these mechanical circuits may be in the range of tens of milliseconds. As a result, each time a gust of wind hits the turbine, a fast and strong variation of electrical output power can be observed. These load variations not only require a stiff power grid to enable stable operation, but also require a sturdy mechanical design to absorb high mechanical stresses. This strategy leads to expensive mechanical construction, especially at high-rated power.

(ii) ***Adjustable Speed Generators***

Modern high-power wind turbines are capable of adjustable speed operation. Key advantages of adjustable speed generators (ASGs) compared to fixed-speed generators (FSGs) are:

- They are cost effective and provide simple pitch control; the controlling speed of the generator (frequency) allows the pitch control time constants to become longer, reducing pitch control complexity and peak power requirements. At lower wind speed, the pitch angle is usually fixed. Pitch angle control is performed only to limit maximum output power at high wind speed.
- They reduce mechanical stresses; gusts of wind can be absorbed, i.e., energy is stored in the mechanical inertia of the turbine, creating an "elasticity" that reduces torque pulsations.

DOI: 10.2202/1553-779X.1070

- They dynamically compensate for torque and power pulsations caused by backpressure of the tower. This backpressure causes noticeable torque pulsations at a rate equal to the turbine rotor speed times the number of rotor wings.
- They improve power quality; torque pulsations can be reduced due to the elasticity of the wind turbine system. This eliminates electrical power variations, i.e., less flicker.
- They improve system efficiency; turbine speed is adjusted as a function of wind speed to maximize output power. Operation at the maximum power point can be realized over a wide power range.
- They reduce acoustic noise, because low-speed operation is possible at low power conditions.

Following are adjustable speed generator schemes:

(a) ***Direct-in-line ASG system***

One possible implementation scheme of ASGs is shown in Fig.1. A synchronous generator is used to produce variable-frequency ac power. A power converter connected in series with the ASG transforms this variable-frequency ac power into fixed-frequency ac power. Although these direct-in-line systems have been built up to 1.5 MW, several disadvantages are apparent:

- The power converter, which has to be rated at 1 p.u. total system power, is expensive.
- Inverter output filters and EMI filters are rated for 1 p.u. output power, making filter design difficult and costly.
- Converter efficiency plays an important factor in total system efficiency over the entire operating range.

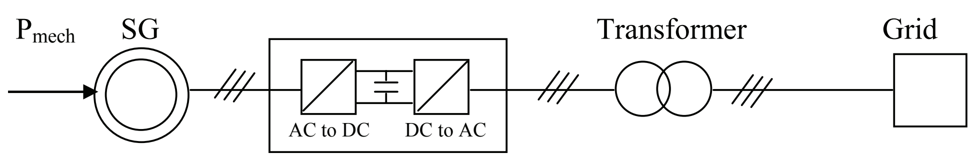

Fig. 1 Direct in line wind turbine system

(b) ***Doubly fed induction generator (DFIG) ASG system***

The typical DFIG configuration, consists of a wound rotor induction generator (WRIG) with stator winding directly connected to the three-phase grid and rotor winding connected to the grid via a partial scale back to back power converter as shown in Fig. 2. An alternative ASG concept that consists of a DFIG with a four-quadrant ac-to-ac converter based on insulated gate bipolar transistors (IGBTs) connected to the rotor windings. Compared to direct-in-line systems, this DFIG offers the following advantages [11]:

- Reduced inverter cost, because inverter rating is typically 25% of total system power, while the speed range of the ASG is 30% around the synchronous speed.
- Reduced cost of the inverter filters and EMI filters, because filters are rated for 0.25 p.u. total system power, and inverter harmonics represent a smaller fraction of total system harmonics.
- Improved system efficiency.

Power-factor control can be implemented at lower cost, because the DFIG system (four-quadrant converter and induction machine) basically operates similar to a synchronous generator. The converter has to provide only excitation energy.

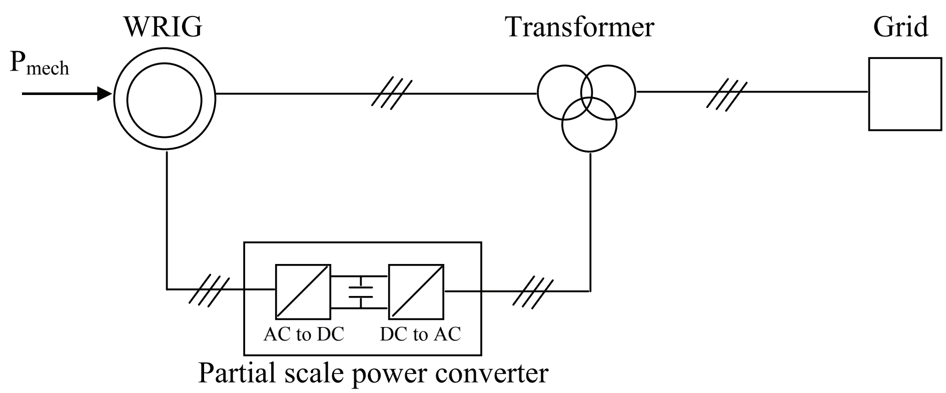

Fig. 2. Schematic diagram of doubly fed induction generator

3. 3 According to the orientation of turbines:

There are two great classes of wind turbines, horizontal and vertical axis machines [8,9]:

(i) ***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 the horizontal axis windmills. Depending upon the number of blades these may be classified as single-bladed, double-bladed, three-bladed, multi-bladed and bicycle-bladed [3,8]. 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 in the wind machines have some means for keeping the rotor in to wind. Consequently, either the entire wind machine and its tower, or the top of the wind machine where the rotor is attached must change its position relative to the wind. On smaller wind machines, such as the farm windmill the tail vane keeps the rotor pointed in to 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. They passively change the orientation of the wind turbine with respect to changes in the wind direction without the use of human or electrical power. Down wind rotors don't need tail vanes or fantails. Instead the blades are swept slightly down wind, giving the spinning rotor the shape of a shallow cone with its apex at the tower. This coning of the blades causes the rotor to inherently orient itself down wind.

(ii) ***Vertical Axis***
In vertical axis wind turbines (VAWT), the axis of rotation is perpendicular to the direction of wind. These machines are also called as cross-wind axis machines. Main designs of vertical axis machines are 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 [10]. On the negative side VAWT requires guy wires attached to the top for the support, which may limit its application particularly for the offshore sites.

4 Choice of generators
There are mainly following three classes of generators [14]:

4.1 D.C. generators
D.C. generators are relatively unusual in wind/micro-hydro turbine applications because they are expensive and require regular maintenance. Nowadays for most of 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.

4.2 Synchronous generators
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, which require the reactive power. It is normal for a stand-alone wind-diesel system to have a synchronous generator, usually connected to the diesel. 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 flexible coupling in the drive train, or to mount the gearbox assembly on springs or dampers to absorb turbulence. Synchronous generators are more costly than induction generators, particularly in smaller size ranges. Synchronous generators are more prone to failures.

4.3 Induction generators
Induction generator offers many advantages over a conventional synchronous generator as a source of isolated power supply. Reduced unit cost, ruggedness,

brush less (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 [15-18]. Further induction generators are loosely coupled devices, i.e. they are heavily damped and therefore have the ability to absorb slight change in rotor speed and drive train transient to some extent can therefore be absorbed. Whereas synchronous generators are closely coupled devices and when they are used in wind turbines which is subjected to turbulence and requires additional damping devices such as flexible couplings in the derive train or to mount gearbox assembly on springs and dampers. Reactive power consumption and poor voltage regulation under varying speed are the major drawback of the induction generators, but the development of static power converters has facilitated the control of induction generator, regarding output voltage and frequency.

5 Main design 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 and foundations etc. Modern wind turbine manufacturer 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 turbulent sites will generally have rotors of smaller diameter and more robust than turbines for lower-wind sites. The design criteria specified by the International Electro-technical Commission (IEC) base the design loads on the mean wind speed and the turbulence level. Minimizing cost is the next most important design criteria. 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 fuel-based generators, unless environmental benefit of wind power are accounted for. If the cost of wind energy could be cut by an additional 30 to 50%, then it would be globally competitive. The goal to achieve this 30 to 50% reduction has inspired the 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 [4, 19]. Table 1 shows the increase in the size and corresponding diameters of commercially available wind turbines since 1985.

DOI: 10.2202/1553-779X.1070

Table 1. Increasing size of commercial wind turbines since 1985

S. No	Year	Capacity (MW)	Rotor Diameter (metres)
1.	1985	0.05	15
2.	1989	0.3	30
3.	1993	0.5	40
4.	1995	1.3	50
5.	1997	1.6	65
6.	2000	2	80
7.	2004	5	116

6 Problems Related with Grid Connections

In Europe, substantial wind penetration exists today and will only increase over time. The impacts on the transmission network are viewed not as an obstacle to development, but rather as obstacles that must be overcome. High penetration of intermittent wind power (greater than 20 percent of generation meeting load) and may affect the network in the following ways and has to be studied in detail:

6. I Poor grid stability

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

6.2 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 standard frequency of 50 Hz) through wind conditions are favorable, with consequent loss in output [20]. This deficiency apart, the output of WEGs at low frequency operation is considerably reduced, due to reduced speed of the rotor. The loss in output could be about 5 to 10% on the account of low frequency operation.

6.3 Impact of low power factor

WEGs fitted with induction generators need reactive power for magnetizing. Normally in conventional energy systems, generators apart from supplying active power will be supplying a reactive power. But in 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 [21] may be required to reduce the reactive power burden on the grid.

6.4 *Power flow*

It is to be ensured that the interconnecting transmission or distribution lines will not be over-loaded. This type of analysis is needed to ensure that the introduction of additional generation will not overload the lines and other electrical equipment. Both active and reactive power requirements should be investigated.

6.5 Short circuit

It is required to determine the impact of additional generation sources to the short circuit current ratings of existing electrical equipment on the network.

6.6 Power Quality

Fluctuations in the wind power may have direct impact on the quality of power supply. As a result, large voltage fluctuations may result in voltage variations outside the regulation limits, as well as violations on flicker and other power quality standards.

7 Autonomous Hybrid Power Systems

Even today there are still many locations in the world, which do not have an electrical connection to the central utility network. It may be due to remoteness, cost, or non-availability of sufficient grid power especially in the developing countries. A power system which can generate and supply power to such locations is called by various names as remote, decentralised, stand-alone, autonomous, isolated power system, etc [14]. The most common way to supply electricity to these loads is with diesel power plants. The main advantage of a diesel system is that it is an extremely proven technology and is highly reliable if maintained properly. The major disadvantage with diesel electric network is that the cost of electricity is very high which is mainly due to the cost of fuel, transportation cost and cost of operation and maintenance. For a small isolated diesel system the peak load may be as high as five times the average load. It is not un-common for the designers of the system to choose a diesel with a capacity of two times the peak load to provide a safety margin and room for future expansion of load. Such a system of its own will produce extremely costly electricity. The cost of electricity can be made comparable with the grid power by integrating diesel systems with other non-conventional energy systems (wind, small hydro, etc.) depending upon siting conditions. This system will have additional advantages of reductions in size of diesel engine and battery storage system, saving in the fuel and reduced pollution. Such systems having parallel operation of diesel with one or more

DOI: 10.2202/1553-779X.1070

renewable energy based sources to meet the electric demand of an isolated area are called autonomous hybrid power systems.

It is very important to know the operation system of a diesel engine. There are two main modes of system operation, involving running the diesel engine either continuously or intermittently. Continuous diesel system operation has the advantage of technical simplicity and reliability. The main limitation of this approach is low utilization of wind/hydro energy and correspondingly moderate fuel savings. Manufacturers usually recommend that minimum diesel loading should be 40% of the rated output, then minimum fuel consumption will be about 60% of that at full load [14]. Diesel fuel savings under these circumstances will therefore be not very significant. To achieve large fuel savings, it may be desirable to have the diesel running only when wind energy is lower than the demand. However unless the load is significantly less than the energy supplied by the wind turbine, the diesel generator will not be able to stay off for long period, because the wind power would on that occasion drop to less than the load. Frequent start-stop of diesel is undesirable because it would produce excessive strain on the engine and the starter motor. With the use of energy storage methods frequency of start-stop can be reduced. To guarantee the continuity of supply under these circumstances, added complexity in the architecture or control strategy is required.

The stand-alone wind/diesel system may be anything from a 10 kW wind turbine operated in conjunction with a 5 kW diesel electric set upto several MW of wind turbines/diesel [14]. A small autonomous hybrid power system is typically of 10 kW to about 5 MW of power. Such a system will generally have one or two diesel electric sets and one or two wind turbines may be introduced into the system. Another possible option available is to add other types of energy source e.g. small hydro generation in parallel to wind-diesel systems if the hydro systems are available in some of the geographical regions. Small hydro systems have low investment cost and short gestation period.

Generally, in an autonomous hybrid power system, the wind/hydro power generators are the main constituents of the system and are designed to operate in parallel with local diesel grids to improve the reliability of system. The main reasons are to obtain economic benefit of no fuel consumption by wind/hydro turbines, enhancement of power capacity to meet the increasing demand, to maintain the continuity of supply in the system, etc. As wind is highly fluctuating in nature, and it will affect the quality of supply considerably and even may damage the system in the absence of proper control mechanism.

8 Reactive Power Control of Wind System

In general, in any hybrid energy system there will be more than one type of electrical generators [14]. In such circumstances it is normal though not essential for generator(s), usually on the diesel to be synchronous, and wind/hydro turbine generator(s) to be asynchronous (induction). An induction machine will run as an induction generator when it is operated above synchronous speed. If an appropriate capacitor bank is connected across the externally driven induction generator, an e.m.f. is induced in the machine windings due to the excitation provided by the capacitor. This phenomenon is termed as 'Capacitor Self Excitation' and the induction generator is called as 'Self Excited Induction Generator (SEIG)' [16-18]. As discussed in the choice of generator section, An induction generator offers many advantages over a synchronous generator in an autonomous hybrid power system. The major disadvantage of the induction generator is that it requires reactive power for its operation.

In case of grid-connected system induction generator can get the reactive power from grid/capacitor banks, whereas in case of isolated/autonomous system reactive power can only be supplied by capacitor banks. In addition, most of the loads are also inductive in nature, therefore, the mismatch in generation and consumption of reactive power can cause serious problem of large voltage fluctuations at generator terminals especially in an isolated system. The terminal voltage of the system will sag if sufficient reactive power is not provided, whereas surplus reactive power can cause high voltage spikes in the system, which can damage the consumer's equipments or affect their performance. Therefore wind system requires proper control of reactive power to maintain the voltage within specified limits.

9 Environmental Aspects of Power Generation Using WECs

This section briefly discusses the environmental aspects of power generation using WECs.

9. 1Environmental benefits of WECs

Wind turbines are most environment friendly method of producing electricity. They donot pose any adverse effect on the global environment, unlike the conventional coal or oil-fired power plants. The pollution that can be saved per year from a typical 200 kW wind turbine, involving of substitution of 120-200 tonnes of coal which contain pollution contents as, Sulphur dioxide (SO_2): 2 –3 tonnes, Nitrogen oxide (NO_X): 1.2 to 2.4 tonnes, and other particulates of 150-300 kg. [20].

9.2 Audible noise

The wind turbine is generally quiet. 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 meter distance from the turbine and 40 dB at a 250 meter distance [4, 22] comparable with the noise level in motor car which may be approximately 75 dB. This noise is, however, is a steady state noise. The wind turbine makes loud noise while yawing under the changing wind direction. Local noise ordinance must be compiled with before installing the wind turbines.

9.3 Electromagnetic interference (EMI)

The wind turbine may cause interference to radio and television (TV) signals upto some extent in case of blades comprising of metals or signal is very weak [8]. Modern turbine use plastic or fibreglass blades so chances of interferences with radio and TV signal are negligible.

10 Economics of Wind Power Systems

The purpose of all types of energy generation ultimately depends on the economics. Renewables in general and wind in particular have seen generation costs falling over recent years. It is estimated that wind power in many countries is already competitive with fossil fuel and nuclear power if social/environmental costs are considered [23].

Installed cost of wind system is the cost of wind turbine, land, tower, and its accessories and it accounts less any state or federal tax credits. This tax credit may be base on how much wind energy is pumped into the grid or it may be percentage of installed cost. Maintenance cost of wind system is normally very small and annual maintenance cost may be about 2% of total system cost .The cost of financing to purchase the wind system can add significantly to overall cost of wind system. In addition there may be some hidden costs like property tax, insurance of wind system and any accident caused from the wind system, etc. On the other hand income from the wind system is the product of annual energy output and per unit cost of electricity. One of the chief advantage of generating electricity from wind system over conventional means is that fuel (wind) is free. The bulk of cost of wind system occurs once. On the other hand conventional generation consumes non-renewable fuels whose cost continues to escalate.

Research and development is going on to make wind power competitive with fossil fuel and nuclear power in strict sense, without taking into account of wind power’s social factors such as environment benefits. Efforts are being made to reduce the cost of wind power by design improvement, better manufacturing technology, finding new sites for wind systems, development of better control strategies (for output and power quality control), development of policy and instruments, human resource development, etc. [23].

11 Latest Trend of Wind Power Generation from Off Shore Sites

In Europe, offshore projects are now springing up off the coasts of Denmark, Sweden, UK, France, Germany, Belgium, Irelands, Netherlands, and Scotland with approximate installed capacity of more than 250 MW. Recently, GE installed a wind turbine of largest capacity of 3.6 MW, having the rotor diameter of 104 meter for off shore sites. The next generation of off shore wind turbine will generally fall in the range of 3.5 to 5 MW.

Largest off shore wind plant at Horns Rev of 160 MW installed capacity consisting of 80 turbines each of 2 MW capacity [24]. It is situated 54 km from the transmission network. Plant gets disconnected in case of grid faults, but it reconnects after few seconds the fault has disappeared. Some of the wind power plant's control functions are controlled centrally for the entire plant, where as others are managed by individual turbine. Reactive power can be controlled centrally or for each turbine, depending on the limits for intake and consumption. Each turbine has its own frequency control. In addition, the reactive power can be controlled locally so that wind power plant's total consumption/intake of reactive power is kept within ± 16 MVAr at the 34 kV side of wind farm transformer if the central control is not connected.

12 Conclusions

An attempt has been made in this paper to discusses number of issues related to the power generation from WECs, i.e. factors affecting wind power, their classification, choice of generators, main design considerations in wind turbine design, problems related with grid connections, wind-diesel autonomous hybrid power systems, reactive power control of wind system, environmental aspects of power generation, latest trend of wind power generation from off shore sites. Today wind power accounts for about 0.4% of world's electricity demand. And there is a target estimated by EWEA to reach wind power generation nearly 12% of the world's electricity supply by 2020, which needs strong political commitment worldwide wind energy industry could install an estimated 1200, 000 MW by 2020, which needs global exploitation of available wind potential and to generate power from off shore sites.

References

1 Vries, E.D. (2002) 'On a grand scale: the world's largest commercial wind prototype', *Renewable Energy World*, Vol. 5, No. 5, pp. 70-75.
2 "Global wind scenario", *Power Line*, B-17, Qutab Institutional Area, New Delhi (India), Vol. 7, No. 7, pp. 49-53, April 2003.
3 Culp, A.W. (1991) 'Principles of energy conversion', *2nd Edition, Mc-Graw Hill International Edition*, New York.
4 Bansal, R.C., Bhatti, T.S., and Kothari, D.P. (2002) 'On some of the design aspects of wind energy conversion systems", *Int. Journal of Energy Conversion and Management*, Nov. Vol. 43, No. 16, pp. 2175-2187.
5 Johnson, G.L. (1978) 'Economic design of wind electric generators', *IEEE Transactions on Power Apparatus and Systems*, March/April, Vol. PAS-97, No. 2, pp. 554-562.
6 Jayadev, T.S. (1976) 'Windmills stage a comeback, Nov., *IEEE Spectrum,* pp. 45-49.
7 Twidel, J.W. and Weir, A.D. (1987) 'Renewable energy sources', *English Language Book Society (ELBS)*, University Press Cambridge, Great Britain.
8 Gipe, P. (1995) 'Wind power', *Chelsea Green Publishing Company*, Post Mills, Vermount, USA.
9 Rai, G.D. (2000) 'Non conventional energy sources', *Khanna Publishers*, 4th Edition, New Delhi (India).

DOI: 10.2202/1553-779X.1070

10 K.T. Fung, R.L. Scheffler, J. Stolpe, "Wind energy- a utility perspective", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-100, No. 3, pp. 1176-1182, 1981.
11 Muller, S., Deicke, M., and Doncker, R.W.D. (2002) 'Doubly fed induction generator systems, *IEEE Industry Applications Magzine*, May/June, pp. 26-33.
12 Singh, B. (1995) 'Induction generator-a prospective', *Electric Machines and Power Systems*, Vol. 23, pp. 163-177.
13 Sandhu Khan, P.K. and Chatterjee, J.K. (1998) 'Three-phase induction generators: a discussion on performance, *Electric Machines and Power Systems*, Vol. 27, pp. 813-832.
14 Hunter, R., and Elliot, G. (1994) 'Wind-diesel systems, a guide to the technology and its implementation', *Cambridge University Press*, Great Britain.
15 Bansal, R.C., Bhatti, T.S., and Kothari, D.P. (2003) 'A bibliographical survey on induction generators for application of non-conventional energy systems', *IEEE Trans. Energy Conversion*, Vol. 18, No. 3, pp. 433-439.
16 Elder, J.M., Boys, J.T. and Woodward, J.L. (1983) 'The process of self excitation in induction generators', IEE Proceedings- Pt. B, Vol. 131, No. 2, pp. 103-108.
17 Murthy, S.S., Malik, O.P. and Tandon, A.K. (1982) 'Analysis of self excited induction generator', *IEE Proceedings-* Pt. C, Vol. 129, , No. 6, pp. 260-265.
18 Tandon, A.K., Murthy, S.S., and Berg, G.J. (1984) 'Steady state analysis of capacitors excited induction generators, *IEEE Trans. Power Apparatus and Systems*, Vol. PAS-103, No. 3, pp. 612-618.
19 Quarton, D.C. (1998) 'The evolution of wind turbine design analysis – a twenty years progress review", *International Journal on Wind Energy*, Vol. 1, pp. 5-24.
20 Bansal, R.C., Bhatti, T.S., and Kothari, D.P. (2001) 'Some aspects of grid connected wind electric energy conversion systems", *Interdisciplinary Journal of Institution on Engineers (India)*, May, Vol. 82, pp. 25-28.
21 Saad-Saund, Z., Lisboa, M.L., Ekanayka, J.B., Jenkins, N. and Strbac, G. (1998) 'Application of Statcoms to Wind farms', *IEE proceedings-Generation, Transmission and Distribution*, Sept. Vol. 145, No. 5, pp. 511-516.
22 Patel, M.R. (1999) 'Wind and Solar Power Systems', *CRC Press*, Boca Raton, FL.
23 Beurskens, J. and Jensen, P.H. (2001) 'Economics of wind energy-prospects and directions, *Renewable Energy World*, Vol. 4, No. 4, pp. 103-121.
24 Bonefeld, J. and Jensen, J.N. (2002) 'Horns Rev- 160 MW offshore wind', *Renewable Energy World*, Vol. 5, No. 3, pp. 77-87.

Biographies

Dr. R.C. Bansal is faculty in the department of electrical and electronics engineering, Birla Institute of Technology and Science, Pilani. He obtained his ME and Ph. D from Delhi College of Engineering and IIT Delhi (India) in the year 1996 and 2003 respectively. Dr. Bansal is Editor of IEEE Transactions of Energy Conversion. He is senior member of IEEE, member of the Institution of Engineers (India) and life member of Indian society of technical education. He has published more than forty-five papers in national/international journals/conferences. His research interests include reactive power control in renewable energy systems, power system optimization, and artificial intelligence techniques applications in power systems.

Ahmed Faheem Zobaa (M’01-SM’04} received the B.Sc.(hons.), M.Sc. and Ph.D. degrees in Electrical Power & Machines from the Faculty of Engineering at Cairo University, Giza, Egypt, in 1992, 1997 and 2002.

Currently, he is an Assistant Professor in the Department of Electrical Power & Machines, at Faculty of Engineering, Cairo University. He was an Instructor in the Department of Electrical Power & Machines, with the Faculty of Engineering at Cairo University from 1992 to 1997 and Teaching Assistant from 1997 to 2002. His areas of research include harmonics, compensation of reactive power, power quality, photovoltaics, wind energy, education and distance learning. He is an Editorial Board member for *Electric Power Components & Systems Journal*, *International Journal of Emerging Electric Power Systems*, and *International Journal of Computational Intelligence*. He is an Editor for *IEEE Power Engineering Letters* and *IEEE Transactions on Energy Conversion*. Also, he is an Associate Editor for *IEEE Transactions on Industrial Electronics*, *Electrical Power Quality and Utilization Journal*, *International Journal of Power and Energy Systems*, *International Journal on Modelling and Simulation*, *International Journal of Energy Technology and Policy*, and *Neurocomputing Journal*.

Dr. Zobaa is a member of the IEEE Power Engineering / Industry Applications / Industrial Electronics / Power Electronics Societies, Institution of Electrical Engineers, the International Association of Science and Technology for Development and the International Solar Energy Society.

Dr. R.K. Saket is faculty in the department of electrical engineering, Rajiv Gandhi Proudyogiki Vishwavidyalya, Bhopal (India). He obtained his BE, ME and PhD from Govt. Engineering College Rewa, Shri GS Institute of Technology & Science, Indore, and Allahabad Agricultural Deemed University, Allahabad in the year 1995, 1998 and 2005, respectively. He has published many papers in national/international journals/conferences. His research interests include power system optimization and reliability of power systems.