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Research Article

ROLE OF WIND ENERGY IN INDIAN ELECTRICITY SYSTEM

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ABSTRACT
In wind power, we have studied mechanical design of various types of wind turbines, their merits, demerits and applications, isolated and grid-connected wind energy systems with special attention to power quality. It is estimated that India has about 20,000 MW of wind power potential, out of which 1,000 MW has been installed as of 1997. With this, India now ranks in the first five countries in the world in wind-power generation. Based on Gauss-Seidel method, a load flow study was formulated. Individual bus admittance values were used to form admittance matrix. Wind energy may be used as an electrical power for reducing Indian electricity problem.

INTRODUCTION
Wind power has emerged as one of the most attractive solutions. Major factors that have accelerated the wind-power technology development are as follows **(**Brey *et al.*, 2002):

1. High-strength fiber composites for constructing large low-cost blades.
2. Falling prices of the power electronics.
3. Variable-speed operation of electrical generators to capture maximum energy.
4. Improved plant operation, pushing the availability up to 95 percent.
5. Economy of scale, as the turbines and plants are getting larger in size.
6. Accumulated field experience (the learning curve effect) improving the capacity factor.

India has 9 million square kilometers land area with a population over 1 billion, of which 75 percent live in agrarian rural areas. The total power generating capacity has grown from 1,300 MW in 1950 to about 100,000 MW in 1998 at an annual growth rate of about nine percent. At this rate, India needs to add 10,000 MW capacities every year. The electricity network reaches over 500,000 villages and powers 11 million agricultural water-pumping stations. Coal is the primary source of energy (Ezzell *et al.*, 1999). However, coal mines are concentrated in certain areas, and transporting coal to other parts of the country is not easy. One-third of the total electricity is used in the rural areas, where three-fourths of the population lives. The transmission and distribution loss in the electrical network is relatively high at 25 percent. The environment in a heavily- 2 populated area is more of a concern in India than in other countries. For these reasons, the distributed power system, such as wind plants near the load centers, are of great interest to the state-owned electricity boards. The country has adopted aggressive plans for developing these renewable. As a result, India has the largest growth rate of the wind capacity and is one of the largest producers of wind energy in the world (Reed, 1979). In 1995, it had 565 MW of wind capacity, and some 1,800 MW additional capacities are in various stages of planning. The government has identified 77 sites for economically feasible wind-power generation, with a generating capacity of 4,000 MW of grid-quality power. Ahin (1995). It is estimated that India has about 20,000 MW of wind power potential, out of which 1,000 MW has been installed as of 1997. With this, India now ranks in the first five countries in the world in wind-power generation (Froude, 1889).

II. Wind turbine

Wind turbine is a machine which converts wind power into rotary mechanical power. It has aerofoil blades mounted on rotor.

a) *Wind Turbine Generator units:*

A wind turbine generator consists of the following major units:

1. Wind turbine with Horizontal or Vertical axis.
2. Gear chain
3. Electrical generator (Synchronous or Asynchronous generator)
4. Civil, electrical and mechanical auxiliaries, control panels etc

b) *Mono-Blade Horizontal Axis Wind Turbine (HAWT):*

Features:

1. They have lighter rotor and are cheaper.
2. Blade are 15-25 m long and are made up of metal, glass reinforced plastics, laminated wood, composite carbon fiber/ fiberglass etc.
3. Power generation is within the range 15 kW to 50 kW and service life of plant is 30 years.

Advantages:

1. Simple and lighter construction
2. Favorable price
3. Easy to install and maintain.

Disadvantages:

1. Tethering control necessary for higher loads.
2. Not suitable for higher power ratings.

Applications:

1. Field irrigation
2. Sea-Water desalination Plants
3. Electric power supply for farms and remote loads.

c) *Twin-Blade HAWT*

1. They have large sizes and power output in range of 1 MW, 2 MW and 3MW.
2. These high power units feed directly to the distribution network.

d) *3-Blade HAWT*

1. 3 blade propeller type wind turbines have been installed in India as well as abroad.
2. The rotor has three blades assembled on a hub. The blade tips have a pitch control of 0 – 30 0 for controlling shaft speed.

4. The shaft is mounted on bearings.
5. The gear chain changes the speed from turbine shaft to generator shaft.

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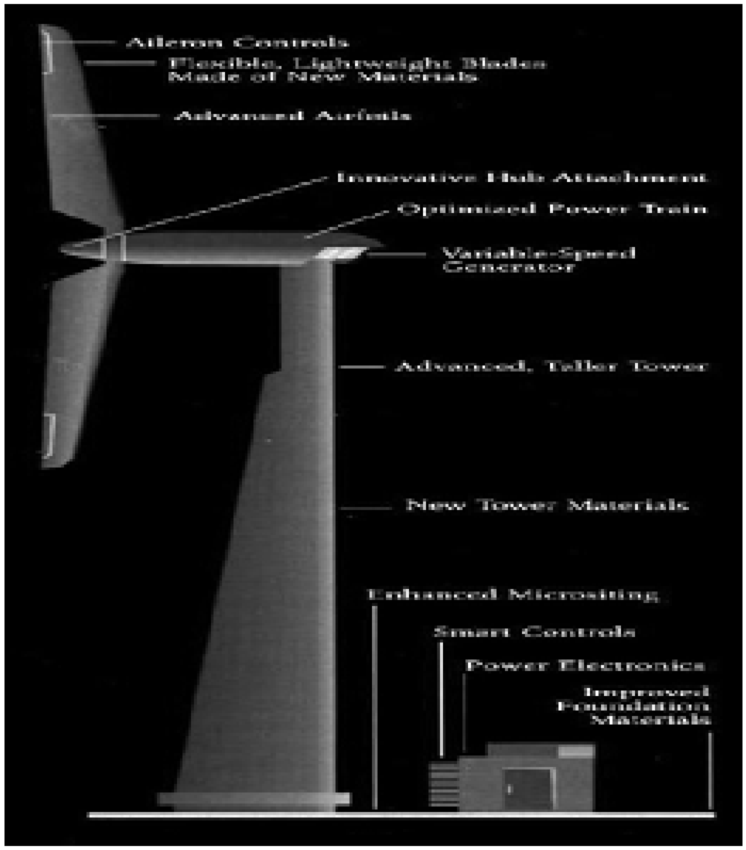

Figure 1: A wind turbine, an option of electricity generator for future generation

Disadvantages of large HAWT units:

1. Complexity in design involving mechanical, metallurgical & aerodynamic.
2. Extremely high stresses during storms.
3. Installation and repair of large units is difficult.
4. Outage affects the power supply to the consumer adversely.

e) Persian Windmill

1. The Persian windmill was the earliest windmill installed. (7th Century A.D. – 13th Century A.D. in Persia, Afghanistan and China)
2. It is a vertical axis windmill.
3. This windmill was used to grind grains and make flour.

f) Savonius Rotor

1. Patented by S.J. Savonius in 1929.
2. It is used to measure wind current.
3. Efficiency is 31%.
4. It is omni-directional and is therefore useful for places where wind changes direction frequently.

g) Darrieus Rotor VAWT

1. It consists of 2 or 3 convex blades with airfoil cross-section.
2. The blades are mounted symmetrically on a vertical shaft.
3. To control speed of rotation mechanical brakes are incorporated. Those brakes consist of steeldiscs and spring applied air released calipers for each disc.

III. Wind energy systems

Based on utilization aspect:

1. Wind electric energy systems connected to grid (without need for energy storage facility).
2. Stand-Alone (Isolated) wind energy systems (with need for energy storage facility).
3. Non-critical wind electric or wind mechanical energy systems (without storage).
4. Wind Electric + Diesel Electric Hybrid or Wind Electric + Solar Electric + Battery hybrid

Based on wind turbine rotor and electrical output (Froude, 1889):

1. Constant speed constant frequency system
2. Variable speed constant frequency system
3. Nearly constant speed and constant frequency system

a) Constant speed constant frequency system

1. Here, shafts of generators are coupled to output shaft of wind turbine. As wind speed is variable, therefore variable pitch blade control and gears are required to maintain constant torque output.
2. Constant frequency systems are essential for modern wind farms as the output is either grid connected or delivered to consumers requiring constant frequency supply.
3. Large WTGs use this method.

b) Variable Speed Constant Frequency System

1. Thyristor convertors are used.
2. Due to variable wind speed, the generator produces variable frequency output.
3. Rectifier-inverter combination delivers constant frequency electrical output to load or grid.
4. Here, there is no need to regulate blade speed. So, turbine operates at maximum efficiency.
5. Demerit is the additional expense on controls and rectifier-inverter systems

c) Nearly constant speed and constant frequency of grid

1. Small and medium generator units rated 100 kW, 200 kW and 300 kW etc. belong to this category.
2. They use induction generators and are connected to grid.
3. Excitation current is received from grid. So, induction generator cannot be operated alone.
4. Power factor correction capacitors are also necessary.

d) Control and monitoring system of a wind farm

1. A complete wind farm is controlled from the control room located in the main sub-station.
2. (X-1, X-2, X-3 …) represent control cables between individual WTG units and the master wind turbine controller.
3. The variables like power, voltage, power factor, frequency, rotor speed, pitch angle, bearing temperature, vibrations, wind direction, wind speed etc. are measured. They are converted to equivalent digital signals and transmitted via (X-1, X-2 ...) to the master controller.
4. The control has 3 levels:
    a. Distribution Network Control Centre
    b. Master Wind Farm Controller
    c. Unit WTG Controller
5. Signals are transmitted by radio signal system.
6. Station controller sets the power level according to instructions from the Central Distribution Control Centre.

IV. Wind power quality

Power quality is term used to describe how closely the electrical power delivered to customers corresponds to the appropriate standards so that the equipments of consumers operate satisfactorily.

a) Origin of power quality issues

1. As load on the generator is removed, wind turbines over-speed. This leads to a high demand for reactive power which further depresses the network voltage.
2. Network voltage unbalance also affects the rotating induction generators by increasing losses and introducing torque ripple.
3. Voltage unbalance can also cause power converters to inject unexpected harmonics currents back into the network.
4. During normal operation, effective rotor resistance to negative sequence currents is very small Rr/2. So, fault current magnitude is very large.

b) *Electrical behavior of Wind Turbine Generators*

Following inequality constraints are:

For Voltage change:

$$\sum S_{WKA}\left(\frac{1}{S_{KE}} - \frac{1}{S_{KSS}}\right) \leq \frac{1}{33}$$

For Voltage Fluctuation:

$$\sqrt{\sum\left(\frac{P_{WKA}}{S_{KE}}\right)^2} \leq \frac{1}{25}$$

S_{WKA} = Wind power generator apparent power.
P_{WKA} = Wind power generator real power
P_{ST} = Short term flicker severity
S_{KE} = Short-circuit level at tie-line
S_{KSS} = Short-circuit level at transformer station bus-bar.

c) Voltage flicker

1. It describes dynamic variations in the network voltage caused by wind turbines or varying loads.
2. The origin of term is the effect of the voltage fluctuations on the brightness of incandescent lights and the subsequent annoyance of customers.
3. Eye is most sensitive to voltage variations around frequency of 10 Hz.
4. Power output, P and network flicker(when subject to random torque change) are related as follows:

$$\frac{\Delta P}{P} = \frac{1}{\sqrt{n}}\frac{\Delta p}{p}$$

n = No. of generators
P, p = Rated power of wind farm and turbine
ΔP, Δp = Rated power fluctuation of wind farm and wind turbine respectively.

d) Harmonics

1. Thyristors are applied to connect the induction generators to grid. As the firing angle changes, harmonics are introduced.
2. Therefore anti-parallel Thyristors need to be by-passed during normal operation.

3. Use of IGBTs significantly reduces harmonics of lower order because they operate at kHz range. High frequency harmonics can be easily filtered.
4. One disadvantage of using IGBTs is that frequencies of kHz range affect the coupling reactance XC. This causes disturbance in the line models of distribution systems.

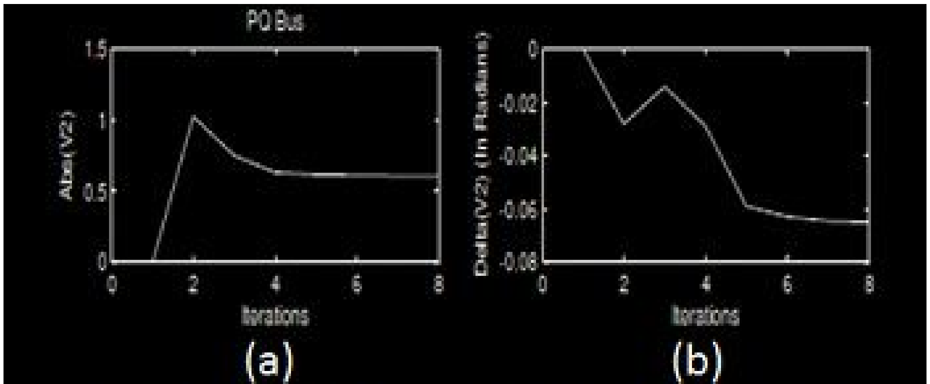

Figure 2 (a) Voltage Abs(V2) vs iterations, (b) Delta (V2) vs iterations

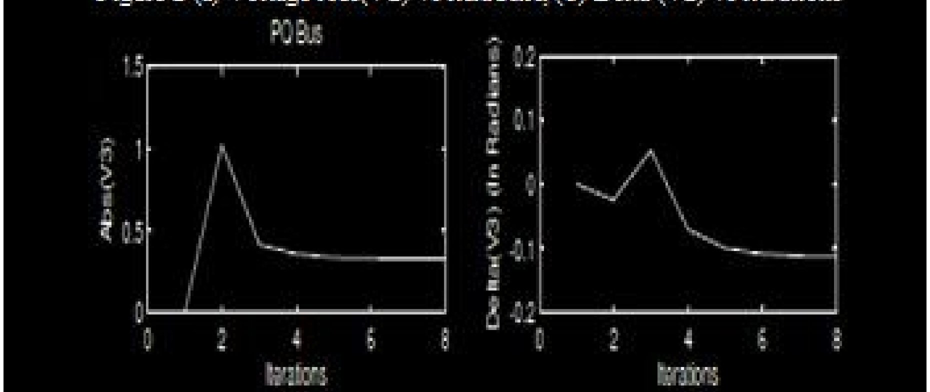

Figure 3 (a)Voltage Abs (V3) vs iterations, (b) Delta (V3) vs iterations

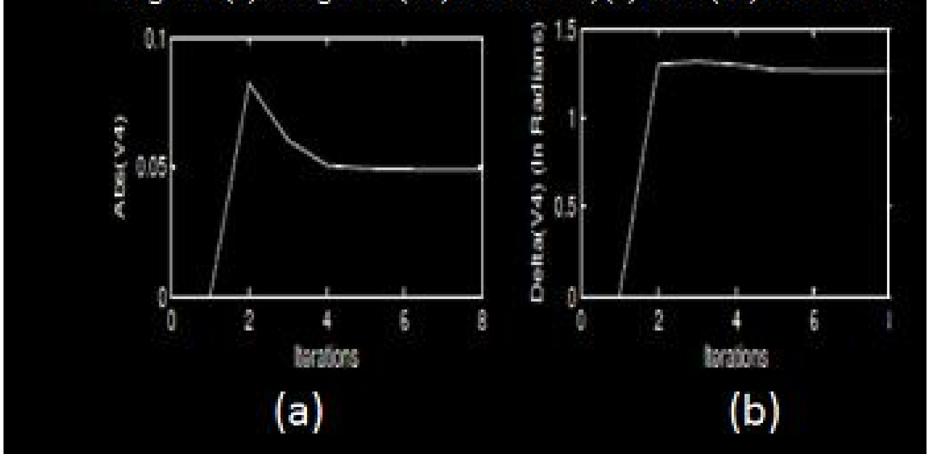

Figure 4 (a) Voltage Abs (V4) vs. iterations, (b) Delta (V4) vs. iterations

RESULT & DISCUSSION

Active power 'P' contributed by wind turbine is a function of cube of velocity where velocity is limited between 8m/s to 20m/s. This program generates a random velocity between the limits and performs load flow, thus calculating the voltage Abs (V2), Abs (V3) & Abs (V4) and Delta (V2), Delta (V3) & Delta (V4) as shown below.

Conclusion

In wind power, we have described various types of wind turbines, their merits, demerits and applications, isolated and grid-connected wind energy systems with special attention to power quality. Based on Gauss-Seidel method, a load flow study was formulated. Individual bus admittance values were used to form admittance matrix. It is estimated that India has about 20,000 MW of wind power potential, out of which 1,000 MW has been installed as of 1997. With this, India now ranks in the first five countries in the world in wind-power generation.

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