Impact of Wind Generation on Losses and Voltage Profile in a Distribution System

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Abstract- The Distributed Generation (DG) technology is developing rapidly and many countries have plans to install large percentage of new generating units at dispersed locations. When fixed and variable costs are considered, then the wind generation becomes an attractive alternative. With the grid interconnection, one has to address the issues like interfacing, protection, tariff structure, transmission pricing, etc. While considering the tariff issues, the reduction in Transmission & Distribution (T&D) losses has a major role to play. Though it is known that T&D losses reduce with the placement of wind generator near the load, the reduction has to be quantified and its effect on tariff has to be adequately considered. There are other benefits like improvement in voltage, which also should be quantified.

1. INTRODUCTION
During the last decade of the twentieth century, world-wide installed capacity of wind generation has doubled approximately every three years [1]. Wind energy is a form of clean energy, free of air pollution, and currently it is the most competitive among the renewable energies. Like all the non-conventional energy sources, the wind energy is expensive in terms of initial capital cost, but is relatively inexpensive in terms of operating costs [2].

Wind energy has become a techno-economically viable source of energy and is considered as a preferable renewable energy source in the power sector in India [3]. Presently the total installed capacity from all the renewable energy sources in India is 4500 MW and India has the 5th largest wind power installed capacity in the world which has reached 1870 MW (as on March 2003) [4].

Wind is not a steady source of energy and therefore it may not on its own meet the consumer needs at all the times [5]. Necessarily, it has to be integrated with some other source to provide constant back up. Wind electric generators operate on one of the following modes, viz. stand-alone mode, backup mode (e.g. wind-diesel, wind-micro-hydro) and grid connected mode. Normally the bulk of the wind generators are operated in the grid connected mode, because it has several advantages [6] viz. improvement in voltage profile, reduction in T&D losses and cost-effectiveness in meeting peak demand. There are two types of grid interconnections with wind electric generators: in the first one, the lower rating generators are normally connected together to a single step-up transformer, and in the second type each high rating generator is connected to a separate step-up transformer. Normally, wind generators are of two types: induction generators or synchronous generators. Induction generators are popular for fixed speed operation.

In this paper for a sample system, the exact quantification of reduction in T&D losses and improvement in voltage profile in various time zones as per Maharashtra State Electricity Board (MSEB) Time Of Use (TOU) tariff is done. This may play an important role in deciding the tariff for a local network with wind generation.

2. DISTRIBUTED GENERATION
DG, which includes the application of small generators scattered throughout the distribution network, offers a valuable alternative to traditional sources of electric power for industrial and residential applications. A series of technological innovations, particularly within the last decade and the advent of compact, highly efficient generation units have laid the foundation for the emergence of DG [7]. The function of an electricity generator is to transform one form of energy (e.g. chemical energy in fuels or kinetic energy in wind) into electrical energy as efficiently as possible. As such, the choice of generation technology is strongly dependent on the primary energy supplies available at the point of generation. DG uses some form of conventional fossil fuel, like gasoline, diesel, natural gas, propane, methane or gasified coal to produce electric power. Due to steady depletion of conventional fossil fuels, the recent research and development activities in the field of fuel cell

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Electricity Boards are being unbundled into three segments: conditions of Indian Distribution system through DG. The DG is very much relevant to India now, when the State restructuring and automation, the added dimension and opportunity offered by DG have to be studied. The necessity for flexible electric systems, changing regulatory and economic scenarios, energy savings and environmental impact along with the need to protect sensitive loads against network disturbances will provide impetus to the development of DG. Studies have projected that DG may account for up to 20% of all new generation going online by the year 2010 [8].

DG makes a large use of the latest modern technology and can be efficient, reliable and simple to own and operate; hence it can compete with conventional generation systems. The various advantages of DG can be summed up as follows [6]:

1. DG units are modular in size and modularity has two major advantages; firstly the units are standardized to common designs, site requirements and operating methods, which simplifies engineering and installation, thus lowering the cost. Secondly modular units are available “Off-the-shelf”, with a little lead-time and at a standard price.

2. DG units are closer to the customers so that T&D costs and losses are avoided or reduced.

3. Usually DG plants require shorter installation time and the investment risk is not so high.

The DG is very much relevant to India now, when the State Electricity Boards are being unbundled into three segments: Generation, Transmission and Distribution with selective privatization of Distribution sector. Meeting ever-increasing electricity demands within the financial constraints and the reduction of T&D losses are the most important priority areas of Indian power sector. While the efforts are on for improvement in the overall reliability and financial conditions of Indian Distribution system through restructuring and automation, the added dimension and opportunity offered by DG have to be studied.

Wind Powered Generation

Wind is one of those intriguing forms of natural energy, which is totally harnessable. It could supply all of the world’s energy needs for decades to come. But the problem is that only a very small percentage of this free energy can be captured for human use due to economic constraints. Wind generation is non-polluting and it doesn’t require any fuel except air. Two types of generation units are modular. These types of generation units are modular with fairly linear power versus cost relationship for large scale installation. The role of wind power within a distributed generation infrastructure would most likely be limited to geographical regions with high quality and regular wind conditions or to remote areas isolated from the network [9].

3. GRID CONNECTED WIND ELECTRIC GENERATION

The power in the wind due to its mass and velocity of the air molecules is

\[ P_w = \frac{1}{2} \rho A V^3 \text{ watts} \]  

where \( V \) is the wind velocity in m/sec, \( A \) is the swept area of rotor disc in m², and \( \rho \) is the density of air in kg/m³. The density is a function of pressure, temperature and relative humidity. The wind power is converted to mechanical power, which drives the generator. As the wind increases from a low value, the turbine is able to overcome all the mechanical and electrical losses, and it starts delivering electrical power to the load at its cut in speed. The rated power output of the generator is reached at rated wind speed. At the furling speed, the machine is shut down to protect it from high winds [5].

There are basically two design philosophies of the wind machines: fixed and variable speed operation. The generators can be either directly driven or through a gear box [10]. A fixed speed wind turbine is usually connected to an induction generator via a gear box. The generator stator winding is connected to the grid. If the rotor is of squirrel cage type, which is usually the case, then it draws reactive power from the grid. This is undesirable, especially in weak networks, and therefore the reactive power consumption of a squirrel cage generator is usually compensated with the help of auxiliary capacitors. In variable speed wind turbine, it is necessary to decouple the speed of the rotor from the frequency of the network through some form of power electronic converter. In direct drive synchronous generator, the rotor is directly coupled to the generator and no gear box is needed. The stator winding is coupled to a voltage source converter or a diode rectifier. When back to back voltage source converter is used, the generator torque is controlled by changing the stator current through controlling generator side converter voltage. When a diode rectifier is used, the generator is controlled indirectly by controlling the DC link voltage using the voltage source converter at the grid side. In doubly fed induction generator, the back-to-back voltage converter feeds the rotor winding, while the stator winding is connected directly to the grid, thus enabling variable speed operation of the wind turbine [11].

The various benefits of grid connected wind power projects are [12]:

1. Recovery of investment during the life of project.
2. Low operating cost.
3. Extremely low gestation period enables quick capacity addition.
4. Pollution free perennial source.

4. EVALUATION OF SYSTEM T&D LOSSES AND VOLTAGE PROFILE

Optimal placement and penetration level assessment of DG needs to be determined [13] for reduction in losses and for
improving voltage profile with due consideration of fixed and variable costs. Further, the optimal siting of a DG on a feeder depends greatly on the load distribution along the feeder. A detailed study for minimizing the losses and maximizing capacity savings with optimal placement of DG in Eastern Washington system is reported in [14]. The availability of wind generation in various time-slots in a day and the type of DG technology have an impact over the T&D losses [15].

The T&D losses will play an important role in formulating the new tariff structure of MSEB, one of the major utilities in India. Recently on 6th January 2003, Maharashtra Electricity Regulatory Commission (MERC) [12] has issued an interim order in the matter of levying of T&D loss charges on the basis of differential (circle/zone wise energy accounting data) T&D loss evaluation. Accordingly, the circles/zones with T&D loss lower than benchmark of 26.87% will be exempted from levy of T&D loss charge. The circles which have T&D losses above 26.87% will continue to pay the existing T&D loss charges. Since the Captive Power Plants (CPP) or Distributed Generation (DG) can improve the T&D losses, evaluation of these losses is important for finding their impact on the tariff.

In this work, a simple steady state load flow analysis is carried out to evaluate the reduction in the losses and improvement in voltage profile. Induction generators are considered in the study. In steady state condition, the induction generators can be modeled as ‘negative load’, hence the buses with injection of wind generation are considered as load buses (−P, −Q) in the load flow analysis. The analysis is done on per unit basis and the base considered is 100 MVA. The same study can be extended further to the system with synchronous generators and in such a situation the modeling aspect of synchronous generator may not be the same as that of induction generator. It can be modeled as a controlled voltage source whose total real power output is specified. In the steady state, the generator is modeled by a balanced three phase excitation voltage source behind its three phase synchronous impedance [16].

As per the TOU tariff of MSEB, the 24 hours of the day are divided into 4 time zones i.e. 'A' Zone from 22 hrs to 6 hrs, 'B' Zone from 6 hrs to 9 hrs and 12 hrs to 18 hrs, 'C' zone from 9 hrs to 12 hrs and 'D' Zone from 18 hrs to 22 hrs. The electricity use in the peak period (C and D zones) is levied extra charge and the usage in off peak period (A zone) gets a rebate. The availability of wind is quite uncertain, and hence in this paper the exact quantification of reduction in T&D losses and improvement in voltage profile for various time zones is reported.

5. Sample System and Results

In this paper, a sample system of 488 buses is considered, which includes 400 kV and 220 kV interconnected network grid. Actually the injection of proposed wind generation is at 33 kV level, hence the buses in the vicinity of this localized generation including 33 kV and 110 kV buses are also considered for this study. Our aim is to quantify the reduction in T&D losses and improvement in system voltage profile of the network shown in Fig. 1. The dotted lines represent the proposed network for incorporating wind generation; rest of the network is shown by dark lines. The values of generation/load at various buses in the considered system are shown in Table 1. The rated wind generation is of the order of 250 MW and the seasonal variation in the load is not considered in this work. The buses M, N and S are considered as load buses, and bus I is purely meant for wind generation without any load. L, P and R are the three buses with wind generation as well as local load, and hence the real and reactive power injected at each bus is decided by deducting the value of local load from the generation. For example at 33 kV bus L, the wind generation is around 50 MW and the local load is 25 MW, hence the actual real power injection at this bus is −25 MW. The reactive power fed to the grid is assumed to be 60% of the real power injection. This assumption is based on a linearization of practical quadratic curve showing the relationship between P and Q. The power factor of the load is assumed to be 0.85.

In the considered sample system, bus M is able to handle the power flows with proposed rated wind generation. The other two 220 kV buses are mainly meant for accommodating the local wind generation at respective 33 kV buses, hence the change in voltage profile at respective 33 kV buses, hence the change in voltage profile with and without inclusion of generation at bus M is very important. Results are presented for the sample system, which confirm that the losses for a system in the vicinity of DG reduce as well as the voltage profile at bus M improves. Due to economic benefits in terms of losses and voltage profile, the distribution area near the distributed generation will be most benefited.

Reduction in T&D losses

Initially, the load flow is carried out for exact quantification of T&D losses without any wind generation, and it is compared with the system having rated wind generation, 80% of wind generation and 40% of wind generation at the above mentioned buses. Due to the availability of extra generation at 33 kV level, the local load requirement gets satisfied immediately as shown in Table 1. This results into reduction of total T&D losses in the local network, which comes out to be 1.45% of total load of 210 MW for the rated wind generation. There will be maximum reduction in the losses when total load at 33 kV buses gets satisfied. The same study is extended further by considering the variation
Voltage Level of the Bus | Bus Name | Real Power Generation $P_G$ (Per Unit) | Reactive Power Generation $Q_G$ (Per Unit) | Real Power Load $P_L$ (Per Unit) | Reactive Power Load $Q_L$ (Per Unit) | Net Real Load $P_{L-P_G}$ (Per Unit) | Net Reactive Load $Q_{L-Q_G}$ (Per Unit) |
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<td>0.000000</td>
<td>0.625000</td>
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<td>33 kV</td>
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<td>0.210000</td>
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<td>-0.150000</td>
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| 33 kV                     | R       | 0.650000                            | 0.390000                             | 0.450000                        | 0.382500                      | -0.200000                      | -0.007500                      

The load flow is conducted in all the four time zones for evaluating the T&D losses. The reduction of losses in time zones A and B is much more than that of C and D. This is quite obvious as the injection of generation is quite high in slots A and B, which satisfies maximum load requirement at buses L, P and R.

**Improvement in Voltage Profile**

The inclusion of wind generation results into improvement in the voltage profile. Being induction generators, wind generators initially draw reactive power from the grid for magnetization but in steady state condition they inject into the grid the reactive power due to the auxiliary capacitors. This reactive power injection helps in improving the voltage profile of the grid. The voltage at 220 kV bus M without any local generation is 0.954 p.u. and with wind generation it comes out to be 0.971 p.u.
6. CONCLUSION

With the passing of Electricity Act 2003, DG will play a significant role in the Indian Power Sector. The various technical issues related to the grid connected DG will become important. Wind generation, one of the major renewable energy sources has much potential to improve the distribution system performance by reducing the T&D losses and improving the voltage profile of the system. As per MERC orders, the area with minimum T&D loss will get a benefit in terms of tariff.

In this paper a large interconnected sample system of 488 buses is considered. The injection of wind generation is considered at four different locations in MV distribution system. The variation in average wind generation throughout the year is also taken into account. The exact quantification of reduction in T&D losses and improvement in voltage profile in the above system are reported. It is observed that there is maximum reduction in T&D losses when the system load requirement and wind generation match.

The same study can be extended further by modeling permanent magnet synchronous generators, which are expected to become popular for use in wind electric generation systems.

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