PROBABILISTIC METHODS FOR WIND POWER DATA ANALYSIS AND ITS APPLICATIONS TO POWER SYSTEM OPERATION

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ABSTRACT

The contribution of wind power in supporting the electricity demand is one of the key areas in wind integration studies. Wind generation is different from conventional units as the available outputs of different wind farms cannot be approximated as being statistically independent, and hence near-zero variable output is possible across an entire power system. Power system operators are evolving alternate approaches, by changing the rules and practices which were used in past based on history of operations.

This paper addresses the understanding the variability of wind power along with demand profile through probabilistic data analysis. The analysis of data has been carried out over different months/seasons. The load following and regulation for each day over a span of one year has been computed to help the operator to understand the spinning reserve requirements and to determine the day ahead conventional generation scheduling. Through this paper an effort has been made to understand the applicability of wind power data in future operation of power system with large penetration of variable generation. Case studies have been carried out for one of the high wind penetrating states of Southern India.

Keywords: data analysis, generation scheduling, power system operation, probabilistic analysis, spinning reserve, variable generation, wind power.

Introduction

The intermittence of wind energy presents a special challenge for utility system operations. Furthermore, wind power generation does not lend itself readily to participate in the traditional generation scheduling process where controllable generators are scheduled to meet a variable load. In view of intermittency and variability of the wind, conventional power plants must be kept running to meet the actual demand for electricity and certain power system resources must be allocated separately to hedge against unavailability and variability of wind power during a low or no wind condition. Therefore, additional capacities above that need to meet actual load demands are made available either on-line/on-standby referred as operating reserve. Operating reserve allows system operators to compensate for unpredictable imbalances between generation and demand caused due to sudden outages of generating units, changes in generation from variable sources, errors in load forecasting and unexpected deviations by generating units from their production schedules.

Though wind power output is intermittent and uncertain, in a sufficiently long time interval, the output exhibits statistical behavior that is meaningful enough to be characterized by probability distribution [Jason (2010)]. Due to intermittent nature of variable generation, it may suddenly decrease the reliability of the power system if the required amount of operating reserve is not available. In order to improve the reliability in power system operation, we need to have an estimate of the minimum and maximum net demand (total demand – wind power) requirement, the ramp rates of the net demand and its extent of variation from the base load.
and regulation. By this information the operator can be prepared and can make sure that the system safety and security is kept intact.

The impacts of high penetration levels of wind power on power system operation are well addressed in the literature [George (2011), Kirby (2007), Pavlos (2008) and Zhao (2010)]. Different types of statistical methods are applied to analyze the historical data to find load following and regulation for practical power systems [Yuri (2008), Wan (2006) and Jason (2010)]. This paper further focuses on the analysis of historical wind power data along with demand through probabilistic data analysis. The ramp up and ramp down rates calculated in this paper can be used by system operator or scheduling algorithms with appropriate operating reserves from conventional generation.

**Methodology for Wind Data Analysis**

In order to deal with the presented problem, the practical historical wind data has been analyzed for one of the high wind penetrating states of Southern India. The wind and demand patterns over different time scales (comparison between two days, weekday and weekend, seasons, week-wise throughout the year etc.,) have been analyzed to check the wind penetration effects during various periods. Net demand (demand-wind) has been resolved into three components- Base load, Load following and Load regulation [Yuri (2008)]. The maximum and minimum regulation and ramp rates, for each day has been computed. This has been computed for demand including wind, excluding wind and wind generation alone. These are further analyzed in detail to determine the operating reserve requirements to integrate wind power in the grid feasibly.

There are typically three time scales of interest as presented in Figure 1 and Figure 2 [Kirby (2007)], which correspond to the operation of the utility system and the structure of the competitive electricity markets:

a) unit-commitment horizon of 1 day to 1 week with 1 h time increments,

b) load-following horizons of 1 hr with 5–10 min increments (intra-hour),

c) load-regulation horizon of 1 min–1 hr with 1–5 sec increments.

**Case Studies**

Case studies have been performed for one of the high wind penetrating states in INDIA where the present wind installed capacity is around 7300 MW. The total installed capacity of the state including wind installed capacity is 17540 MW. This works out to a wind penetration of around 42% (7300*100/17540). The hydro generation installed capacity of the system is around 2220 MW and the rest of the generation capacity comes from coal, gas, diesel base units [SRLDC, SRPC]. The present case studies have been performed for the year
The installed wind capacity during this study period is around 6250 MW (Aug 2011) and 6550 MW (Nov 2011).

Figure 3 shows the wind generation for 1st February 2011 and 1st August 2011. It can be observed that the wind power values are much higher for August than February. Also, the pattern in which the variation occurs on both the days is also random.

Figure 3: Wind Power Data for 1st Aug 2011 and 1st Nov 2011.

To understand the wind variation along with demand profile, wind and demand data profiles are analyzed in Figure 4. From Figure 4, it is clear that the maximum wind power occurrences are not at the same time of peak demand occurrences and low wind power availability during night times is in-line with demand profile. Hence during the occurrence of net demand ramp ups and ramp downs are important for the considered system data.

Figure 4: Wind and demand profile for one week (1st week of Aug 2011, minute wise data).

**Calculation of ramp rates and regulation:**

The ramp rate gives an idea of variation of wind generation over the day and regulation provides the minute-wise variation in wind generation. The base load of each day was calculated as the one with maximum number of occurrences. The minute-wise change (regulation) was calculated by subtracting both ramp and base load from the demand.

The ramp rates have been calculated to determine the amount of increase or decrease in the net demand, so that the required amount of operating reserves can be estimated. The
minimum and maximum ramps in a day were analyzed for each day throughout the year for net demand. Similarly, maximum and minimum regulations were also analyzed. Case studies are performed considering three scenarios: a) with demand only, b) with wind power only, c) with net demand (demand – wind power). The results of load following and regulation for net demand case has been presented in Figure 5.

Probabilistic Data Analysis for Load following:

Probabilistic data analysis is performed to calculate the probability of occurrence of different ramp rates during any season/month; hence the amount of spinning reserves can be estimated accordingly. This analysis helps the system operator to know the probability of occurrence of ramp rates and accordingly to fix the primary reserve and secondary reserve requirements.

The probability of occurrence of ramp rates for high wind season and low wind seasons are presented in Figures 6 – 8. Figure 6 presents the ramp rates considering only demand (without wind power), Figure 7 presents the ramp rates considering only wind power (without demand) and Figure 8 presents the ramp rates considering net demand (demand – wind power). From Figure 6, it is observed that the convention systems without wind generation are already handling the considerable amount of ramp rates with existing flexibility in mix of generation in the system. By comparing the Figure 6, Figure 7 and Figure 8, it is clear that the ramp rate events and ramp magnitudes are further increased due the addition of wind generation in the system.
From the Figure 8, it is observed that, the maximum ramp up and down rates is: 275 MW/hr, -325 MW/hr during Aug 2011 (high wind season) and 250 MW/hr, -400 MW/hr during Nov 2011 (low wind season). It is also observed that the magnitude of extreme ramp up and ramp down rates are less during high wind season as compared to low wind season times. This is due to the wind power variability (change in wind power along with time horizon) is more during low wind season as compared with high wind season.

From Figure 8, it is clear that the probability of occurrence of high ramps are very less and hence the system operator need not to provide these high reserves throughout the month. However system operator needs to handle this high ramp rates (considering the number of occurrences of wind ramps along with ramp magnitude) without effecting system security. Operating reserves which are used traditionally is sufficient to meet the normal ramp rates for wind integrated system except at extreme ramp rate events. This extreme ramp rate events (high ramp up and ramp down magnitudes) needs to be compensated by providing extra reserves for the wind integrated power systems. The extra reserves can be provided by having pumped storage systems in the system or interconnection agreements with neighboring states where high generation flexibility exists by means of hydro generation.

Conclusions

In this paper, ramping and regulation requirements have been studied considering historical wind data variations for each day, over different seasons. The probabilistic wind data analysis has been performed for the values of ramps and regulation for a period of one
year together and for every month. The data analyses have been performed for three cases namely demand only, wind only, and net demand to understand the effect of adding wind generation on overall system ramp rates. The calculated ramp rates through probabilistic data analysis will help the system operator or scheduling algorithm to know the probability of occurrence of ramp ups and ramp downs in system along with magnitudes and accordingly to fix the primary reserve and secondary reserve requirements from conventional generation. The extra reserves which are required to handle extreme ramp events can be provided by having more generation flexibility in wind integrated power system. The flexibility in generation can be achieved at extreme ramp events by having pumped storage hydro systems or interconnection agreements with neighboring states where high hydro generation exists or even high solar generation when low wind power exists. Short term wind forecasting and wind ramp forecasting tools will help further to handle the situations in future time intervals i.e. day ahead or hour ahead.

References


