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Wind power variability of selected sites in Kenya and the impact to system operating reserve

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ABSTRACT

Factors which influence wind power impact on a power system include variability, uncertainty, geographical spread and correlations of different sites. Presented is the wind power variability of three sites in Kenya and their potential impact on the system reserve. The sites' power was generated from wind speeds using wind farm models developed in Matlab/Simulink software. The wind power and load data were analysed for hourly variations and the load following reserve requirements in five different futuristic sites integration scenarios. However, forecast errors were not considered.

Results showed that power variations depended on distinctive wind regimes and the number of turbines. Ngong (25 MW) power was evenly distributed between 0 and 100%; Kinangop (60 MW) was concentrated between 20 and 60% and Turkana (300 MW) between 20 and 80% of their respective peak values. The standard deviations reduced as farm capacity increased due to the turbine smoothing effect. The reserve requirements increased on average, 30 MW per percentage wind integration. The combined Ngong/Turkana (325 MW) reserve requirements were less than for Ngong/Kinangop (85 MW), indicating the significance of site correlations. . Also, when Ngong was up-scaled to the same output level as the three interconnected sites (385 MW) reserve requirement increases by 25.5%, thus indicating the importance of geographical spread.

1. Introduction

Wind energy is a renewable energy source that is being widely integrated into power systems by many countries. Kenya is located within equatorial region where wind speeds are low compared to high altitudes regions. However, specific areas of the country have significant wind resources throughout the year. This is because of the complex topographical features and varying nature of surfaces in various regions of the country [12]. Kenya electricity generating company (KenGen) has proposed to increase the country's wind energy contribution to its generating mix. The wind integration is set to increase from the current 0.3% to surpass 20% of the load demand by 2015 [9].

Wind power variability and uncertainty presents challenges to systems' operators and planners. When the integrated wind power is very low, its uncertainty can be accommodated by the existing system load reserve. However, as the wind penetration increase, the variability problem cannot be ignored. This becomes crucial when a large amount of wind energy is integrated in the power system [1,6]. The knowledge of wind power variability and forecast ability is important for proper system operations. Prior information of future wind power sources is useful for system planning.

A number of studies [2,6,13,15] have shown that a system operating reserve increases with increase in the level of wind penetration. This is necessary in order to meet acceptable reliability of the power system due to increased wind power [15]. For example, in the California power system [13] the total load reserve was to increase by about 4% when the projected wind power generation was to increase from 600 MW to 3000 MW. In the Sweden power system [2], hourly variations increased from 20 MW (0.5% installed capacity) to 80 MW (1.0% installed capacity) as wind power penetration increased from 4000 MW to 8000 MW. When all Nordic countries were considered [6], the increase in operating reserve requirement due to wind power corresponded to about 2% of installed wind power at 10% penetration and 4% at 20% penetration respectively. Therefore as KenGen plans to increase integration of wind power, an insight into the potential impact of the

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wind sites is necessary.

The increase of reserve requirements is dependent on the relative size of the wind farm (number of turbines) as well as the variability characteristics. In addition when more than one site are considered, the geographical or regional spread of the sites becomes an important factor. Indeed it was found [7] that the increase in reserve requirement for a single Nordic country was twice as much as that for the whole region. This was attributed to better smoothing of the wind power variations over a wider regional area.

In order to simulate or predict future wind integration scenarios, the wind power estimates and variability for each site must be determined. Further, the distribution of sites i.e. site correlations, has to be considered. In this study an attempt is made to determine the wind variability of three potential sites for KeGen system. Also estimated is the potential impact of the wind power sources on the system in terms of scenarios involving different sites correlations.

In some studies [2,3,6,13] there has been reliance on single point measurement of actual wind data and up-scaled to represent wind power production of a larger area. Up-scaling of single point data however neglects the impacts of small deviation in grid quantities resulting to erroneous representation of wind power characteristics over a region. For instance, the correlations between different sites and distance have been used [6] to upscale actual wind power data. This results in linearity in the relationship between wind penetration levels and reserve sizes. However, there is no simple relation between the reserve requirements and the installed wind capacity or wind generation [11].

Another approach is the use of the simulation methods that are based on mathematical models. The models usually include the most important operation and physical aspects of the power system. The model approach has been widely adopted for direct conversion of site's speed into probability density at different power levels. This approach is preferred because of its applicability to all sites and for all types of wind turbines [10] et al.; [4]. It involves the judicious application of conditional probability models in incorporating the wind regime representation of a region. It also quantifies the variable effects of net systems requirements at different scenarios. The approach was used in developing farm models for the three KenGen sites. The models then generated the potential wind power data from wind speeds.

Additional reserve requirements for a power system due to wind integration can be estimated by combining the standard deviation of the load and wind variations [2,5,6,14]. It is assumed that the power system is closed and wind power is the only generation added. Since load and wind power production are uncorrelated, the net load is obtained by a simple root mean square (RMS) combination of the load and wind power variations Wind variability increases the inherent variability that already exists due to loads. Consequently, the distribution of changes in net load flattens and broadens when large-scale wind is added to the system. An additional operating reserve is therefore required to manage 99% of the net load variations. In a large-scale wind plant, an increase of turbines from 14 to 250 resulted in reduction of average hourly variations from 7.0 to 5.2%. The standard deviation reduced from 10% to 7.9% [14]. Recently, recommendations have been made [8] on requirements in studies involving wind integration. For system reserve requirements, important study parameters include data, the methods, time scales and the need to combine wind and load variability and uncertainty. However, in this study the wind/load forecast error estimations were not included. Wind variability due to meteorological fluctautions, correlation of site specific instantaneous variation of wind and load and the geographical spread were considered.

Three potential wind farms, Ngong (25 MW), Kinangop (60 MW) and Turkana (300 MW) are proposed to be integrated to KenGen's power system. As the plans to integrate the wind power sources are considered, it is important to understand the impact of the multiple point wind power sources to the net system requirements. This paper presents five different potential scenarios for integrating the three sites into the power system based on future wind power expectations. The first scenario is the integration of the Ngong farm (25 MW), the second and third are respectively the combination of Ngong and Kinangop (85 MW) and Ngong and Turkana (325 MW) sites. The fourth and fifth are respectively the combination of the sites, Ngong, Kinangop and Turkana (385 MW) and the Ngong site up-scaled to a total of 385 MW.

The objectives of this study were therefore 1) to analyse the wind power variability at three potential wind sites – Ngong, Turkana, and Kinangop; and 2) to estimate the impact on the power system reserve with different site integration scenarios.

2. Materials and methods

2.1. Wind power characteristics

The wind farm model in MATLAB/Simulink was used to convert the actual wind speed data into simulated wind power output. The software uses an aggregated wind turbine model representing an entire wind farm. The aggregate wind farm model (Fig. 1) was implemented using a combination of electrical components available in the MATLAB/Simulink library. The electrical network was simulated to depict the existing power distribution within Ngong. In the model, the wind farm is connected to a 25 kV network, via 25 km line 120 kV/25 kV transformer. The 25 kV network is further connected to the 120 kV network through a 30 km 25 kV line and a 120/25 kV transformer. All the network parameters were set to a frequency of 50 Hz to comply with the Kenya's grid specifications.

In order to eliminate the need for up scaling, each wind farm was composed of a specific number of turbines depending on the wind farm power output. Each turbine was rated at 0.85 MW (Vestas V52 model). Therefore, Ngong wind farm (25 MW) consisted of 30 turbines while Kinangop consisted of 71 turbines. As for Turkana site with 353 turbines multiple simulations were done using different data sets and the data summed up using 1-h sliding window. It was assumed that the Vestas turbines use Opti-speed concept which refer to their technical variance between the fixed speed and the variable speed wind turbine. The concept of full aggregation for each run assumes that wind speeds and mechanical speeds are almost the same was applied here. Further, the correlation coefficient of wind between turbines is assumed negligible and the aggregate capacity of the wind farm was used. This was a modelling assumption considering Matlab/Simulink software limitation regarding actual wind park parameters.When enough turbines from a large enough area are combined, the smoothing effect reaches saturation and the time series can be upscaled with representative hourly variations [6]. In order to determine the turbine power output, variable wind speed was fed into the wind turbine model from the workspace containing the wind speed data. This was repeated on multiple occasions using different wind speeds data sets and then summed up using 1-h sliding window to generate the total wind farm output [16].

The Ngong wind speed data was obtained from KenGen installed Vestas V52 turbines at a hub height of 50 m. The wind speed data for Turkana and Kinangop were obtained from the Ministry of Energy whereby the data had been measured at 40 m height. Here, measurements were made at multiple points and from multiple masts. The latter was converted to that corresponding to 50 m height according to Equation (1) [1]. and fed into the wind farm model. The impacts of large-scale wind power production (exceeding 20% of installed capacity) were taken into