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ANALYSIS OF A MULTI-MEGAWATT GRID CONNECTED WIND FARM

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ABSTRACT

The increasing global population and more rapidly growing needs of energy have become matter of concern to people from all walks of life. In order to meet power demands new and renewable sources of energy are being as supplemental source in addition to the regular fossil fuel based power generation. This paper presents the wind speed data, frequency distribution, local wind shear exponent, energy yield, air density and turbulence intensity analysis for a site located in the eastern region of Saudi Arabia. Overall mean wind speed values at 20, 30 and 40 meter above ground level were found to be 4.72, 5.34 and 5.74 m/s, respectively. The mean local wind shear exponent and air density were found to be 0.302 and 1.126 kg/m^3, respectively. Lower turbulence intensities were noticed at higher altitudes. The proposed wind farm of 550MW installed capacity could generate 2,433.8 GWh of electricity with a plant capacity factor of 50.3% during the year.

INTRODUCTION

The increasing fuel prices; levels of air, water and soil pollution; and widening gaps between the demands and supplies of power have become the critical issues to all human beings. The fast technological development and competitive costs of wind power generation, wind sources are being encouraged these days. The wind farms could be erected within months and lasts at least 20 years and require minimal operation and maintenance cost. In the present scenario, there are two important issues in the energy sector. First is the energy security and the second is the environmental damage due to the consumption of the conventional sources of energy. On top of it, the need of supplying electricity to remote communities is a critical task in developing and even developed countries.

Due to increasing environmental awareness and technological advancement, the renewable electricity generation capacity has reached an estimated 240GW worldwide in 2007, an increase of 50 percent over 2004 [1]. Renewable represent 5 percent of global power capacity and 3.4 percent of global power generation. The largest component of renewable generation capacity is wind power. At the end of June 2010, the cumulative global wind power installed capacity reached 175GW according to World Wind Energy Association (WWEA, [2]), and it is expected to reach 200GW by the end of year. The top five leaders who contributed towards global wind power installed capacities were USA, China, Germany, Spain and India and their respective installed capacities were 36.3GW (20.7%), 33.8GW (19.3%), 26.4GW (15.1%), 19.5GW (11.1%), 12.1GW (6.9%) and rest of the world installed capacity was 46.9GW (26.9%).

Dale et al., [3] studied the additional cost estimates of energy generation from wind power. The study showed that the extra cost from renewable energy as compared to the energy cost by traditional means is just over 0.3pence/kWh. Bergmann et. al. [4] carried out study to estimate the magnitude of external costs and benefits for using the renewable technologies in Scotland. Herman et. al. [5] conducted study on the development of large wind turbine for the design of 500 MW offshore wind farm. The study showed that the project included the design and testing of a 2.75MW NEG Micon prototype machine, which has been erected at the ECN Wind Turbine Test Farm Wieringermeer in February 2003. Moran and Sherrington [6] assessed the economic feasibility of a large scale wind farm project in Scotland. El-Osta and Califa [7] carried out feasibility study for a wind farm of 6.0MW capacity in Zwara, Tripoli, Libya. The results of the study showed that the project is economically feasible. Ammari and Maaitah [8] presented feasibility study of utilization of wind energy for power generation in Jordan. Their analysis showed that the annual mean wind speeds at a height of 24 m could reach as high as 7.6 m/s and available wind energy density close to 3MWh/m^2/year. Marafia and Ashour [9] carried out an economical feasibility study and assessment of the potential of off-shore/on-shore wind energy as a renewable source of energy in Qatar. The results of the study indicate the suitability of utilizing small to medium-size wind turbine machine.

The studies related to wind resources assessment for Saudi Arabia have been carried out and reported in the literature (Naif [10], Rehman et. al. [11], Mohandes et. al. [12], Rehman and Halawani [13], Rehman and Ahmad [14] and Rehman et. al., [15 and 16]). Naif [10] assessed the wind energy resource for five different locations in Saudi Arabia. He found out that Dhulom and Arar sites have higher wind energy potential with annual wind speed average of 5.7 and 5.4 m/s. Rehman et. al. [11] carried out work on wind speed data analysis such as Weibull parameter determination and distribution. The results of the study show that the wind speed was well represented by Weibull distribution function. Rehman and Ahmad [12] carried out detailed wind energy assessment for coastal locations of the Kingdom of Saudi Arabia. The study showed that the Yanbo is the best location, among the sites analyzed, for harnessing wind power. Rehman et. al. [15] calculated the electrical energy cost from the wind using long term hourly mean wind speed data at twenty locations in the Kingdom of Saudi Arabia. Recently, Rehman et. al. [16] carried out detailed wind data analysis and power resource assessment for Rafha, a city in northern part of Saudi Arabia. In the study, the plant capacity factors and energy yield were determined using the three different sizes of wind machines.

This study presents detailed analysis of a wind farm of 550 MW capacity in Saudi Arabia. The specific objectives of the study are to assess the wind power, wind shear exponent, air density, air turbulence intensity, energy yield, plant capacity factor and effect of hub height on energy yield and PCF for an isolated site in Saudi Arabia.

SITE AND DATA DESCRIPTION

The meteorological data (wind speeds, wind direction, air temperature, relative humidity, surface station pressure, global solar radiation) was collected at a remote location (Latitude 29° 8.282' N, longitude 44° 19.817' E, and altitude of 443 meters above sea level) for a period of about three years between September 2005 and November 2008. The data collection site is an open area from all directions except a couple of ware house shades and diesel storage tanks in the far vicinity of wind mast. Data was recorded every 10 minutes on a removable data card. The wind speed data was collected at 20, 30, and 40 meters above the ground. At each height, two sensors were installed (opposite to each other of the mast) and recorded data was tagged as WS1 & WS2 at 20 meters, WS3 & WS4 at 30 meters, and WS5 & WS6 at 40 meters. The wind direction data was recorded at 30 and 40 meters as WD1 and WD2, respectively. A schematic diagram of the 40meter tall tower used in the present study is shown in Figure 1. The surface air temperature (˚C), relative humidity (%), surface station pressure (in. of Hg), and global solar radiation (W/m^2) data was also collected at 2 meters above the ground surface. The raw data was transferred from the data acquisition system to the computer using data logger software from NRG, USA.

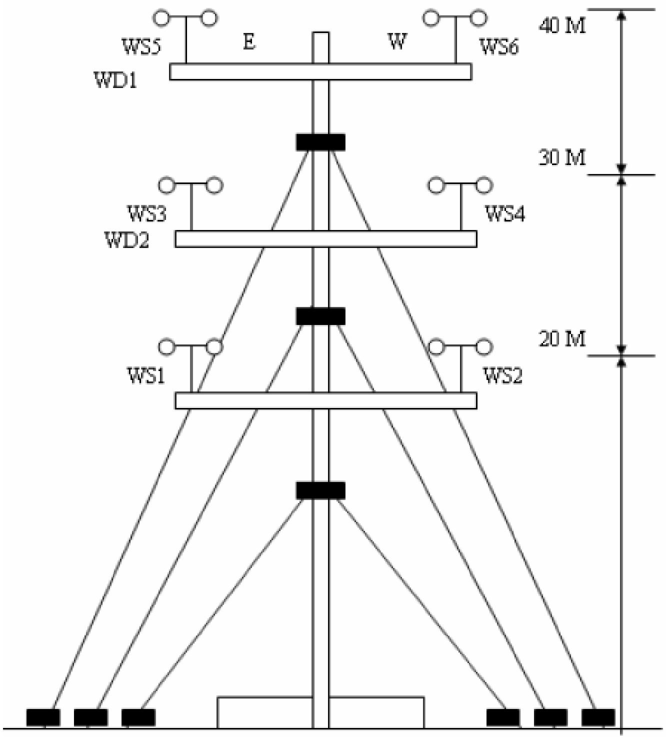

Figure 1 Schematic diagram of the 40m tall tower

RESULTS AND DISCUSSION

The analysis of the data includes data checking for completeness and erroneous values through visual and graphical inspection, calculation of monthly, daily and hourly mean values of all the parameters, estimation of wind shear exponents using wind speed values at different heights, and calculation of air density using surface temperature and pressure values. The wind data analysis provides an idea of the annual, seasonal and diurnal variability and availability of wind speed.

Variation of Wind Speed and Wind Power Density

The hourly variation of wind speed at different heights during entire data collection period is shown in Figure 2. It is evident from this figure that as the height increases the range of wind speed during 24 hours decreases which is indicative of lesser fluctuations and hence less turbulence at higher altitudes. This implies a continuous operation of the wind turbine whereas diurnal cycle is concerned. Furthermore, higher wind speeds during day time would be advantageous in Saudi Arabia to meet daytime air conditioning loads. The seasonal variation of wind speed, Figure 2, also provides confidence on the availability of wind throughout the year and additionally higher wind winds in summer time which is critical for Saudi Arabia due to increased energy requirements.

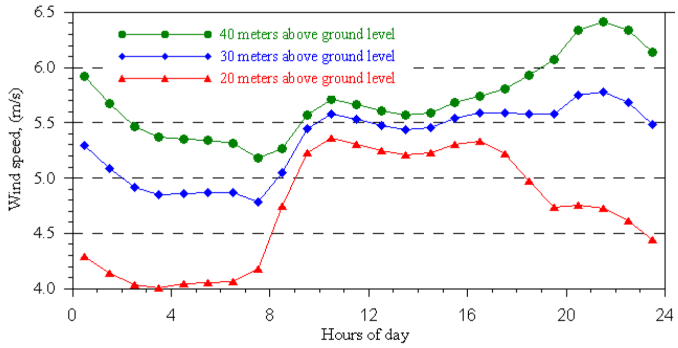

Figure 2 Diurnal variation of wind speed at different heights

The monthly mean variation of wind power density values, calculated using local air density values, as shown in Figure 4, followed the same trends as the wind speed at different heights depicted Figure 3. At 40 meters AGL the wind speed is found to be 15.5% of the times less than or equal to 3.0 m/s while for 84.5% of the time above it, as can be seen from frequency distribution diagram shown in Figure 5. Most of the modern wind turbines start producing electricity at 3.5 to 4.0 m/s, hence at the present site of measurements, the wind turbines with 4.0 m/s cut-in-speed could produce electricity for 74% of the time during the year.

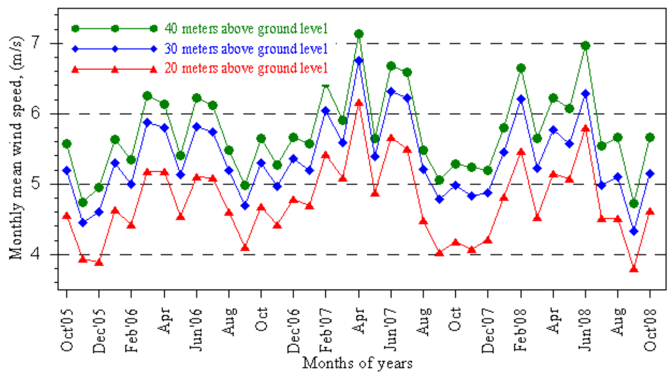

Figure 3 Monthly variation of wind speed at different heights

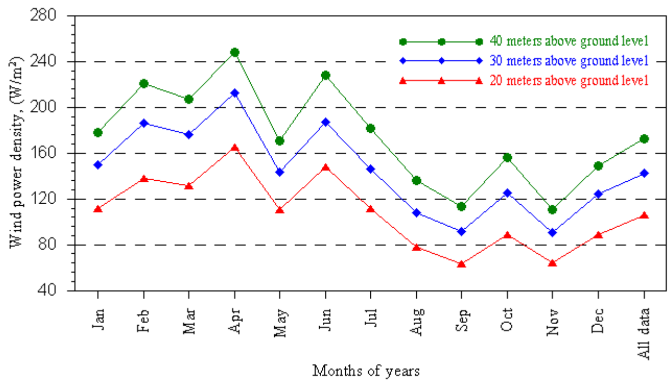

Figure 4 Monthly variation of wind power density at different heights

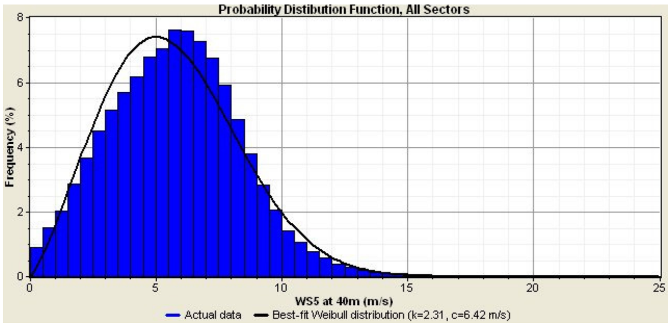

Figure 5 Frequency distribution of wind speed at 40 meters

Variation of Wind Shear Exponent, Air Density and Turbulence Intensity

The measured values of wind speeds at 20, 30 and 40 meters were used to obtain the local wind shear exponent (WSE).The seasonal variation of WSE along with extreme values is shown in Figure 6. A mean minimum value of WSE of 0.258 was observed in April while a maximum of 0.347 in October with the overall mean remained as 0.302. The wind power density is directly proportional to air density and hence is important from energy generation point of view. Higher values of air density were observed during winter season and lower in the summer months, as can be seen from Figure 7. The highest mean, maximum and minimum values were found in the month of January (1.198 kg/m^3) while the lowest in August (1.078 kg/m^3).

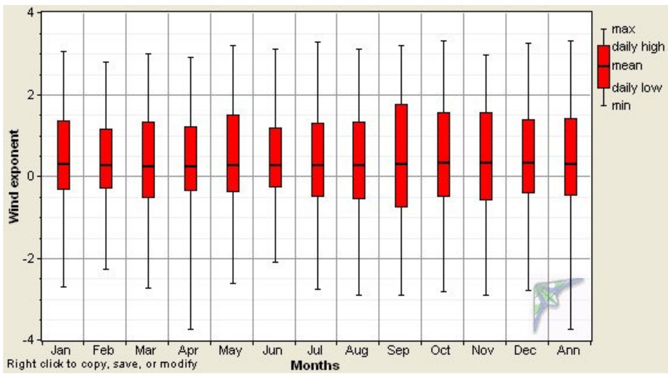

Figure 6 Monthly variation of WSE

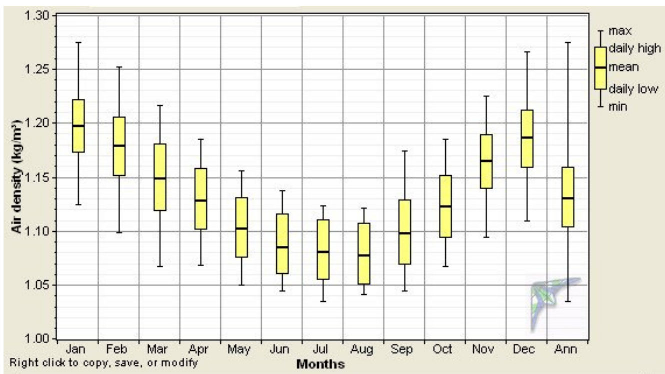

Figure 7 Monthly variation of air density

An accurate and quantitative knowledge of turbulence intensity (TI) is critical from working life of wind turbine. Greater the turbulence lesser will be the life of wind turbine and vice versa. Today's modern wind turbines have hub heights of more than 100 meters with a rotor diameter of the same magnitude and had to carry tons of loads of nacelle unit under dynamic load conditions. The monthly mean values of TI were calculated at different heights over entire period of data collection and it was found that TI decreases with increasing height, as can be seen from Figure 8. Furthermore, higher TI's were observed during summer time and lower during winter period.

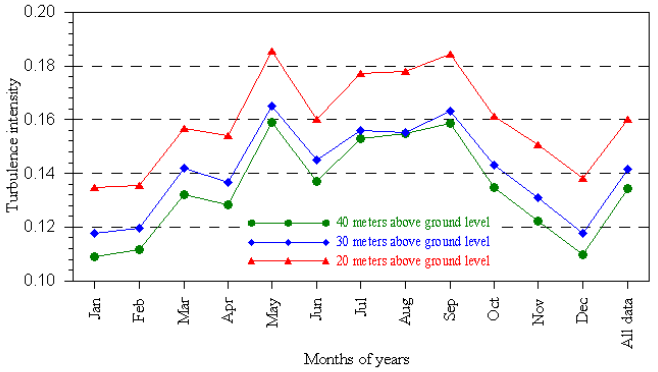

Figure 8 Monthly variation of turbulence intensity

Wind Energy Yield Estimation and Analysis

For energy yield estimation, 200 wind turbines, type V100, each of 2.75MW rated power from Vestas were considered. The rotor diameter of V100 was 100 meters and a hub height of 100 meters was considered for the present application. The cut-in-speed of V100 was 2.0 m/s while the rated and cut-out speeds were 11.5m/s and 25m/s, respectively. The wind energy yield was estimated using Windographer software [17]. The wind power curve, shown in Figure 9, of the wind turbine was used from the built in library of Windographer software. The wind farm energy losses like array, icing, down time and miscellaneous were taken as 2%, 5%, 2% and 3%, respectively.

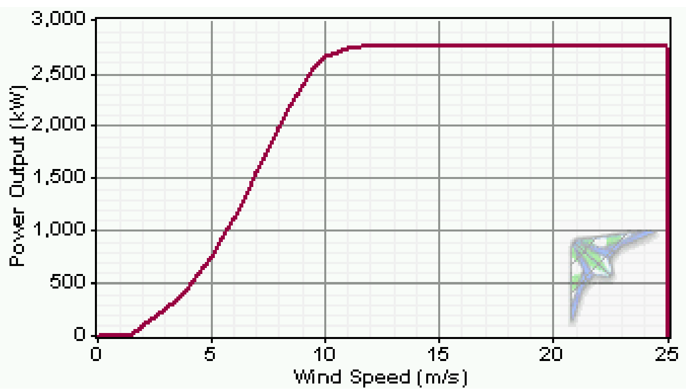

Figure 9 Wind power curve of V100 Vestas wind turbine

A maximum of 236.8 GWh of electricity was produced in the month of June (as shown in Figure 10) by the proposed 200 wind turbines. A minimum of 170.7 GWh of electricity was generated in the month of November. With existing wind intensities, a total of 2,433.8 GWh of electricity could be produced with an overall mean plant capacity factor of 50.3% from the proposed hypothetical wind farm of 550MW installed capacity. The seasonal variation of achievable plant capacity factors is shown in Figure 11. The plant capacity factor was found to vary between a minimum of 43.1% and a maximum of 59.8% corresponding to November and June months of the year, respectively. Furthermore, it was noticed that plant capacity factor remained above 47% during most of the months during the year. Overall, the zero and rated capacities were found to be 3.9% and 9.3% during entire year. This shows that the proposed wind farm could not produce energy only for a mere 3.9% of the time during entire year of operation.

CONCLUSION

The study utilized wind speed, ambient temperature and barometric pressure data measured for a period of almost three years between September 2005 and November 2008 at a remotely located power plant. The wind speed measurements were made at three heights namely 20, 30 and 40 meters above ground level to obtain the local wind shear exponent for wind speed extrapolation up to hub heights of 100 meters. Specifically, following observations were made:

- The mean wind speed over the data collection period was 4.72, 5.34 and 5.74m/s at 20, 30, and 40 meters above ground level. Higher values were observed during day time and summer months and lower during night time and winter months. The wind power density values also followed the same trend as that of wind speeds.
- An overall wind shear exponent of 0.302 is suggested to be used at this sight and in the surrounding area up to 200 km radius because the area is almost flat with gentle topographical features. Higher values of the exponent were observed during winter and lower in the summer time.
- The local air density values calculated using ambient air temperature and barometric pressure were found to be between 1.078 kg/m^3 in August and 1.198 kg/m^3 in June with an overall mean of 1.126 kg/m^3.
- The proposed 550MW installed capacity wind farm could generate a net 2,433.8GWh of electricity at a plant capacity factor of 50.3% with a hub height of 100 meters. Maximum net energy of 236.8 GWh could be obtained from the proposed wind farm at a plant capacity factor of 59.8% in June while a minimum of 170.7GWh with plant capacity factor of 43.1% in November.

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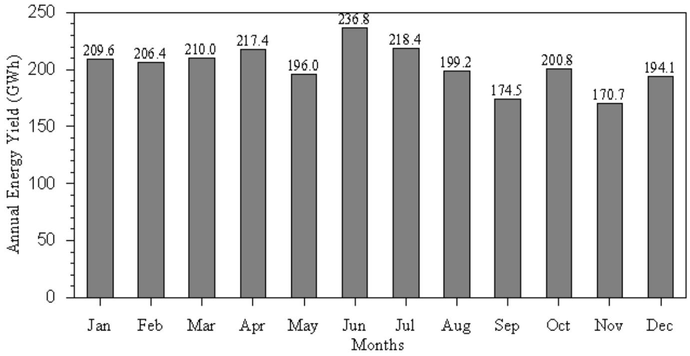

Figure 10 Monthly variation of total wind energy yield from 550MW installed capacity wind farm

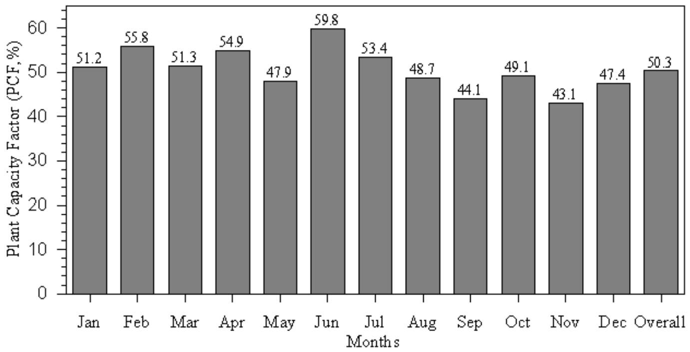

Figure 11 Monthly variation of plant capacity factor of the proposed grid connected wind farm

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