Renewable and Sustainable Energy Reviews 52 (2015) 1193–1204

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Wind speed and power characteristics for Jubail industrial city, Saudi Arabia

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ARTICLE INFO

Article history:
Received 16 November 2014
Received in revised form
19 May 2015
Accepted 25 July 2015
Available online 25 August 2015

Keywords:
Wind speed
Wind rose
Weibull parameters
Frequency distribution
Wind shear exponent
Capacity factor

ABSTRACT

This paper presents the wind characteristics and resource assessment of the largest industrial base in the Middle East (Jubail industrial city) using measured hourly mean wind speed data at 10, 50 and 90 m above ground level (AGL) from 2008 to 2012. At respective heights, the mean wind speeds were found to be 3.34, 4.79 and 5.35 m/s. At 50 and 90 m AGL, the availability of wind speed above 3.5 m/s was more than 75%. The prevailing wind direction was from the north-west. The local wind shear exponent calculated using measured wind speed values at three heights was found to be 0.217. The mean wind power density values at measurement heights were 50.92, 116.03 and 168.46 W/m^2 respectively. The comparison of energy output from five commercially selected wind turbines of rated power ranging from 1.8–3.3 MW showed that the most efficient wind turbine is 3.0 MW rated power. The annual energy production from this turbine was estimated to be 6285 MWh with a plant capacity factor of 25%.

Contents

1. Introduction

The cleanest sources of energy are those which use the natural resources of the earth. These sources are known as renewable sources of energy and will never die out unlike fixed reserves of fossil and nuclear fuels. Some of the common sources of renewable energies are wind, solar photovoltaic, solar thermal, hydro, wave, geothermal, and biomass. Wind is a very promising energy source and is receiving global recognition compared to other renewable energy sources, due to its low production, operation and maintenance cost and ease of maintenance, besides availability of efficient multi-megawatt wind turbines.

Saudi Arabia is experiencing rapid population as well as industrial growth and resulting in ever increasing demand on power and water supplies. The total population of Saudi Arabia increased by more than five times within last four and half decades, from 5,772,000 in 1970 to 30,770,375 in 2014 [1]. The number of operating industries has

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http://dx.doi.org/10.1016/j.rser.2015.07.109
1364-0321/

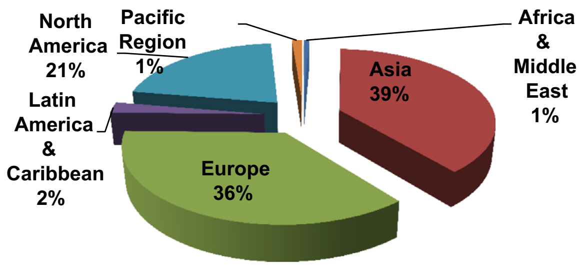

Fig. 1. Regional distribution of global Installed wind power capacity. Data source: [3].

increased by more than thirty times within last four decades, from 198 in 1974 to 6471 in 2013 [2]. Total GDP (in constant prices) achieved by the manufacturing industries increased from US $ 4 billion in 1975 to more than US $ 45 billion at the end of 2013. Also, the growth rate of the manufacturing industries continued to increase throughout this period at an average of 6% per annum, which is considered one of the highest among the other economic sectors [2]. The region-wise share of the global installed wind power capacity is presented in Fig. 1 [3]. The installed wind power capacity in Africa and Middle East is just 1% of the global installed capacity of 369,596 MW by the end of year 2014. Therefore, Saudi Arabia is exploring alternate sustainable and reliable sources of energy for generating power and reducing consumption of the nation's fossil fuel reserves. So, it was determined that a balanced energy mix of alternative and conventional energy is strategically important to Saudi Arabia's long term prosperity, energy security and its leading position in the global energy market [4]. Wind energy utilisation is one of the renewable energy options Saudi Arabia is considering seriously.

Meteorological parameters; such as wind speed, wind direction, temperature, relative humidity, barometric pressure, global solar radiation etc.; are highly site and time dependent in general while wind speed and direction are highly fluctuating components among these parameters. Hence, it is necessary and critical to understand the wind speed variability and availability during different hours of the day and different months of the year for successful and profitable development and utilisation of wind power. So, it is required to perform wind resource assessment of the site of interest to determine the feasibility of the wind farm development. Moreover, a small error in wind speed data gives a large error in energy yield calculations. Hence, accuracy in wind speed measurements can minimise the risk of huge investments [5].

The wind speed measurements are typically made at a different and lower height compared to the wind turbine hub height. The wind speed increases with height by a site-dependent power factor known as wind shear exponent. Wind speed can be extrapolated to the hub height by using the wind power law in conjunction with local wind shear exponent (WSE). If the estimated WSE is not accurate, the wind power law will lead to an error in the calculation of the wind speed at hub height and consequently the energy yield estimation [5]. Air density is another critical parameter that depends on air pressure and temperature at the site and directly affects the wind power density (WPD) and hence the energy yield estimates. Therefore, the actual air density should be calculated using the local pressure and temperature measurements for accurate energy output estimation [5].

To optimise the design of a wind turbine, data on speed range over which the turbine must operate to maximise energy extraction is required. This in turns requires the knowledge of the frequency distribution of the wind speed. Masseran et al. [6] presented nine frequency distribution functions suitable for fitting wind data: Weibull, Burr, Gamma, Inverse Gamma, Inverse Gaussian, Exponential, Rayleigh, Lognormal and Erlang. Rehman et al. [7] fitted the wind speed data of ten locations in Saudi Arabia to Weibull distribution function and concluded that this distribution accurately describes the wind data of this region. Similar studies elsewhere also claims that among all the frequency distribution functions that have been proposed for wind speed, the two-parameter Weibull distribution is most widely used to accurately describe wind regimes [8–10].

Various studies on wind resource assessment are reported for Saudi Arabian locations. In 1986, Ansari et al., [11] developed wind atlas for Saudi Arabia by using measured wind speed at 8–12 m height above the ground level for 20 different locations. The hourly mean wind speed and direction data during the period 1970–1982 was used to develop the wind atlas. This atlas showed the seasonal average wind speed contours in different months over the entire kingdom. The long term annual mean wind speed was found to be below 4 m/s in most of the regions. However, the data used were not reliable enough to determine the wind potential because, the sensors were mounted at a height of 8–12 m and the weather stations were located at low windy sites like airports. This wind atlas, which was the first effort towards wind resource assessment, also included the wind speed frequency distribution in different wind speed bins and the wind rose diagrams [11]. To better understand the wind power potential in the kingdom, Alawaji et al. [12] in 1996 performed wind speed measurements at 20, 30 and 40 m AGL at different locations in the Kingdom. In this study, six anemometers were installed on every wind tower, two each at 20, 30 and 40 m height to get reliable results. The annual average wind speed at 40 m AGL at Arar, Dhahran, Gassim and Riyadh was reported to be 5.3, 4.5, 4.0 and 4.5 m/s respectively [12]. Wind shear coefficients of wind speed at 20, 30, and 40 m AGL for Dhahran, Saudi Arabia was determined by Rehman and Al-Abbadi [5]. In this study, the energy yield was found to be around 120,000 MWh/year from a wind farm of 60 MW installed capacity consisting of 40 wind turbines each of 1500 KW rated power with a plant capacity factor of 24% [5]. In similar studies conducted by Shaahid et al. [13] at Taif, the wind speed was found to be less than 3 m/s for 46% of the time during the year. The annual energy produced from 15 MW wind farm (from 25 commercially available wind turbines of 600 kW rated power capacity each at 50 m hub height) was around 20,000 MWh/year. The cost of energy in this analysis was found to be 0.0576 US$/kW h. [13].

Some of the wind resource assessment studies reported for different countries were reviewed and discussed below. Prasad et al. [14] performed extensive literature survey on wind resource assessment (WRA) and discussed different WRA techniques. This methodology included preliminary wind survey to choose the best site for installing wind speed sensors, potential site selection, selecting the optimum wind turbine suitable for a site and the uncertainties involved in estimating the wind resource assessment using the different techniques. It was concluded that each WRA technique has its own advantages and selection of optimum technique is site dependent.

Fazelpour et al. [15] employed the Weibull probability distribution function for WRA using mean wind data at 10 m AGL over a six-year period at Tabriz and Ardabil, Iran. The hourly, diurnal, seasonal, monthly, and annual wind speed variations were analysed. The yearly values of the Weibull shape parameter vary from 1.81 to 2.13 m/s with a mean of 1.99 m/s for Tabriz and from 2.62 to 2.98 m/s with a mean of 2.86 m/s for Ardabil. Also, yearly values of the Weibull scale parameter vary from 3.35 to 4.45 m/s with a mean of 4.18 m/s for Tabriz and from 3.68 to 4.55 m/s with a mean of 4.16 m/s for Ardabil. The results show that the highest wind power potential occurs during months of August and July in Tabriz and during months of October and September in Ardabil.

Komleh et al. [16] analysed the wind speed data of Firouzkooh, Iran. For this purpose, 10-year period (2001–2010) wind data were analysed to calculate and estimate the wind power generation potential. Weibull and Rayleigh distribution functions were