Analysis of an Onshore Wind Farm in India for Sustainable Development

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ABSTRACT

The rapid development of electricity generation by wind energy is eco-friendly and does not pollute the atmosphere unlike thermal power plant. In this paper, the status like performance, reliability and various problems of a wind farm which is located at Muppandal, southern part of India have been analysed. This wind farm has 15 numbers of wind turbine generators (WTGs) of each 400 kW capacity and its annual average generation was 1.4 x 10^7 kWh. The performance status such as technical availability, real availability and capacity factor for this wind farm were 98.26 %, 83.06 % and 26.61 % respectively. The information from existing data of this wind farm was collected and reliability status like failure rate, mean time to failure, median, mode and reliability were calculated. In this paper an advanced Weibull technique was carried out for estimation of reliability and the reliability results are presented.

Keywords: Wind farm, availability, performance, reliability, Weibull technique

1 INTRODUCTION

The energy requirement in India is increasing multifold over the years. In order to meet the ever-increasing demands of energy applying new sources of wind energy becomes imperative. The estimated potential of wind energy in India is 45195 MW. The installed capacity in India is 10000 MW as on December 2009. The power accounts for nearly 70% of power generated through Renewable energy sources. This paper is a modest attempt to study the status of a wind farm (15 WTGs × 400 kW) located at Muppandal (Southern part of India) with a total capacity of 6 MW. This wind farm experienced a mixture of success and failures. In this study, five years (2000-2004) operational experiences of site-specific data of a wind farm were collected for the analysis. The literature survey was conducted to review the performance and failures of WTGs in different parts of the world. Ammara et al. [1] had found that the inefficient spacing between the turbines reduced the performance associated with the wake effect. Bhatt et al. [2]studied prediction and enhancement of the performance of windfarm in India and found that there was scope for improving the grid and WTG availability. Koji Hisada et al. [3] performed reliability tests for Weibull distribution based on complete data [10]. Lai C.D. et al. [4] developed a modified Weibull distribution to estimate model parameters and model identification. Skiha et al. [5] suggested the steps to be adopted by the government agencies in order to ensure the desired growth of the wind industry in the country and opined that a right choice of WTG with an optimum rated wind speed would improve the wind farm performance. The contribution of this paper would be useful for wind energy production to enhance the power generation by reducing failures.

2 PERFORMANCE ANALYSIS

The performance status like technical availability, real availability and capacity factor was calculated from the following methodology. Technical Availability (TA) is the fraction of time the WTG is available for power generation considering down time due to technical failure alone.

$$TA = \frac{Total\ mission\ time - Down\ time\ due\ to\ (grid\ failure + machine\ failures)}{Total\ mission\ Time} \quad (1)$$

Real availability (RA) is a fraction of actual working time of Wind Turbine Generator.

$$RA = \frac{Total\ mission\ time - Down\ time\ due\ to\ (grid\ failure + machine\ failures + low\ wind)}{Total\ mission\ Time} \quad (2)$$

Capacity factor(CF) is the ratio of actual energy generated over a period of time to the energy produced if the WTG runs at its rated power over that period.

$$CF = \frac{Energy\ Generated\ per\ year\ (kWh)}{Turbine\ rated\ power \times number\ of\ turbines \times number\ of\ hours\ per\ year} \quad (3)$$

The year-wise power generation of the windfarm for the period 2000-2004 is shown in Fig. 1. It is found that there was a wide variation of generation over the years. The generation was maximum (15132716 kWh) in the year 2000 due to favourable wind speed. The annual average generation was 14002165 kWh. The generation was minimum (12756244 kWh) in the year 2001 due to low wind and grid failures. The major causes of grid failure are grid drop, frequency fault, asymmetric current, over voltage and low voltage. In this wind farm more than 350 grid outages were happened per year. The performance of wind turbine also depends on the angle of attack, blade surface smoothness, wind direction change and wake effects. The comparison of capacity factor, real and technical availability of the windfarm is shown in Fig. 2. In this case the technical availability was steady and it was more than 97%. It was maximum (99.02%) in the year 2001 and minimum (97.63%) in the year 2004. The capacity factor was found to vary from 24.71% to 28.81%. The unfavorable grid failure, turbine unavailability and wind characteristics are the causes of reduction in capacity factor. The average technical availability, real availability and capacity factor for the windfarm were 98.26%, 83.06% and 26.61% respectively. By improving the grid and turbine availability there is a scope for improvement in capacity factor.

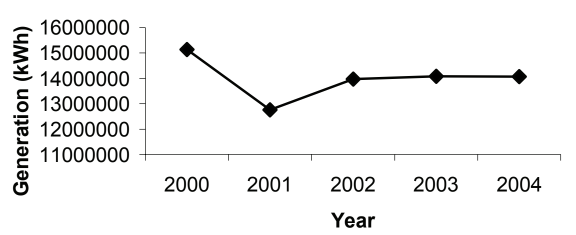

Fig. 1. Power Generation of Wind Farm

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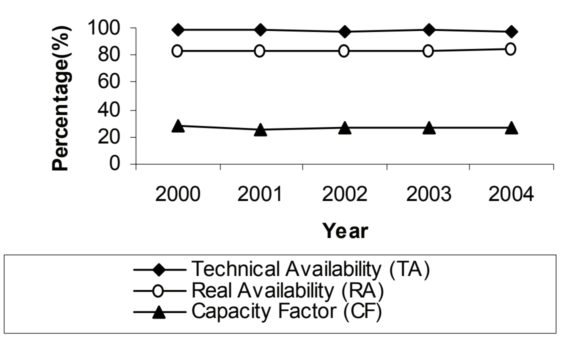

Fig. 2. Comparision of TA, RA and CF

Figure 2: Comparision of TA, RA and CF

3 RELIABILITY ANALYSIS

In this analysis the reliability parameters such as cumulative density function, reliability, mean time to failure, probability density function, median and mode, warranty time were calculated using following methodologies. The two-parameter Weibull cumulative density function is

$$F(T) = 1 - e^{-\left(T/\eta\right)^{\beta}} \qquad (4)$$

Where, F (T) - probability of failure, T - Time,
β - shape parameter, η – scale parameter

Reliability is defined as the probability that an item or an entity performs its intended function over a period of time under stated conditions. The reliability function for the two-parameter Weibull distribution is given as

$$R(T) = e^{-\left(T/\eta\right)^{\beta}} \qquad (5)$$

The mean life or mean time to failure (MTTF or MTBF) is defined as the average time of failure free operation up to a failure event calculated from a homogeneous lot of equipments under operation. The MTTF or MTBF of the Weibull pdf is given as

$$\bar{T} = \eta\, \Gamma\left(\frac{1}{\beta} + 1\right) \qquad (6)$$

where $\Gamma\left(\frac{1}{\beta} + 1\right)$ is called gamma function

The two-parameter Weibull probability density function $f(t)$ is given as

$$f(t) = \frac{\beta}{\eta}\left(T/\eta\right)^{\beta - 1} e^{-\left(T/\eta\right)^{\beta}} \qquad (7)$$

Median is defined as the failure density function equivalent to 50 % probability. Mode is defined as maximum failure intensity of the probability density function. For Weibull the median and mode are given as

$$\text{Median} = \eta + (\ln 2)^{1/\beta} \qquad (8)$$

$$\text{Mode} = \eta\left(1 - \frac{1}{\beta}\right)^{1/\beta} \qquad (9)$$

Warranty time is defined as the estimated time when the reliability will be equal to a specified goal. The reliable life T(R) of a unit for a specified reliability is given by

$$T(R) = \eta\ \{-\ln\ [R\ (T_R)]\}^{1/\beta} \qquad (10)$$

This is the life time for which the unit will function successfully with a reliability of R (T_R). B (X) life is defined as the estimated time when the probability of failure will reach a specified percentage point (X %).

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B(10) life is equivalent to a warranty time for 90% reliability, i.e., 10% of the products are expected to fail within a specified time.

The Weibull properties for this wind farm were obtained and are shown in Fig. 3, 4, 5, and 6. The initial failure rate was 0.000032 and it was reduced to 0.000054 after the end of fifth year (43800 hrs.).

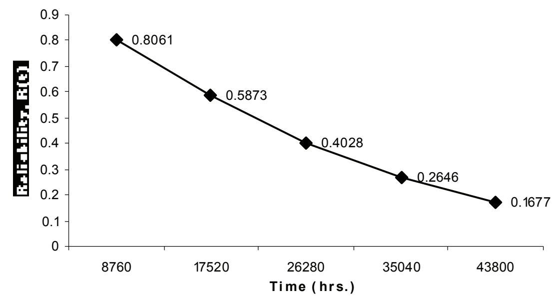

Fig. 3 Reliability of Wind Farm

Figure 3: Reliability of Wind Farm

The observed reliability factor was 0.8061 after one year (8760 hrs.) while the reliability factor was 0.1677 after five years (43800 hrs.). The reliability factor in the initial period after one year seems to be good as the wind farm has lower failure rate of 0.000032.

But the reliability factor becomes very low after five years because of severe occurrence of electrical and electronic component failure followed by hydraulic unit and gearbox failures. By rectifying the above failures the reliability could be improved. The mean, median and mode were 26002, 21398 and 9670 hrs. respectively. The required warranty time for reliability factor of 0.7, 0.8 and 0.9 would be 12939, 9071 and 5139 hrs. respectively. The warranty time is less than one year (5139 hrs.) for the reliability factor of 0.9. The B(X) life information gives time in hours for different percentages of failure. In this wind-farm 10% of failures occur at 5139 hrs.

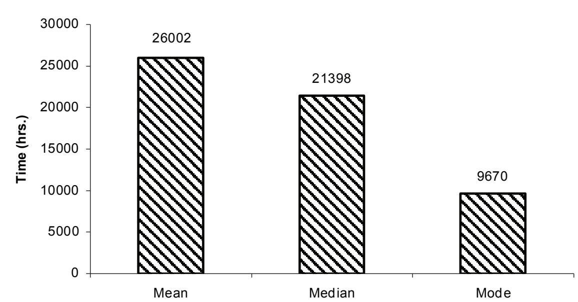

Fig. 4 Mean, Median and Mode for Wind Farm

Figure 4: Mean, Median and Mode for Wind Farm

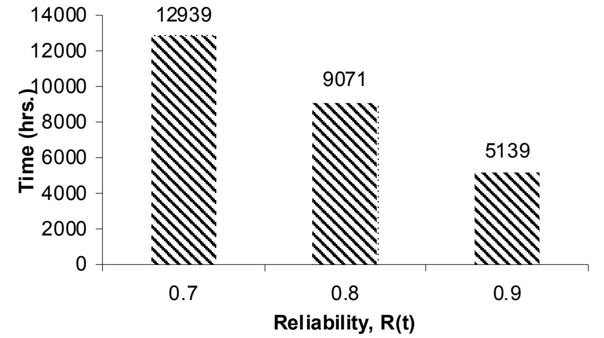

Fig.5 Required Warranty Time for Wind Farm

Figure 5: Required Warranty Time for Wind Farm

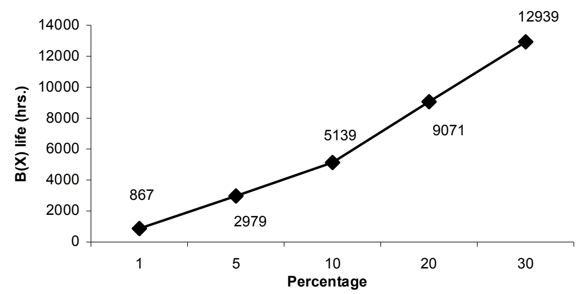

Fig. 6 B(X) Life Information for Wind Farm

Figure 6: B(X) Life Information for Wind Farm

4 FAILURE ANALYSIS

In this analysis various types of failures of wind turbine components were identified. The total frequency of failures appeared in the windfarm was 61**.** The failures were categorized as blade failure, gearbox failure, yaw unit failures and hydraulic unit failure. The blade bearing wear, blade rope failures and blade bent were the major causes of blade failures. There were 5 failures identified in gearbox unit and among this gearbox bearing was predominant failure. In the hydraulic unit a total of 6 sub-component failures were reported and among those hydraulic burst disc problem was the highest. Similarly in yaw unit, 6 sub-component failures were noted and yaw brake spring failure and bearing failure were higher than the other sub-component failures. The failure due to wear, vibration, high temperature and lack of lubrications were the important causes of gearbox failures in wind turbine generators. The year-wise failure for the windfarm is shown in Fig. 7.

The failures in the year 2004 were more than the other four years. There was an increase in failures during the years 2002, 2003 and 2004 over the years.

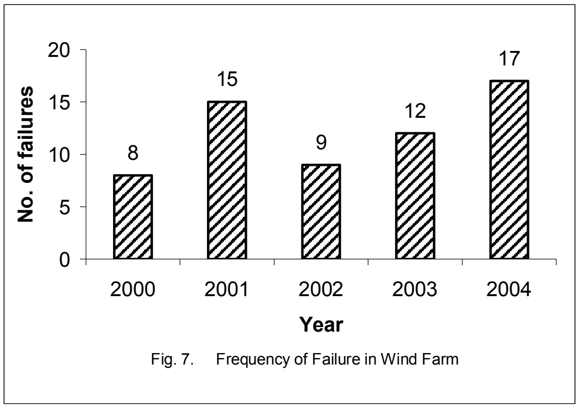

Figure 7: Frequency of Failure in Wind Farm

Less frequency of failure occurred in the year 2000 and more frequency of failures occurred during the year 2001 and 2004 due to hydraulic unit problem and electrical and electronic component failures. The percentage of distribution of failures of mechanical and electrical & electronic components was identified. The failures of mechanical components were 67% and failures due to electrical & electronic components were 33%. The failure of thyristor, power contactor coil failures and generator coil failures were the other reasons for the failure of wind turbine components. The yaw unit failure is more (75%) in the year 2000 followed by brake pad failure (25%).

The main reasons for yaw unit failures were due to poor quality of yaw gear and sudden dynamic load imposed because of rapid variation of wind direction, yaw motor and yaw gear failures. More percentage of failures occurred due to hydraulic unit (27%) and electrical & electronic component (27%) in the year 2001. More electrical &electronic failures (45%) happened in the year 2002 followed by yaw unit and hydraulic unit failures. The major causes of failures of hydraulic unit failures were due to failures of diaphragm in the accumulator and hydraulic hose failure. The maximum percentage of failures due to electrical & electronic component failures (50%) happened during the year 2003 followed by gearbox failure (17%) and hydraulic unit failures (17%) and during 2004 electrical & electronic component failure (40%) was more and hydraulic unit failure (18%). By implementing effective maintenance strategies the failures can be reduced considerably.

5 CONCLUSION

The status of a wind farm in India was analyzed. It is concluded that the performance parameters such as technical availability, real availability and capacity factor for this windfarm were 98.26 %, 83.06 % and 26.61% respectively. The percentage of average stoppage time due to grid failure, low wind, electrical component failure, mechanical component failure and preventive maintenance were 13 %, 79 %, 2 %, 5 % and 1 % respectively. The reliability analysis reveals that the reliability of wind farm was high during the first year of operation and with time it degrades drastically beyond economical viability and is reduced to 17% at the end of fifth year of operation. If more attention is given to the trouble shooting of WTG components the overall reliability can be further improved. Failure analysis reveals that mechanical component failures were more when compared to electrical & electronic components failures of wind turbine generators.

It was critically observed that some of the components like gearbox bearing, burst disk, spring in hydraulic unit, bearing in yaw unit, brake pad, and anemometer and blade rope have frequently failed. As the cost of these components is not very high they must be replaced at regular intervals during preventive maintenance period.

The various types and causes of failure of wind turbine were also dealt in details. The performance of wind turbine can be improved by optimum design, reduced down time, the best maintenance and service. The timely maintenance action and the best quality and the reliable components can reduce the break down time. The new research techniques on wind turbine technologies will have a bright future in India.

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