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Proposed Expansion of Kanjikode Wind Farm; A Techno Economic Analysis

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ABSTRACT
Growing energy demand and environmental consciousness have re-evoked human interest in wind energy. A precise knowledge of wind regime characteristics is a pre-requisite for the efficient planning and implementation of any wind energy project. In the present study, a method for characterizing wind regimes, bringing out their energy potential, is discussed. A weibull distribution was adopted for defining the distribution of wind velocity in terms of its probability density and cumulative distribution functions. Wind energy potential of a site can be characterized in terms of the energy density; energy available in the wind spectra in a time period and the energy received by turbine have been developed. Wind data from Kanjikode site falling under wind class-3 in palakkad district in Kerala, India are analyzed using the WERA software. The performance expected from eight commercial Wind turbines by leading manufactures differing in their working velocity band in terms of cut-in and cut-out wind speeds, best suited for this site is identified, modeled and compared.

Keywords *- wind turbine; wind energy potential; wind turbine performance; weibull shape factor; weibull scale factor; Cut-in velocity; Cut-out velocity; Capacity factor*

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I. INTRODUCTION

With the present day's energy crisis and growing environmental consciousness, the global perspective in energy conversion and consumption is shifting towards sustainable resources and technologies. This resulted in an appreciable increase in the renewable energy installations in different part of the world. For example, Wind power could register an annual growth rate over 25% for the past 7 years, making it the fastest growing energy source in the world. The global wind power capacity has crossed well above 160 GW today and several Multi-Megawatt projects-both on shore and offshore-are in the pipeline. Hence, wind energy is going to be the major player in realizing our dream of meeting at least 20% of the global energy demand by new-renewable by 2020.

Assessing the wind energy potential at a proposed site and understanding how a wind turbine would respond to the resource fluctuations are the initial steps in the planning and development of a wind farm project. Energy yield from the Wind Energy Conversion System (WECS) at a given site depends on (1) strength and distribution of wind spectra available at the site (2) performance characteristics of the wind turbine to be installed at the site and more importantly (3) the interaction between the wind spectra and the turbine under fluctuating conditions of the wind regime.

Thus, models which integrate the wind resource as well as the turbine performance parameters are to be used in estimating the system performance. Based on the above parameters, methods for assessing the available wind energy resource at a proposed site and the performance expected from a wind turbine installed at this proposed site is presented in this paper. Both the Capacity Factor and annual energy output normalized to the rotor swept area are considered for assessing the performance.

II. LITERATURE REVIEW

Kerala State Electricity Board (KSEB) has approached National Institute of Wind Energy (Formerly centre for Wind Energy Technology), Chennai for preparing report for Repowering/Intercropping of their existing wind farm located at Kanjikode site in Palakkad district in Kerala. NIWE has studied the data and carried out detailed Repowering/Intercropping analysis after a site visit on 14.09.2015 & 06.10.2015. The Kanjikode site is having very good wind potential based on the 80m mast. However, generation from the existing turbines seems under-performing. Based on the visit, it is understood that the existing turbines are located amidst industrial buildings and so facing severe obstructions. Due to this reason and because of the hub heights, generation from these turbines seems to be lesser than possible. By considering the wind potential, the site can be said to be "under-utilized". Hence, it is advisable to install higher hub height, advanced technology wind turbines for the effective utilization of the site.

"Repowering concept" the process of replacing old turbines with modern wind turbines is called repowering. It includes all measures which improve the efficiency and capacity by means of retrofit to the latest technology. Possible modifications on wind turbines are limited, thus repowering affects the whole plant in general and essentially the entire wind farm. In short, aim of the repowering is to use the existing renewable energy resources on site more efficiently, respectively in a technically adapted or improved manner.

"Intercropping concept", means instead of removing all existing WTGs, removing the few machines and deploy the new higher rating WTG in the same boundary area in such way that the generation from the wind farm will not be affected much (due to adjacent wake).

Based on Repowering and intercropping study multy megawatt machines can be installed within the existing wind farm subject to the shifting of the existing 220kV transmission line.

Similarly, a single machine can be installed at the proposed new location nearby the 1MW solar plant at Kanjikode. The installable capacity in the range of 1.8 to 2.625 MW and Capacity utilization factor ranging from 19.9% to 34.1%.

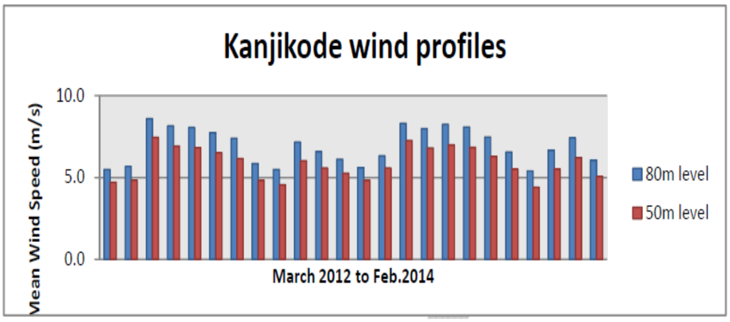

Fig.1 Kanjikode wind profiles at different hub heights

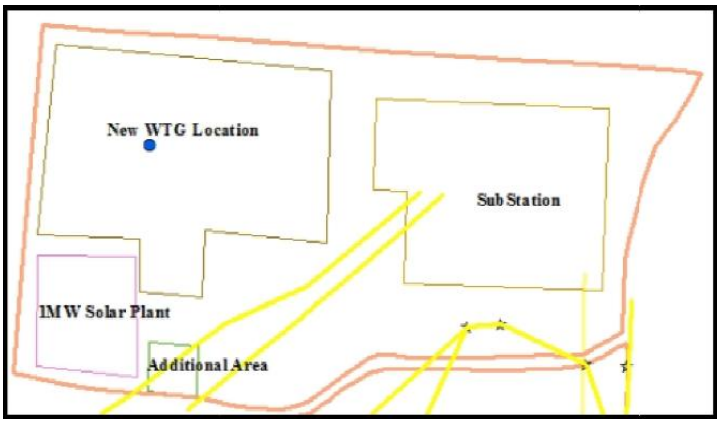

Fig.2 New wind turbine generator layout

III. WIND REGIME CHARACTERISTIS

In this section we will discuss how the characteristics of the wind regimes can be incorporated in assessing the wind energy potential as well as estimating the output from a wind energy conversion system.

A. Boundary Layer Effects

The first factor to be considered while estimating the wind resource and wind turbine performance at a given site is the variations in wind velocity due to the boundary layer effect. Due to the frictional resistance offered by the earth surface (caused by roughness of the ground, vegetations etc.) to the wind flow, the wind velocity may vary significantly with the height above the ground. For example, wind profile at a site is shown in Fig. 1. Variations

in the wind velocity with height are quite evident in the figure. Thus, if the wind data available are not collected from the hub height of the turbine, the data are to be corrected for the boundary layer effect.
Ground resistance against the wind flow is represented by the roughness class or the roughness height (Z0). The roughness height of a surface may be close to zero (surface of the sea) or even as high as 2 (town centers).
Some typical values for the roughness heights are 0.005 for flat and smooth terrains, 0.025–0.1 for open grass lands, 0.2–0.3 for row crops, 0.5–1 for orchards and shrubs and 1–2 for forests, town centers etc. On the basis of the roughness height of the terrain, wind data collected at different heights are to be extrapolated to the hub height of the turbine. If the wind data are available at a height Z and the roughness height is Z0, then the velocity at a height ZR is given by

$$V(Z_R) = V(Z)\ \frac{\ln\left(\frac{zr}{z0}\right)}{\ln\left(\frac{z}{z0}\right)} \tag{1}$$

Where $V(Z_R)$ and V(Z) are the velocities at height s ZR and Z respectively. Thus, if the velocity of wind measured at a height of 10 m is 7 m/s and the roughness height is 0.1, the velocity at the hub height—say 100 m—is 10.5 m/s. It should be noted that the power available at 100 m would be 3.4 times higher than at 10 m.
In some cases, we may have data from a reference location (meteorological station for exa mple) at a certain height. This data is to be transformed to a different height at another location with similar wind profile but different roughness height (for example, the wind turbine site). Under such situations, it is logical to assume that the wind velocity is not significantly affected by the surface characteristics beyond a certain height. This height may be taken as 60 m from the ground level . With this assumption and equating the velocities at 60 m height at both the sites as per Eq. 1, we get

$$V(z) = V(Z_R)\ \left(\frac{\ln\left(\frac{60}{z0R}\right)\ln\left(\frac{z}{z0}\right)}{\ln\left(\frac{60}{z0}\right)\ln\left(\frac{ZR}{Z0R}\right)}\right) \tag{2}$$

where Z_{OR} is the roughness height at the reference location.

B. Wind Velocity Distribution

Being a stochastic phenomena, speed and direction of wind varies widely with time. Apart from the seasonal variations, the differences can be considerable even within a short span of time. These variations can significantly affect the energy yield from the turbine at a given site. For example, a turbine may deliver entirely different amount of energy when it is installed in two sites with the same average
wind velocity but different velocity distributions. Similarly, two wind turbines with the same output rating but different in the cut-in, rated and cut-out velocities may behave differently at the same site. Statistical distributions are used to take care of these variations in wind energy calculations.
Several attempts were made to identify the statistical distribution most suitable for defining the characteristics of wind regime. A wide range of distributions are Analysis of Wind Regimes and Performance of Wind Turbines 73 being tried by the researchers. The Weibull distribution, which is a special case of Pierson class III distribution, is well accepted and commonly used for the wind energy analysis as it can represent the wind variations with an acceptable level of accuracy . In some situations, Rayleigh distribution—which is a simplified form of Weibull distribution—is also being used. However, a recent study comparing various statistical distributions in wind energy analysis has established the acceptability of Weibull distribution . Hence we will follow the Weibull distribution in our analysis.
The Weibull distribution can be defined by its probability density function f(V) and cumulative distribution function F(V) where:

$$f(V) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e(^{v}/c)^{\wedge}k \tag{3}$$

$$F(V) = \int f(v)\,dV = 1 - E^{(-V/C)^{\wedge}K} \tag{4}$$

where k is the Weibull shape factor, c the scale factor and V is the velocity of interest. Here, f(V) represents the fraction of time (or probability) for which the wind blows with a velocity V and F(V) indicates the fraction of time (or probability) that the wind velocity is equal or lower than V. From Eqs. 3 and 4, it is evident that k and c are the factors determining the nature of the wind spectra within a given regime.
There are several methods for determining k and c from the site wind data. Some of the common methods are the graphical method, moment method, maximum likelihood method, energy pattern factor method and the standard deviation method [2]. For example, in the standard deviation approach, the relationship between the mean (Vm) and standard deviation (rV) of the wind velocities and k are correlated as

$$\left(\frac{\sigma v}{Vm}\right)^2 = \frac{\sqrt{}(1+\frac{2}{k})}{\sqrt{}^{2}(1+\frac{1}{k})} - 1 \qquad (5)$$

Once Vm and rV are calculated for a given data set, then k can be determined by solving the above expression numerically. Once k is determined, c is given by

$$c = \frac{Vm}{\sqrt{}(1+\frac{1}{k})} \qquad (6)$$

In a simpler approach, an acceptable approximation for k can be made as

$$k = \left(\frac{\sigma v}{Vm}\right)^{-1.090} \qquad (7)$$

C. Energy Density

The power available in a wind stream of velocity V, per unit rotor area, is given by

$$Pv = \frac{1}{2}\rho_a V^3 \qquad (8)$$

Where PV is the power and qa is the density of air. The fraction of time for which this velocity V prevails in the regime is given by the probability density function f(V). Thus, the energy contributed by V, per unit time and unit rotor area, is PV f(V). Hence, the total energy contributed by all possible velocities in the wind regime, available for unit rotor area in unit time (that is energy density, ED) may be expressed as

$$E_D = \frac{2}{3}\rho_a \frac{c^3}{k}\sqrt{}\left(\frac{3}{k}\right) \qquad (9)$$

D. Velocity–Power Response of the Turbine

Power curve of a 2 MW pitch controlled wind turbine is shown in Fig. 3. The turbine has cut-in, rated and cut-out velocities 3.5, 13.5 and 25 m/s respectively. The given curve is a theoretical one and in practice we may observe the velocity power variation in a rather scattered pattern.

In this curve, we can observe that the turbine has four distinct performance regions.

1. For velocities from 0 to the cut-in (VI), the turbine does not yield any power.
2. Between the cut-in and rated velocities (VI to VR), the power increases with the wind velocity. Though, theoretically, this increase should be cubic in nature, in practice it can be linear, quadratic, cubic and even higher powers and its combinations, depending upon the design of the turbine.
3. From the rated to cut-out wind speed (VR to VO), the power is constant at the rated power PR, irrespective of the change in wind velocity.
4. Beyond the cut-out velocity, the turbine is shut down due to safety reasons.

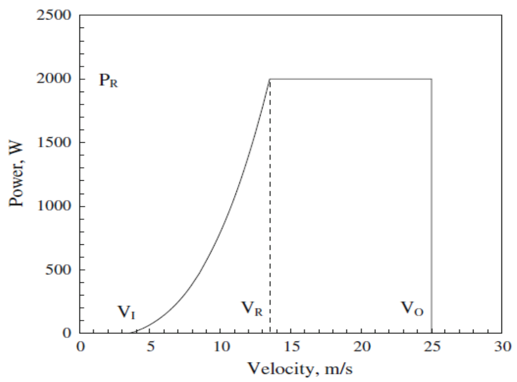

Fig.3 Theoretical Power curve of a 2MW wind turbine

E. Energy estimation of wind regimes

Assessing the energy available in the wind regime prevailing at a site is one of the preliminary steps in the planning of a wind energy project. Wind energy density and the energy available in the regime over a period are usually taken as the yardsticks for evaluating the energy potential. The wind energy density (E_D) is the energy available in the regime for a unit rotor area and time. Thus, E_D is a function of the velocity and distribution of wind in the regime. We can arrive at the total energy available in the spectra (ES), by multiplying the wind energy density by the time factor.

Other factors of interest are the most frequent wind velocity (V_{Fmax}) and the velocity contributing the maximum energy (V_{Emax}) to the regime. Peak of the probability density curve represents VF max. Due to the cubic velocity-power relationship of wind, the velocity contributing the maximum energy is usually higher than the most frequent wind velocity. A WECS operates at its maximum efficiency at its design wind velocity, V_d. Hence, it is advantageous that V_d and $V_{E\ max}$ are made as close as possible. Once the velocity responsible for maximum energy could be identified for a particular site, the designer can design his system to be most efficient at this velocity or more practically, a planner can select a machine having design wind speed very close to V_{Emax} , if he is not constrained by other factors. In the following sections we will discuss the methods to estimate the energy potential of a wind regime based on the above indices, considering both the Weibull and Rayleigh models.

IV.METHODOLOGY

A.Wind regime

Inorder to demonstrate the performance of the of the site is shown in the table.1.One year of wind data from the site was collected and analysed.As the available wind data from this location was from 50m mast height, it had to be transformed to 80m and 100m equalent, to represent the standard hub height of a modern wind turbine
After transforming the velocities to 100m, the wind spectra at this site were modeled using weibull distribution,which is characterised by the Probability Density Functions f(V) and the Cumulative Distribution Function F(V) . From the wind data, k and c were calculated following the standard deviation method.

	Latitude (°N)	Longitude (°E)	Altitude >MSL (m)	Annual average wind speed at 80m	Standard deviation	Wind class	Weibull parameters at 80m		Weibull parameters at 100m	
							k	c	k	c
Kanjikode	10.47	76.49	130	6.99	2.50	3	3.06	7.89	3	7.7

Table.1 Details of the site

A.Wind Turbines

Eight wind turbines from different commercial manufactures were considered for the study. For uniformity in the comparison, turbines with rated capacity around2MW were chosen. To avoid the use of trade names, these turbines are represented by T1,T2,…T8. The technical specifications of these turbines, which are relevant to the present analysis, are show in table 2.

SL NO	Name of WTG	Rotor diameter(m)	Hub height(m)	Capacity (KW)	Cut-in velocity	Rated velocity	Cut-out velocity
1	GAMESA,G-80	80	78/80	2000	4	13	25
2	LEITWIND,LTW-70	70.1	60	2000	3	13	25
3	SUZLON-88	88	79	2100	4	12.5	25
4	VESTAS,V-80	80	80/100	2000	4.5	13	34
5	ENERCON,E-82	82	98/108	2000	2	13	34
6	GAMESA,G-97	97	90/115	2000	3	12.5	25
7	VESTAS-100	100	80/90/125	2000	3	11.5	20
8	WINDTECH-93	93	70/80/100	2000	3.5	11	20

Table.2 List of turbine suggested

B.Performance Of turbines at the site

The typical power curve of a pitch controlled wind turbine, as considered in this study.The capacity factor C_F, which is the ratio of energy actually produced by the turbine to the energy that could have been produced by it if the machine would have operated at its rated power through out the time period can be calculated as:

$$C_F = \frac{E}{P_R T} \quad (9)$$

The Capacity factor compares the energy output of the turbines with its rated output. The rated output solely depends on the generator size. Hence, for the present study, in which turbines with different rotor sizescoupled to generators of almost same size are compared.

V. RESULTS AND DISCUSSION

The wind energy potential of the proposed site is simulated. The wind energy density, annual energy availability, most frequent wind velocity and the velocity corresponding to the maximum energy of proposed site is calculated. Results are shown in the table.3. The energy output expected from the 8 turbines at the proposed site

was simulated. Results are shown in fig. 4-5.In general, the turbine designed for low wind speed conditions showed better capacity factor under the simulation. For example, the estimated C_F for the turbine t8 is0.32 this is followed by the performance of T6 and T5. T3 is also performed well under reduced rotor diameter.
The higher C_F shown by these low wind speed turbines at the site can mainly be attributed to their bigger rotor sizes, which are not proportionate to the rated power of the generators they are coupled with. For example compared to T3, T8 and T7 has a rotor which is larger in area where as generator ratings are approximately same.
The higher C_F implies better assurance in getting expected energy output from the system,Which is obviously an advantyage. However enlarging thesize of the rotor ,non propotional to generator rating, may lead to some side effects.For example the blades contribute approximately 20 percent of the total costof wind turbineand hence ,with the increased blade size ,the system cost will also scaled up.
Comparing the normalized energy for the 8 turbinesis found to be hieghest for T8.This turbinewas found to produce 5664.40Kwh.This indicate that ,T8 would perform well under low wind ciondition as wel,.followedby T6 and T7.The major reason for the impressive performance of this turbine is its low cut in velocity and larger rotorsize.and betterpower response fromcut-into rated velocities.Turbine T3 also showed good performance at the site under reduced rotor size.

k	**c**	**E_D** (KW/m^2)	**E_I** (KWh/m^2)	**V_{FMAX}** (m/s)	**V_{Emax}** (m/s)
3.06	7.89	0.30	2624.30	6.93	9.30

Table.3 Wind energy potential based on weibull analysis

Turbines	**Energy (MWh/yr)**	**C_F**
T_1	3469.009	0.2
T_2	3683.38	0.21
T_3	4081.62	0.22
T_4	3319.86	0.19
T_5	3798.49	0.22
T_6	4120.74	0.24
T_7	5173.45	0.30
T_8	5664.40	0.32

Table.4 Performance of wind turbines at the site

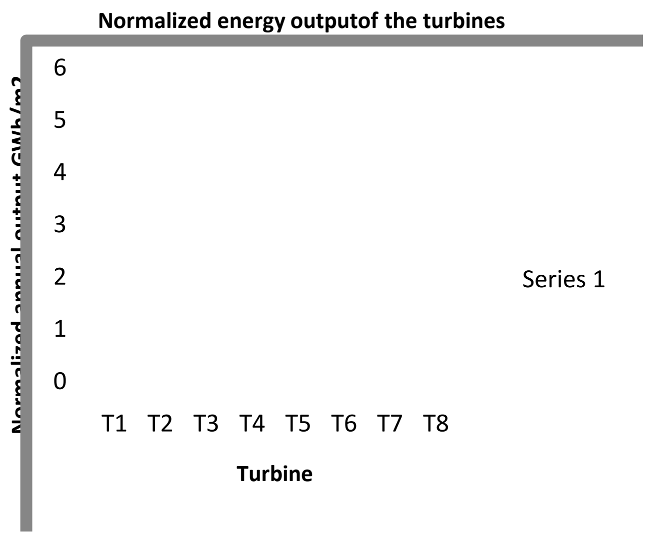

Fig.4 Comparitive performance of wind turbine

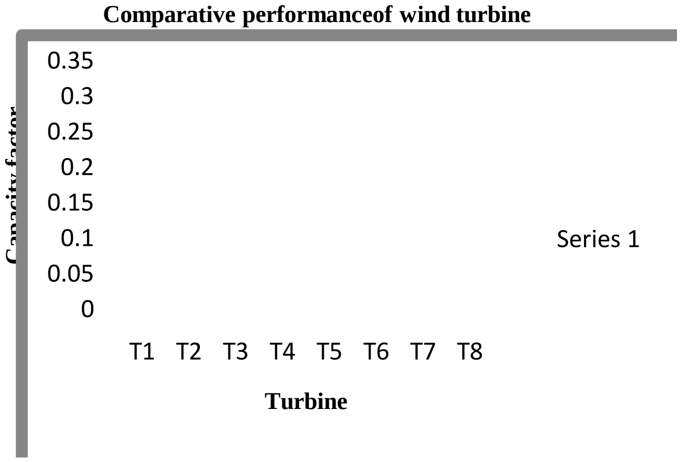

Fig.5 Comparative performance of wind turbines

IV. CONCLUSION

The performance of 8 commercial wind turbines was simulated and compared in this study. Turbine T8 is found to be performing well. The turbine with highest CF is the best suited one for the location. This is purely on the technical basis. Capacity factor and Normalized energy were taken as the performance indices. It should be noted that, as the cost of rotor accounts for a significant portion of the total turbine cost ,the low wind speed system with bigger rotor would obviously cost higher, per unit rated size. On the other hand, annual energy output from the system per unit area of rotor found larger. If we have to consider costs,a more elaborate analysis based on levelized cost of energy would be required for such decision making.

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