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Reliability Evaluation of Wind Power Plant Using Matlab

Apoorva Kulakarni
PG Scholar, Department of Studies, EEE, University BDT College of Engineering, Davanagere, Karnataka, India
Sharada Prasad C. R.
Associate Professor, Department of Studies, EEE, University BDT College of Engineering, Karnataka, India

Abstract:
Wind is a clean source of electricity as it doesn't produce harm to environment. But the output obtained from wind resource is uncertain. Power output from the wind electric conversion system is variable. Hence the main objective of this project is to develop a method to evaluate the reliability of output power obtained from wind electric conversion system The approach used here involves the simplified reliability model for the wind energy conversion system.
In this methodology, four factors are calculated which are wind availability factor, constant power output factor, variable power output factor, factors for mechanical failure. In order to calculate these factors turbine design parameters such as shape factor (β), which is dependent on the height of the tower and station, Scale factor (α), which is nearer to the average wind speed are considered. These parameters are determined using weibull distribution. For the reliability evaluation, plants considered in this project are Jajikalgudda, Kappatagudda, Seegegudda, and Chitradurga The procedure centers on the determination of Forced outage rate. Sensitivity graphs for the several key parameters are plotted in MATLAB.

1. Introduction

Electrical power systems are very complex networks. This is because of its size, wind coverage area; power systems have national and international interconnections. Power flow in the network will not follow the rules framed by manufactures; rather it flows according to the physical laws. The most significant difficulty is electrical energy can't be stored efficiently and effectively in large quantities. Basic objective of the power system is to supply power to the small and large customers economically with a acceptable degree of reliability and quality [2].

In a modern society because of increasing number of working hours and high standard of life style, power supplied should meet the demand. This may not be possible all the times because of some random failures occurring in a system. But the probability of customers being not supplied can be reduced by increasing the investment either during the planning phase or operating phase or both Hence the reliability can be defined as, the ability of an item to perform its required function under given conditions for a given time interval. Hence there will be conflict between reliability and economy of a system. This will lead to the difficulties during the decision making stages. Power system reliability assessment both deterministic and probabilistic, is divided into two categories that is system security and system adequacy. System security does not include the system disturbances; it only includes the static conditions of the system. System security relates to the response for the disturbances arising within the system [2].

The reliability study is useful in the area of optimization of maintenance and operations and risk analysis. Risk analysis involves the identification of causes, effects of the failure.

2. Reliability of Wind Power

"Reliability is a design engineering discipline which applies scientific knowledge to assure a product will perform its intended function for the required duration within a given environment."

Poor reliability of WECS units result in an increase of operating and maintenance cost, reduction in the system availability. The well known measure for the evaluation of reliability of electric supply is by calculating loss of load probability. As the penetration of electrical power generated by the wind increases into a conventional system, Loss of Load Probability increases [6]. This is because of the fact that power generated from the wind energy conversion system is not as high as compared to conventional unit. There are various factors which reduces the power generated from the wind energy conversion system.

2.1. Forced Outage Rate

Forced outage rate is one of the most important parameters in the estimation of component reliability. Components experience forced outage if emergency conditions related to a component force it out of service (4). The long-term probability of finding the component in the down state is called its 'forced outage rate' (FOR).

2.1.1. FOR of Conventional Generating Units

FOR of a generating unit is often termed as the 'unavailability' of that unit. By definition, it is the probability of finding the unit down on forced outage while operating under specified conditions at some distant time in the future(6). In the case of conventional generating units, emergency conditions may arise due to the stochastic nature of weather conditions, system behavior, customer demand or component failures.

If 'λ' and 'μ' are the constant failure and repair rates of a generating unit respectively, then from reliability studies its forced outage rate is given by,

$$FOR=\frac{\lambda}{\lambda+\beta}=\frac{\sum down\ time}{\sum up\ time+\sum down\ time}\ldots\ldots.1$$

2.2. WECS Output Characteristics-Factors Affecting Availability of Electric Output

Figure 1 shows a typical curve for power output from a WECS. Wind-electric system starts generating electric power at a wind speed known as 'cut-in speed' (V_{ci}). It produces rated power (P_r) output above 'rated wind speed' (V_r) as shown in Figure 4. Wind turbine continues to produce the rated output till the wind speed reaches the 'cut-out' value (V_{co}).Beyond V_{co}, the turbine is completely shut down to avoid any damage to its components(6).

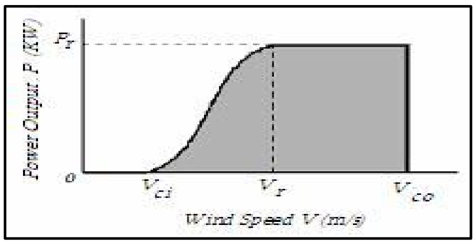

Figure 1: Power Output Curve

The major factors affecting the availability of WECS and in turn the availability of its power output are listed below:

i. Electric power is available from a WECS only for wind speeds between V_{ci} and V_{co}.
ii. Only wind speeds only in the range from V_r to V_{co} generate rated electric power.
iii. Non-linearity of the power curve from V_{ci} to V_r results in a variable power output less than the rated output.
iv. Severe weather conditions exert excessive electrical and mechanical stresses on the system components leading to mechanical failures. In addition, normal wear and tear and fatigue will cause some components to fail. Serious mechanical failures result in turbine shutdown and consequently the unavailability of power output until repair is completed.
v. Wind turbine is disconnected from the grid beyond V_{co} in order to avoid excessive electrical and mechanical stresses on system components.

2.3. Approximation of WECS Power Output Curve

Figure 20shows the approximated power output curve of a wind-electric system. The non-linear part of the curve between V_{ci} and V_r is approximated by a straight line. Thus, the equation for power output becomes

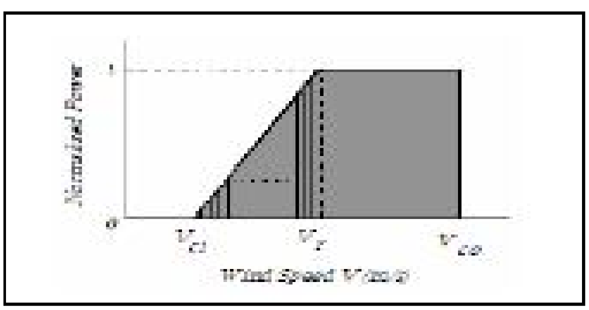

Figure 2: Power Approximation Curve

$$P = \begin{cases} P_r * \frac{V-Vci}{Vr-Vci} & \text{for } Vci \le V \le Vr \\ P_r & \text{for } Vr \le V \le Vr \\ 0 & elsewhere \end{cases} \quad ....2$$

Using Pr as the base value, equation can be normalized as

$$P = \begin{cases} P_r * \frac{V-Vci}{Vr-Vci} & \text{for } Vci \le V \le Vr \\ 1 & \text{for } Vr \le V \le Vr \\ 0 & elsewhere \end{cases} \quad ....3$$

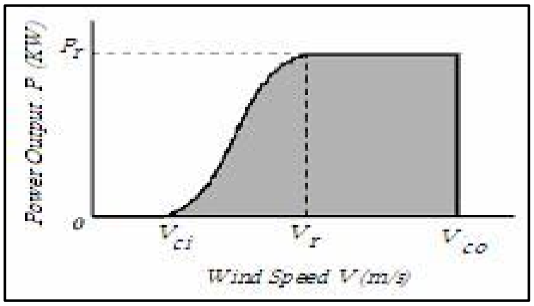

Figure 3: Expected Power Output Calculation for Variable Portion

2.4. Overall Forced Outage Rate of WECS Output

All the factors that affect the availability of wind-electric systems must be quantified to include their effects on the FOR value for WECS.

(1) *Wind Availability Factor* (*PWA*): It is defined as the probability that wind speed is between cut-in and cut-out values.

Wind availability factor=P(Vci ≤ V ≤ Vco) = PWA

P_{WA}= $\exp\left[-\left(\frac{Vci}{\alpha}\right)^{\beta}\right]$-$\exp\left[-\left(\frac{Vco}{\alpha}\right)^{\beta}\right]$……4

(2) *Constant Power Output Factor* (P_{Const}): Since rated power output results for wind speeds between V_r and V_{co}, the expected normalized power output in this speed range will be the probability of the wind speed lying in this speed range. Hence,

P_{cons}= $\exp\left[-\left(\frac{Vci}{\alpha}\right)^{\beta}\right]$-$\exp\left[-\left(\frac{Vco}{\alpha}\right)^{\beta}\right]$……5

(3) *Variable Power Output Factor* (P_{Var}): Expected value of normalized power output over the speed range from V_{ci} to V_r can be calculated as follows The region from V_{ci} to V_r is divided into n small intervals as shown in Figure 3.Probability that the wind speed is between any two values, say V_1 and V_2 (Figure 2), will Be

a_1=P=($V_1 < V < V_2$)

P_{Var}=$\exp\left[-\left(\frac{Vci}{\alpha}\right)^{\beta}\right]$ -$\exp\left[-\left(\frac{Vco}{\alpha}\right)^{\beta}\right]$….6

Then, the expected normalized power output over the speed range from V_1 to V_2 will be,

$$E(P_{1,2}) = a_1 * \frac{\left(\frac{V_1+V_2}{2}\right) - V_{ci}}{V_r - V_{ci}} \quad …………7$$

P_{WA}= $\exp\left[-\left(\frac{Vci}{\alpha}\right)^{\beta}\right]$-$\exp\left[-\left(\frac{Vco}{\alpha}\right)^{\beta}\right]$……..8

Summation of the expected normalized power outputs calculated in this way for each small interval in the variable part will yield the expected normalized power output for the region from V_{ci} to V_r. Thus,

$P_{Var} = {}^{\Sigma E}(P_{1,2})$……………………………………..9

(4) Factor for mechanical failures (P_{Mech}): Forced outage rate for a mechanical component with a constant failure rate of ‘λ’ per hour and a mean repair time of ‘r’ hours
is given by,

Forced Outage Rate ≡λy ………………..10

Wind turbine consists of several mechanical components as shown in Figure 8 with different failure and repair rates. With a serious failure of any one component, the wind turbine goes out of service. Therefore, from reliability point of view of all the components can be seen to be logically in series as shown in Figure 9. Then, the FOR of mechanical system will be a summation of individual component FORs .

$FOR_{Mech} = \Sigma\lambda_i r_i$………………..…………………11
Hence,
$P_{Mech} = 1 - FOR_{Mech}$
Collecting all the factors discussed above, the reliability R for a WECS can be expressed as
$R = P_{WA} * E(P) * P_{Mech}$ ……………12
where

$E(P) = P_{var} + P_{const}$

4. Study Examples
In this chapter, the concepts of FOR and expected power output of WECS are applied to assess the influence of the penetration of wind power into a conventional generation system. Published failure data for wind power systems of suzlon global services limited, Harappanahalli, Jajikalgudda, chitradurga, Gadag, Hassan are used in the example studies.

4.1. FOR and Expected Power Output of WECS
For the study, three different wind regimes, labeled as low, moderate and high with their corresponding Weibull parameters as listed in Table 1 are chosen [9]. Values of cut-in, rated and cut-out wind speeds are chosen as 3.6 m/s, 8 m/s and 21 m/s respectively (1 mile/hr≈ 2.24 m/s). Table 2 lists failure data for various components taken from published literature [10].Table 3 lists the values of expected power output, wind availability factor, WECS reliability three different wind regime using the same component failure.

Wind speed	α (m/s)	β
Low	3.25	1.79
Moderate	8.6	2.00
High	13.22	3.10

Table 1: weibull distribution factors for harapanahalli site

Wind speed	α (m/s)	β
Low	3.16	1.76
Moderate	9.00	2.10
High	14.5	3.00

Table 2: weibull distribution factors for Chitradurga site

Wind speed	α (m/s)	β
Low	2.84	1.75
Moderate	9.7	1.8
High	15.55	2.89

Table 3: weibull distribution factors for Sigegudda site

Wind speed	α (m/s)	β
Low	2.84	1.75
Moderate	9.7	1.8
High	15.55	2.89

Table 4: weibull distribution factors for Kappatagudda site

Wind Speed	Low	Moderate	High
E(P)	0.1230	0.6581	0.9089
PWA	0.4204	0.8829	0.9750
FORMech	0.0017	0.0017	0.0017
R	0.0516	0.5801	0.8846
FOR_{Pow}	0.9484	0.4199	0.1154

Table 5: Simulated results for harapanahalli site

Wind Speed	Low	Moderate	High
E(P)	0.0579	0.5553	0.8351
PWA	0.3021	0.8695	0.9476
FORMech	0.000379	0.000379	0.000379
R	0.0175	0.4827	0.7911
FOR_{Pow}	0.9825	005173	0.2089

Table 6: Simulated results for Chitradurga site

Wind Speed	Low	Moderate	High
E(P)	0.0482	0.5892	0.8243
PWA	0.2724	0.8511	0.9107
FORMech	0.000216	0.000216	0.000216
R	0.0131	0.5013	0.7505
FOR_{Pow}	0.9869	0.4987	0.2495

Table 7: Simulated results for Sigegudda site

Wind Speed	Low	Moderate	High
E(P)	0.0419	0.5818	0.8217
PWA	0.2366	0.8374	0.9086
FORMech	0.000519	0.000519	0.000519
R	0.0099	0.4869	0.7462
FOR_{Pow}	0.9901	0.5131	0.2538

Table 8: Simulated results for Kappatagudda site

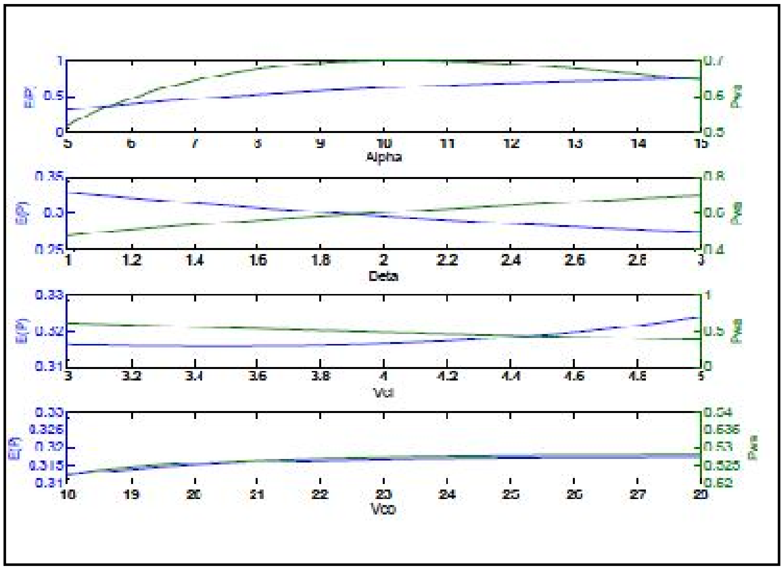

Figure 4: graphs for high speed for Harappanahalli Site

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