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Reliability Measures of constant pitch constant speed Wind Turbine with Markov Analysis at High Uncertain Wind

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Abstract

In order to increase the life of a wind turbine (WT), it is important to estimate the reliability level for all WT components. In this paper, the concept of Markov analysis (MA) is used to model the failure characteristics of the major components for calculating the probability, availability and reliability of various system states of WTs with a capacity of 225 kW, 250 kW and 400 kW located at Muppandal main pass having high uncertainty in wind flow. Due to the uncertain wind flow, the probability of component failure is independent of the past history. MA yields surprising results about the overall power generation will be reduced due to the failure of rotor is up to 10.32%, gear box is up to 3.25% and generator is up to 3 %.

Keywords:Wind turbine; Reliability; Markov Analysis: State Transistion diagram; Availability.

1. Introduction

The WT system has a complex and repairable components. The failure of any of these components causes insufficient generation of power. The reliability of the WTs is increased considerably, but the failure of the wind turbine depends on many factors such as wind speed, wind direction, location. The main purpose of determining the system availability and reliability is to identify the weakness of the system and quantify the failure rate of different components. This paper deals with the availability analysis for the major components of wind turbine, such as rotor, gear box, brake system, generator, hydraulic system, clock wise yaw motor and anti clock wise yaw motor at uncertain wind, occurs in the main pass and hill. The main objective of this paper is to identify the individual characteristics, time exhausted in logistics, time taken to detect failure and time taken to rush back in service for the failed components to increase the availability of the components which has frequent failures.

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The most common methods currently utilized in practice for quantifying the reliability of the wind turbine system with sub assemblies having failure rates are based on Weibull analysis. [1] They are easy to solve and accuracy, dependability and availability and safety of the component at different states cannot be predictable. In this paper, MA is accomplished by drawing the system state transition diagram for analyzing how undesired states are reached. The main objective of this paper is to carry out a MA on the constant speed and constant pitch wind turbines of 225 kW, 250 kW and 400 kW by considering all the major sub assemblies to quantify the probability and availability at Muppandal site, India.

Rajesh Karki [2] developed a simplified method for reliability evaluation of power systems with wind speed model to multiple wind farm locations by determining the minimum multistate representation. The influence of availability [3] of off shore wind turbine is evaluated by Monte Carlo simulation based on maintenance method such as preventive maintenance, corrective maintenance and condition monitoring, transport ships, and climatic conditions for Danish site. High wind penetration can lead to high-risk levels in power system reliability and stability. In order to maintain the system stability, wind energy dispatch is usually restricted and energy storage is considered to smooth out the fluctuations and improve supply continuity [4].

2. Wind Turbine system and its sub Assemblies

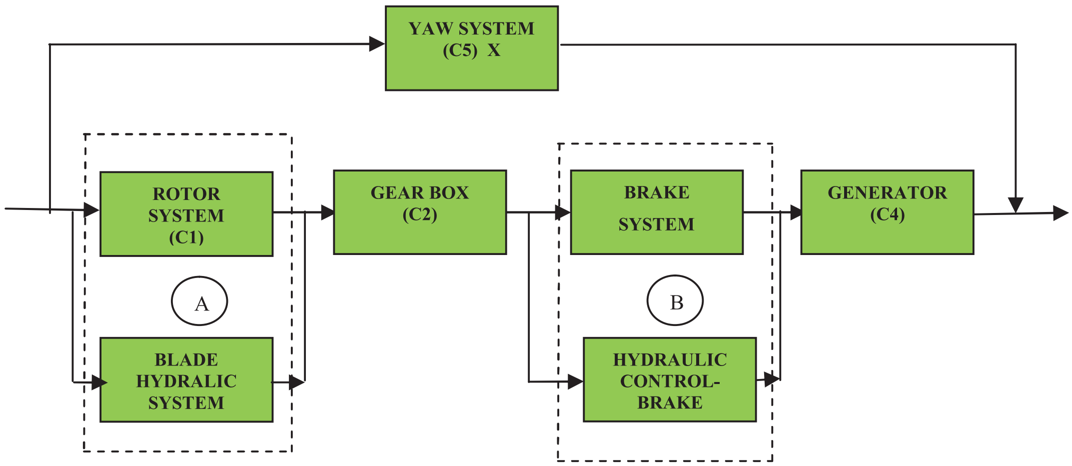


Figure: 1 Block diagram of Wind Turbine system and its sub Assemblies

Wind turbine system can be classified into two main categories according to the pitch control, constant and variable pitch. Similarly, according to the speed, it is classified into constant and variable speed turbines. The wind turbine consists of rotor system, gear box system, brake system, generator system, hydraulic system, electrical system, and electronic system as shown in figure 1. The rotor system consists of three blades assembled on the hub, main bearing, pitch control, and tip opening mechanism. The hydraulic control in the rotor actuates the tip opening mechanism in constant pitch machines and pitch control mechanism in the variable pitch turbines [5]. The gearbox changes the turbine shaft speed to generator shaft speed. The different brakes present in the WT system are electronically actuated brake, hydraulic brake, mechanical brake and tip brake or pitch mechanism. This brake system should actuate simultaneously, otherwise it will be directly attributed to some other critical failure.

The yaw system of the wind turbine is the component responsible for the orientation of the wind turbine rotor towards the wind. The main components of a typical yaw system are yaw motor, yaw bearing, yaw brake, yaw bed with bolt, and planetary gear. If the direction of wind frequently changes, then yaw motor actuates frequently and gets failed. The generator system has dual generator G1 and G2 to work with low and high wind. If there is any fluctuation in the wind, that is higher to lower, suddenly the tip will open to reduce the speed to change over the WTG from G1 to G2. Similarly, during very high wind, very often the system faces huge problem in the hydraulic system to operate tip mechanism above the cut off speed. The frequent opening of tip mechanism causes failures in the rotor hydraulic system. Mostly, the tips get open and it causes reduction in power generation.

The modern system often has some additional components like power electronic equipments and control system incorporating a computer. The issue of reliability becomes more critical since the complexity level is high in mechanisms like pitch control, yaw control, hydraulic system, electrical and electronics control, braking system, grid availability, sensors and other mechanical components.

3. Markov Analysis of wind Turbine

MA is an analysis technique for modelling system transitions and calculating the probability of reaching various system states from the model. The block diagram shown in figure 2 is the typical representation of Markov Analysis carried out in this process. MA is a tool for modelling complex system designs involving timing, sequencing, repair, redundancy and fault tolerance. MA is accomplished by drawing the system state transition diagram to denote how some undesired states are reached and their relative probabilities are obtained. The Markov Analysis is a random process in which changes occur continuously over a period of time, where the future depends only on the present state and is independent of the past history. The WT system has a complex and repairable components. The complexity and number of states of the WT depends on the number of sub systems

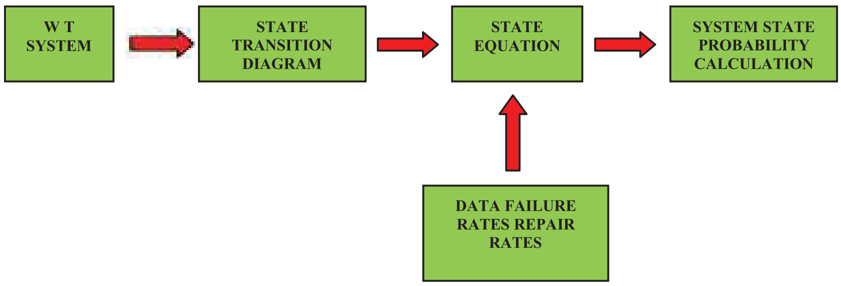
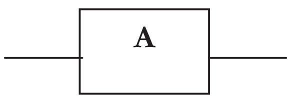
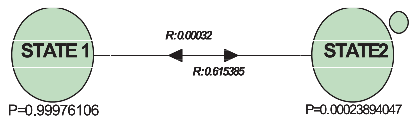


Figure: 2 Block diagram of Markov Analysis

ITEM Tool kit version 8.0.2 software is used for MA and the input data fed for the analysis are the probability of failure of a particular state as state property, Mission time in hours, Number of intermediate points and failure rate and repair rate as transient properties. The inspection and failure analysis is carried out in every three year interval for a total span of 15 years. The Markov model is constructed in three major steps for a wind turbine system. They are the system specification based on probability of failure, specification of transition rate between the states and analysis of model.

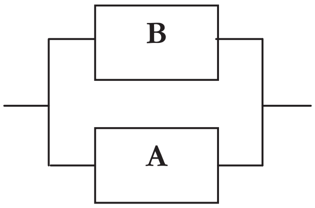


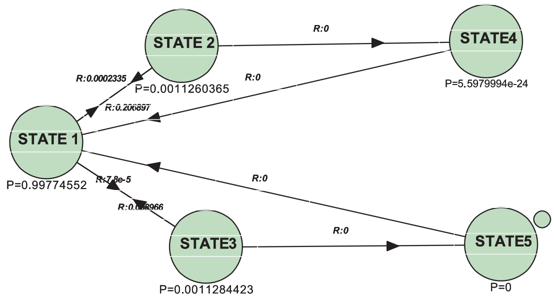
3(a)Single element



3(b) Two state system

The figures 3A and 3B shows a two state system, the success of the system could be achieved only when it operates successfully and failure occurs if it fails.





4(a)Two component system **4(b)Two component with five states system**

The figures 4A and 4B illustrate the system comprising of two components B and A. λ_A and λ_B are the failure rates. The system success requires that both must operate successfully at the same time, but the system failure occurs if both fail or even if A fails before B. If B fails before A, then also the system operates successfully. [6] The equation for probability of survival of each state is shown in formula (1).

$$P = \frac{\lambda_A\left(1 - e^{-\lambda_B T}\right) - \lambda_B\left(e^{-\lambda_B T} - e^{-(\lambda_A + \lambda_B)T}\right)}{\lambda_A + \lambda_B} \quad (1)$$

4. Discussion

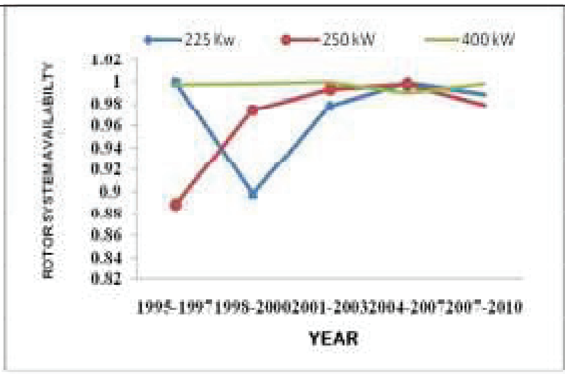
The failure rate for three years (26304 hours) for the wind turbine components varies from a lower value of 0.00004 to 0.0005. The figure 5 compares the availability of rotor systems in different capacity WTs over a period of fifteen years. It can be seen that the curve representing 400 kW WTs is reasonably flat and nearly 99.9%, which means that the rotor system of 400 kW WTs is more consistant than other WTs. But, the availability becomes very low in the year 1999, because of the frequent occurrence of failure of rotor system, followed by the occurrence of gearbox and generator failures. The Larger repair times make the MTTR very lager at that time.

However, as far as the brake system is concerned, nothing can be concluded about the consistancy of different capacity WTs, and all capacities show reasonable variations. Comparatively, brake systems used in 250 kW WTs are more reliable than their counter parts in other capacities.

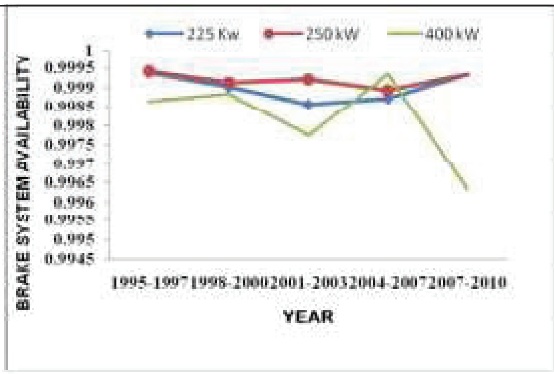
The rotor failures are high in stall controlled WT because of the frequent opening of tip open mechanism, in sufficient rigidity of blade, lightening and hydraulic control failure. For 225 kW WT, the availability is varying from 0.89865 to 0.999, for 250 kW WT, the availability is varying from 0.8891 to

0.991 and for 400kW WT, the availability is varying from 0.996 to 0.9991 shown in figure 5A. It clearly illustrates that the failure of rotor reduces the overall power generation up to 10.22 percent.

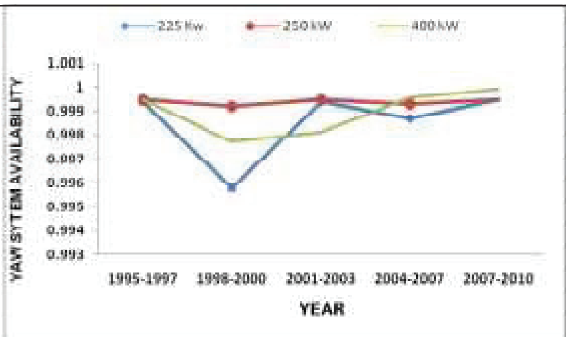
For all wind turbines, the major failures occur in the yaw system. The most affected yaw system components are yaw brake, yaw motor, yaw magnetic coil, yaw gear and planetary wheel. The failure rate of yaw system for 225 kW WT varies from 0.000233 to 0.0.0004. Similarly, the failure rates for 250 kW WT with three intervals are 0.0004, 0.000273, 0.00042, 0.000364 and 0.0003241.



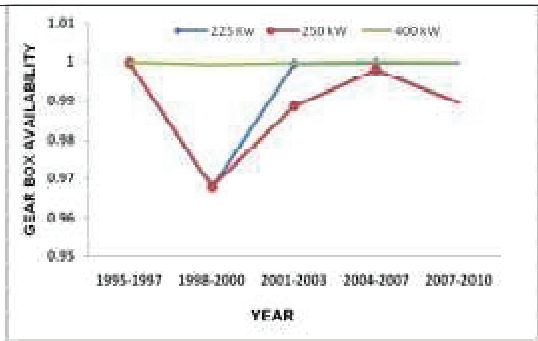
5(a) Rotor system Availability



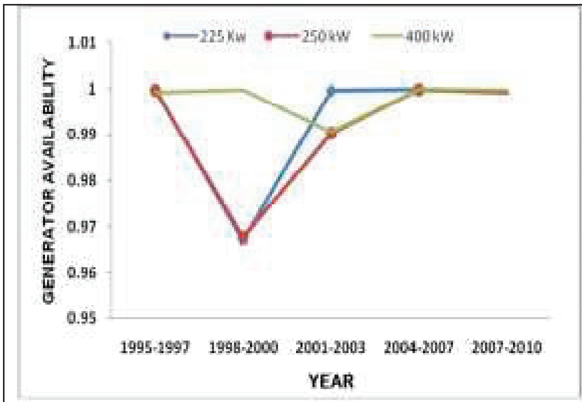
5(b) Brake system Availability



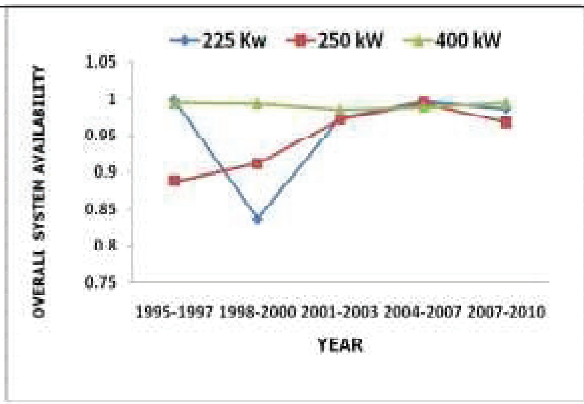
5(c) Yaw system Availability



5(d) Gear box Availability



5(e) Generator Availability



5(f) Overall system Availability

Figure: 5 Availability Analyses using Markov Chain of Wind Turbine sub Assemblies

.The figure 5C reveals that the failures are independent in the yaw system. The larger spare availability and quick repair results lower MTTR as 12, 18, 12, 16, 12 hours and it reduces the repair rate. It is similar for 400 kW WT also. If the yaw system is considered, the availability of 250 kW WTs is well above other capacities. More fluctuations can be seen in 225 kW WT followed by 400 kW. This is due to uncertainity in the particular location. But, again in recent years almost all capacities' yaw systems perform well in view of less number of failures

The figures 5 show that, it can be concluded that 400 kW WT considered here is less problematic, more reliable than others' throughout the span under consideration. Other two capacities show equally oscillating performance over different years. It shows that the failures are independent.

The generator failures for the different capacity WTs from 1995 to 2010 are shown in figure 5E. The variations are steep and sudden. But, 400 kw WTs show slightly better performance than others. However, it can be clearly stated that in the recent years, all capacities WTs have availabilities is well above 95percent. But it is necessary to improve the availabilty to 99.999 percent.

5. Conclusion

The MA analysis is carried out in this paper to compute the availability and performance of wind turbines with different capacities at high uncertain wind. An effort is made in the present study to estimate the availability of a wind turbine using ITEM Toolkit version 8.0.2 as a measure of performance.

The overall system availability of the 225 kW WT is varying from 84.0449 to 99.77, 250 kW WT is varying from 88.803 to 99.48 and 400 kW WT from 98.7 to 99.75. The failures of the rotor, gear box and generator revealed that if they are eliminated, the availability will be improved to an extent of 99.999 percent throughout the life of the WT. It clearly illustrates that the overall power generation will be reduced due to the failure of rotor up to 10.32 percent, the failure of gear box is up to 3.25 percent and the failure of generator is up to 3 percent.

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The low wind at Muppandal is varying from 1262 to 1637 hours per year. During this period, the preventive maintenance (PM) has to be carried out by trained employees to reduce the failures and increase the availability and reliability of the WTs. The repair time must be reduced by efficient spare parts management, good logistics at nearby sites from the WT manufacturers or Annual Maintenance contactors and providing Standby support for the critical components. This work will be helpful in planning timely and cost-effective maintenance of wind turbines.

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