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Availability Analysis of Wind Turbines and Its Sub Assemblies with Markov Analysis at Uncertain Wind

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Abstract

Energy is one of the major inputs for the economic development of any country. All important activities concerned with present development are depending on energy in one form or other. The power generation from wind energy is technically achievable and economically feasible and its main advantages are zero fuel cost, pollution free and environment friendly. In order to increase the life of a wind turbine, it is important to estimate the reliability level for all components in the wind turbine (WT). Unfortunately, these WTs have to contend with large failures due to the presence of complex and repairable parts. The issue of reliability becomes more critical since the complexity in mechanisms like pitch control, yaw control, hydraulic system electrical and electronics control, braking system, grid availability, sensors and other mechanical components. This paper deals with the availability analysis for the WTs located in hill and main pass having uncertainty in wind. In this paper, the concept of Markov analysis (MA) is used to model the failure characteristics of the major components for calculating probability, maintainability, reliability and availability of reaching various system states of WTs of 250 kW. Due to uncertainty in the wind in the main pass and hill area, the probability, availability and reliability of component failure is independent of the past history. Hence, Markov Analysis is considered as best mathematical tool for modeling wind turbine with complex system. In this paper, the wind turbine availability is estimated for 20 WTs by using ITEM Tool kit version 8.0.2 software, considering different states with respect to the probability of failure, failure rate and the repair rate. The availability for the WTs varies from 94.45%to 99% for three year (26304 hours) intervals during the years 1995-2010.This analysis yields some surprising results about some subassemblies, such as the rotor system and gear system are the most unreliable due to very high uncertainty in the wind.

Keywords: Availability, Probability, Markov Analysis, Transition State, Mean Time between Failures, Mean Time to Repair.

1. INTRODUCTION

As wind power is a renewable energy, it is considered as a better option instead of traditional energy resources like fossil fuels. Wind power is the most efficient among the renewable energy resources. The Wind Turbine (WT) system has a complex and repairable components. The failure of this component causes insufficient generation of power. The availability and maintainability of the modern WTs are increased considerably, but the failure of the wind turbine depends on many factors such as wind speed, wind direction and location, but they are natural [1]. The main purpose of determining the system availability is to identify the weakness of the system and quantify the failure rate (λ), repair rate (μ) and probability of failure of the different components. The reliability is a function of mission time, type of failure and repair characteristics of the system and all its components. Ricardo M Fricks et. al. reviewed the existing reliability importance measures and their interrelationships and to introduce novel techniques on how to obtain these measures using reward rate functions in a Markov reward model[2]. Boudewijn **R.** Haverkort et. al. designed Markov-reward models to analyze the reliability & performance of computer systems [3].

The availability of the system depends on the individual component down time, repair time, grid down time and mean active maintenance time. In the modern age, the higher reliability requirement systems are getting complicated because of the control system, computing system multistage interconnection and critical power system. This complexity causes frequent failures.

This paper deals with the availability analysis for the major components of WT, such as the rotor system, gear system, brake system, generator system, hydraulic system and yaw system at uncertain wind. Uncertain wind means the direction and velocity of the wind changes frequently. The uncertainty of wind occurs in the main pass and hill areas. The main objective of this paper is to increase the efficiency of power generation by improving the life of the component which has premature failure. The system availability is calculated through a study of MA for a twenty numbers of grid connected WTs of 250 kW under successfully completing an intended mission for a specified period of a constant three year interval time over a span of 15 years at Muppandal site, India.

The most common methods currently utilized in practice for quantifying the reliability of the WT system with sub assemblies having failure rates are based on Weibull analysis [4 and 5]. 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 system state transition diagram for analyzing how undesired state is reached. The main objective of this paper is to carry out a MA on the constant speed and constant pitch WTs of 250 kW by considering all the major sub assemblies to quantify the probability and reliability at Muppandal site, India.

2. WT SYSTEM AND ITS SUB ASSEMBLIES

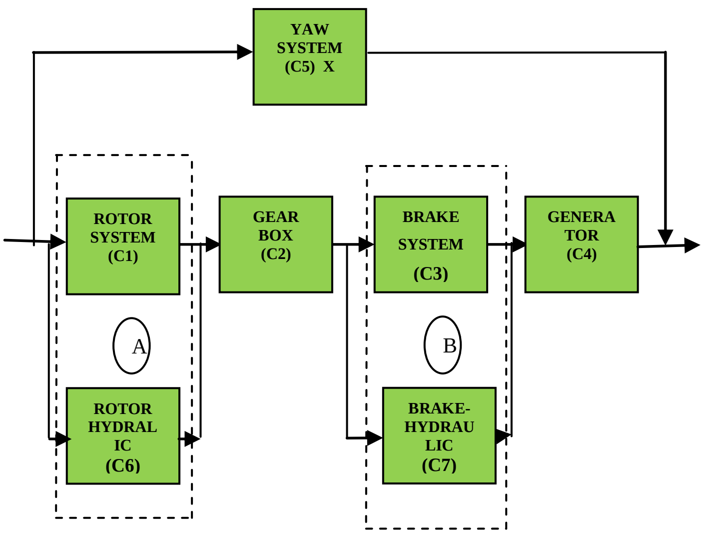

Fig. 1. Block diagram of WT system and its sub Assemblies

WT 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 [6]. The WT consists of rotor system, gear box system, brake system, generator system, hydraulic system, electrical system, electronic system etc as shown in "Fig. 1,"[7]. The rotor system consists of three blades assembled on the hub, main bearing, pitch control mechanism and tip opening mechanism. The hydraulic control in the rotor actuates the tip opening mechanism in constant pitch machines. The gearbox synchronizes the turbine shaft speed to generator shaft speed. It consists of low speed shaft, high speed shaft, high speed gear, intermediate gear, low speed gear, gears, gear oil cooler and temperature sensors. The brakes normally have electronically actuated brake, hydraulic brake, mechanical brake and tip brake or pitch mechanism. The brake system includes brake pad, brake shoe, brake solenoid, oil reservoir, accumulator, hydraulic pump and hydraulic control. The yaw system of WT is the component responsible for the orientation of the WT rotor towards the wind. The main components of a typical yaw system are the yaw motor, yaw bearing, yaw brake, yaw bed with bolt, and the planetary gear. The generator system has dual generators 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 WT generator from G1 to G2. Similarly during very high wind, very often the system faces huge problem in the hydraulic system to operate the tip mechanism above the cut out speed. The frequent opening of tip mechanism causes failures in the rotor hydraulic system. Mostly, the tips get open and it causes reduction in the power generation. If the direction of wind frequently changes, then the yaw motor actuates frequently and gets failed.

3. FAILURES OF WIND TURBINE SYSTEM AND ITS SUB ASSEMBLIES

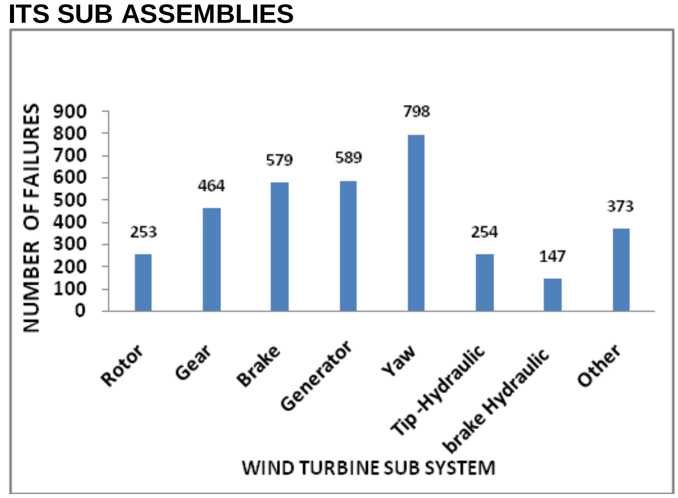

Fig. 2. Number of failures in 20 WTs of 250 kW for 15 years

The results show that the yaw system has very high failures in the WTs and is around 798 as identified from the statistics given in "Fig. 2," Next to yaw system, the generator and brake system have high failures. The rotor has a failure of 253 and gear system has 464. They have fewer failures but they require high Mean Time to Repair. The other failures include control panel and electronic components.

4. MARKOV ANALYSIS

Markov Analysis (MA) is an analysis technique for modelling system transitions and calculating the probability of reaching various system states from the model. MA is a tool for modelling complex system designs involving timing, sequencing, repair, redundancy and fault tolerance. The "Fig. 3," shows the block diagram of MA for WT system and its sub assemblies

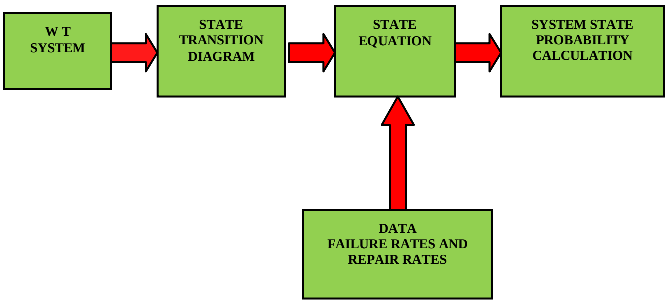

Fig. 3. Block diagram of MA for WT system and its sub Assemblies

MA accomplished by drawing the system state transition diagram to denote how some undesired states are reached and their relative probability. The Markov process is a random process in which changes occurs continuously over a period time, where the future depends only on the present state and is independent of the past history. This paper considers the failure rate of subassemblies that are highly critical. To illustrate the methodology of this paper considers a simple element with two states and two elements with five states are shown in the "Fig. 4 and 5,". The relevance of single element is shown in table 1. For a two component system, the failure occurs only when A fails or component A failed before component B and its relevance is shown in table 2.

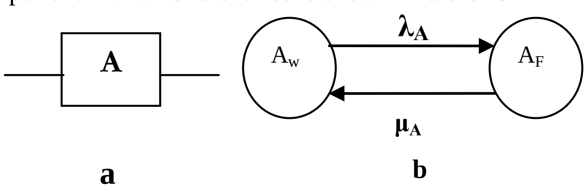

Fig. 4. State transition diagram for single component with of two states

Table: 1. Relevance of single component with two states

State	Component A	System State	Probability in state at time t
1	Success	Success	X_1 (t)
2	Failure	Failure	X_2 (t)

The gear system, brake system and yaw system are considered as single component with two states. The rotor system and the brake system are considered as two parallel components connected with five states. The rotor hydraulic control system is connected parallel to rotor. If the rotor hydraulic control fails before the rotor then the system will be a success. If the rotor or both fails then the system can be a failure. Similarly for the brake system, the brake hydraulic control is connected parallel to the brake system. If the brake hydraulic control fails before the brake system then the system will be a 'success'. If the brake system or both fails, then the entire brake system can fail. The probability rate is derived [8] as follows

$$p(t) = \frac{\lambda}{\lambda+\mu} - \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t} \qquad (1)$$

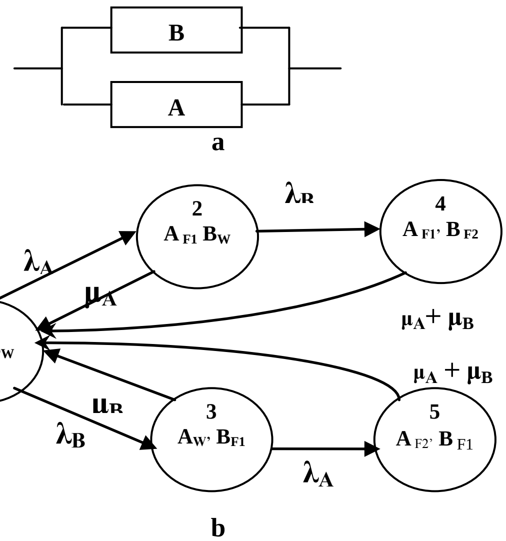

Fig. 5. State transition diagram for Two parallel components with five states

Table: 2 Relevance of Two components with of five states

State	Component A(Rotor)	Component B(Rotor Hydra)	System State	Probability of being in state at time t
1	Success	Success	Success	X_1 (t)
2	Failure	Success	Failure	X_2 (t)
3	Success	Failed	Success	X_3 (t)
4	A Failed before B	Success	Failure	X_4 (t)
5	Success	B Failed before A	Success	X_5 (t)

The probabilities for two component system having five states can be stated as

$$\frac{dP_1}{dt} = -\ \ \lambda_A + \lambda_B \ \ P_1 + \mu_A P_2 + \mu_B P_3 \quad (2)$$

$$\frac{dP_2}{dt} = \lambda_A P_1 - \ \ \lambda_B + \mu_A \ \ P_2 + \mu_B P_4 \quad (3)$$

$$\frac{dP_3}{dt} = \lambda_B P_1 - \ \ \lambda_B + \mu_A \ \ P_3 + \mu_A P_4 \quad (4)$$

$$\frac{dP_4}{dt} = \lambda_B P_2 + \lambda_A P_3 - \ \ \mu_A + \mu_B \ \ P_4 \quad (5)$$

The cumulative probability of the state is

$$P = P_2 + P_3 + P_4 \quad (6)$$

The individual system availability is calculated by ITEM software, [9] by considering the relevance of the state. The system availability is calculated by multiplying the individual availability of the WT components [10].

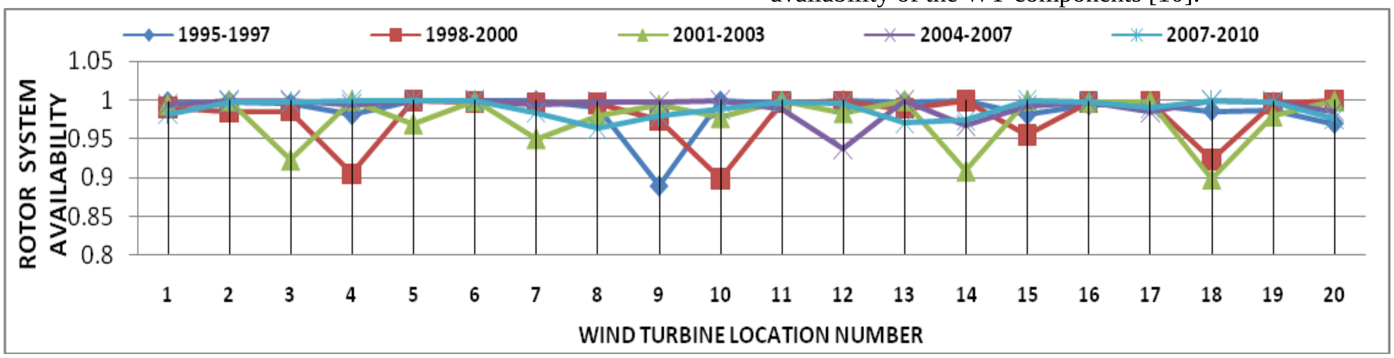

Fig.6a. Availability of Rotor system of WT

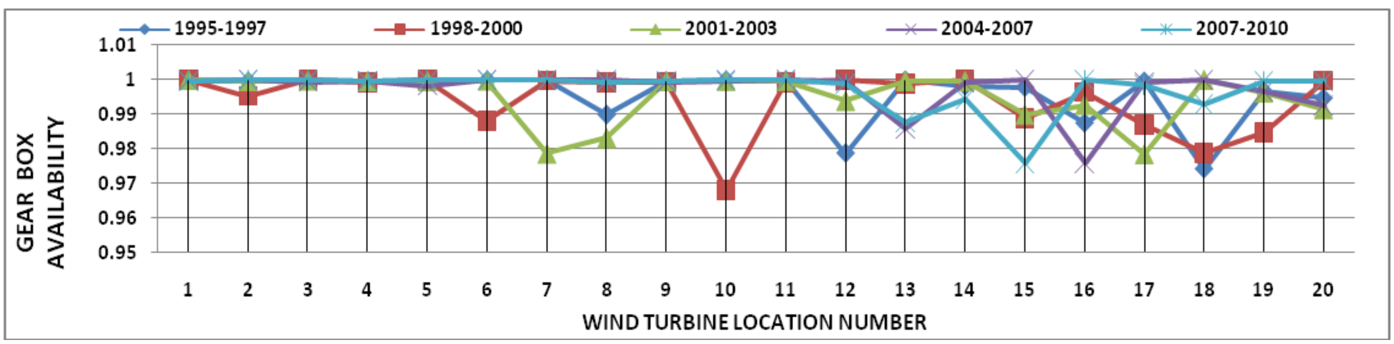

Fig. 6b. Availability of Gear Box of WT

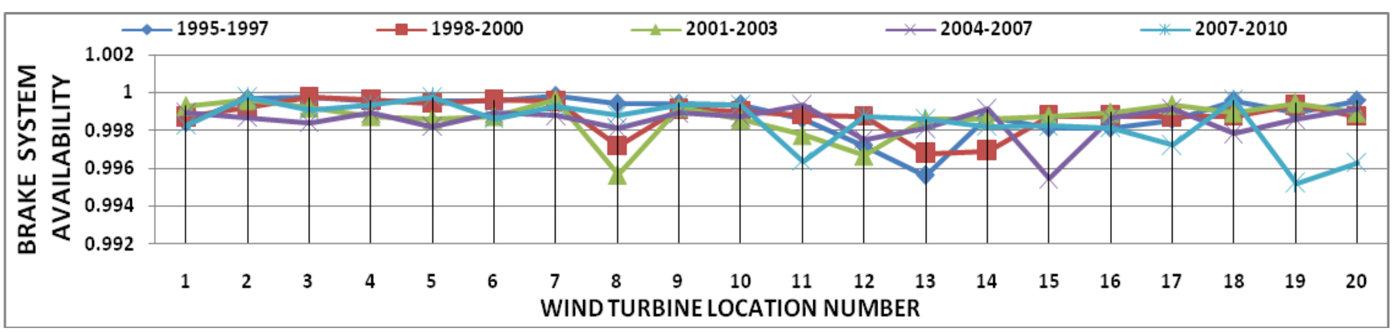

Fig. 6c. Availability of Brake system of WT

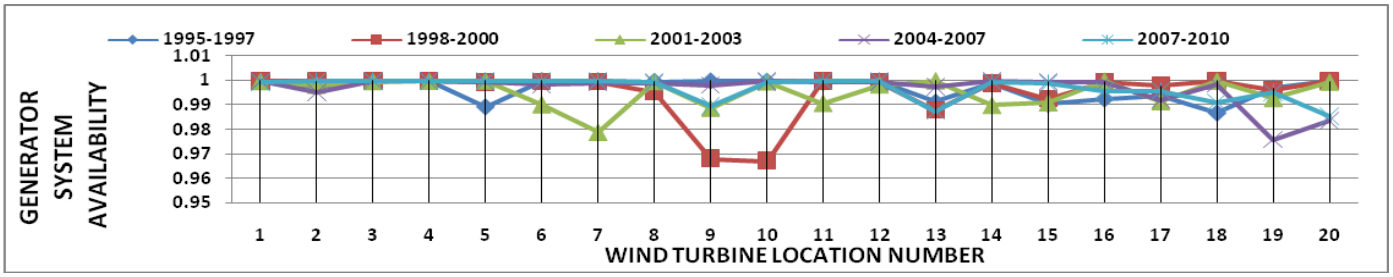

Fig. 6d. Availability of Generator system of WT

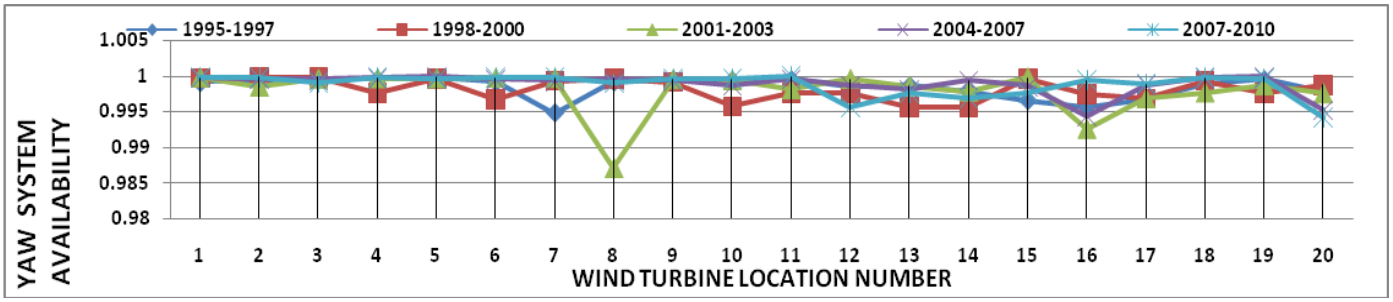

Fig. 6e. Availability of Yaw system of WT

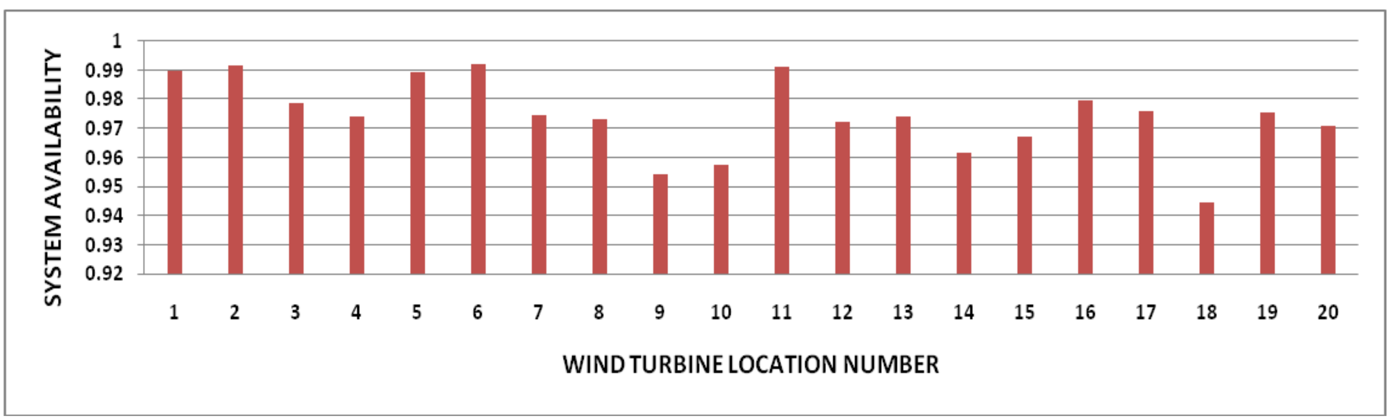

Fig.7. System Availability of the WT system

5. DISCUSSION

The goal of MA analysis is the determination of availability and maintainability matrices of a complete system, by using probability of failure, failure rate MA analysis and repair rate with time. The grid down time of the WT in three years interval varies from 556 to 1306 hours. The availabilities of different sub systems over a period of time have been analyzed and presented in figures “6a to 6e”.The Mean Time between Failure (MTBF) of the rotor varies from 24294 to 25721 hours out of 26304 hours and the Mean Time to Repair (MTTR) varies from 3 to 1338hours. The failure rate per hour of the rotor is in between 0.00004 to 0.00058. The availability of the rotor is reduced considerably in four locations in the year 1998-2000as shown in “Fig. 6a”. The rotor availability is achieved to a minimum of 0.88918 in location number 9 in the year 1995-1997 and a maximum of 0.9998 in many locations. The range of repair rate per hour is 0.0014 to 0.5. The technical availability of the rotor is in between 0.88918 to 0.99989.

For the gear system, the MTBF is in between 24724 and 25627. The failure rate per hour is in between 0.0000403 and 0.000467. The MTTR of the gear system lies between 5 to 870 hours. The larger gear box failure occurred in the gear oil cooling system and the low speed gear. The technical availability of the rotor is in between 0.96799 to 0.9989 as shown in “Fig. 6b”.The brake system has mechanical brake, electronically actuated brake and hydraulic brake. All are actuated simultaneously. The hydraulic brake has a separate control mechanism which is connected parallel to the mechanical and electronic brake. The maximum failures occurred in the brake system for three years period, is 21 times in location number 3. The MTTR of brake system falls to a minimum of 3 and a maximum of 42. The brake system failures are higher in locations 8, 11, 12, 13, 15 and 19 is shown in “Fig. 6c”. The failure rate per hour of brake system is in between 0.000122 and 0.000818.

The availabilities of WT generator for different locations are shown in “Fig. 6d”.The MTBF for the generators are from 24687 to 25712 hours and MTTR are in the range of 3 to 831 hours. The high failure rate per hour in the generator is obtained as 0.000443. The highest frequency of failure is occurred in yaw system. In location number 8, it has a frequency of 20 and a failure rate of 0.0008081 per hour, but the availability of the wind turbine is 98.71%. The availability of the WT is affected less than other components and it is shown in “Fig. 6e”. The availability is not only reduced for the components with high down time, but also it depends on the components that fail frequently

The overall system availability of the twenty WTs is shown in “Fig. 7”.The Results also show that the system availability for the locations 10and 18 are pulled down rapidly because of the severe reduction in the rotor, gear system and generator availability. For the location number 7 and 9, the system availability is reduced rigorously because of low availability of rotor and generator. The location numbers 4, 12 and 14 has a considerable reduction in availability because of rotor and gear system. This reduction in availability is due to larger MTTR, because of the insufficient spares at site and lack of logistic support. It is not possible to provide a redundant system for the rotor, gear box and generator. If there is any major failure occurred in a system, then it has to be dismantled and then once again it could be erected. But for yaw system and brake system, the redundant system can use. These failures are mostly occurred in the high wind period and it considerably reduces the overall power generation.

6. CONCLUSIONS

The MA analysis is carried out in this paper to compute the availability and performance of WTs with capacity of 250 kW at high uncertain wind. An effort is made in the present study to estimate the availability of a WT using ITEM Toolkit version 8.0.2 as a measure of performance of 20 WTs with a capacity of 250 kW exactly placed in the main wind pass. The overall system availability of the WT is varying from 94.45 to 99%. The failures of the rotor and gear box revealed that if they are eliminated, then availability will be improved to an extent of 99.999 percent throughout the life of the WT. The low wind at Muppandal is varying from 1262 to 1637 hours per year. During this period 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 WTs.

7. References and Notes

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