AMR.488-489.1702

Advanced Materials Research Vols. 488-489 (2012) pp 1702-1707
Online available since 2012/Mar/15 at www.scientific.net
© (2012) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.488-489.1702

Computation of Availability and Performance of Wind Turbine with Markov Analysis in India

T. Sunder Selwyn[1 a] and R. Kesavan [2 b],

[1,2] Research Scholar, Department of Production Engineering, MIT, Anna University, Chennai, India.

[1,2] Associate Professor, Department of Production Engineering, MIT, Anna University, Chennai, India

[a]sunder.selwyn@gmail.com, [b] kesavan@mitindia.edu

Keywords: Availability, Reliability, Probability, Mean time between failure, Mean time to repair, Markov Analysis.

Abstract

This paper deals with the availability analysis for the wind turbines (WT) located in hill and main pass having uncertainty in wind**.** Availability is a key performance index for WTs. In this paper, the concept of Markov analysis (MA) is used to model the failure characteristics of the WTs for calculating probability and reliability of reaching various system states of WT having the capacities of 225 kW, 250 kW, and 400 kW. Due to uncertainty in the wind, the probability of component failure is independent of the past history. Hence MA is considered as the best mathematical tool for modelling WT with complex system. The field data obtained from the Muppandal site in India such as Mean time between failure (MTBF), Mean time to repair (MTTR), failure rate and repair rate are used to compute the WT availability, using ITEM Toolkit version 8.0.2 as a measure of performance. No attempt is made to analyze the individual state of the WT system. In this paper, for seven critical components, a resultant of 128 states has been analyzed. This analysis yields some surprising results that some WTs are the most unreliable due to the rapid failure of its sub assemblies in view of the very high uncertainty in the wind and frequent grid failures.

Introduction

Wind farms are effective generators of electricity in the world. India is the fifth country in the world to generate electricity from wind, with an installed capacity of 14.55 GW as on June 2011. In order to increase the availability of the WT, it is important to estimate the reliability for all the components in the WT. 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. The paper deals with the availability analysis for major components of WT, such as rotor (C1), gear box(C2), brake system(C3), generator (C4), yaw system (C5) hydraulic control for rotor system(C6) and hydraulic control for brake system(C7) at uncertain wind. The system availability is calculated through a study of MA for grid connected WTs of 225 kW, 250 kW, and 400 kW for successfully completing an intended mission for a specified period of time at Muppandal site, India. The most common methods currently utilized in the previous papers [1,2,3] for quantifying the reliability of the wind turbine system (WTS) with sub assemblies having failure rates are based on Weibull analysis. They are easy to solve but the accuracy, dependability and availability of the component at different state cannot be predictable. P.Wang and Coit, describes [4] the objective of the system reliability trend to determine whether the pattern of failures is significantly changing with time. In this paper, MA is accomplished by drawing system state transition diagram (STD) 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 WTs of 225 kW (WTS No: PK1), 250 kW (WTS No: D24) and 400 kW (WTS No: SPA2) by considering all the major sub assemblies to quantify the probability and reliability at Muppandal site, India.

WTS and its sub Assemblies

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 [5]. 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.

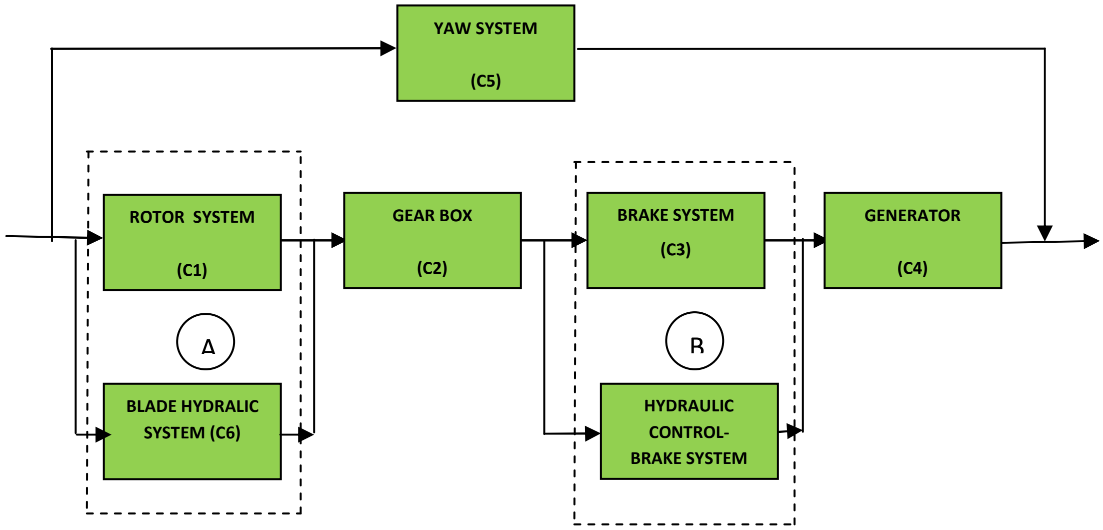

Figure: 1 Block diagram of WTS and its sub Assemblies

The yaw system of a 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 the wind frequently changes, then the yaw motor actuates frequently and gets failed.

Markov Analysis of WTS

Markov Analysis 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 [6]. MA accomplished by drawing the system by drawing the system STD 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 of time, where the future depends only on the present state and is independent of the past history.

State Transition Diagram

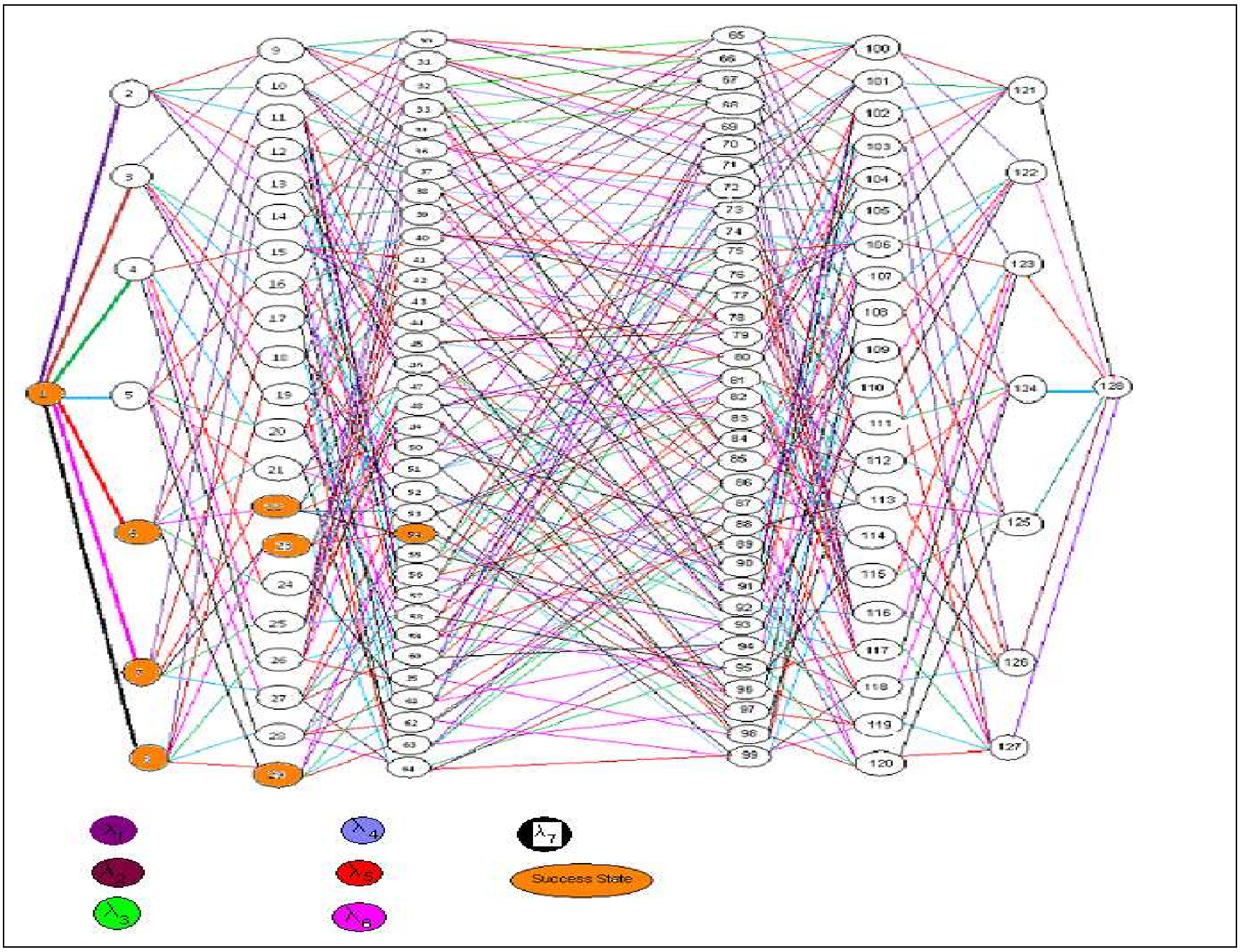

Figure: 2 STD of WTS

The State Transition diagram (STD) is used to give an abstract description of the behavior of a WT system. STD is a directed graph representation of system states, transitions between states, and transition rates. These diagrams contain sufficient information for developing the state equations, which are used for probability calculations. There are 128 states are obtained for 7 components of WT system as shown in Fig.2, and it is listed in the Table: 1. The states 6, 7, 8, 22, 23, 29 and 54 are successful states of the system and the remaining all are the failure states of the WT system. The failure rates λ_1, λ_2, λ_3, λ_4, λ_5, λ_6 and λ_7 are in the forward direction and they denote the failure rates of rotor, gear, brake system, generator, yaw, hydraulic control of rotor and hydraulic control of brake of the WT states. Similarly, μ_1, μ_2, μ_3, μ_4, μ_5, μ_6 and μ_7 are the repair rates and their transition rates are given in the reverse direction. The individual component failure rate and repair rates are calculated by the following formula [5]

$$\text{Failure rate}(\lambda) = \frac{1}{\text{MTBF}}$$

$$\text{Repair rate}(\mu) = \frac{1}{\text{MTTR}}$$

Table 1 Relevance of WTS.

Sl No	COMPONENT							STATE	Sl No	COMPONENT							STATE
	C1	C2	C3	C4	C5	C6	C7			C1	C2	C3	C4	C5	C6	C7	
1	S	S	S	S	S	S	S	S	46	F	S	S	S	S	F	F	F
2	F	S	S	S	S	S	S	F	47	S	S	F	F	F	S	S	F
3	S	F	S	S	S	S	S	F	48	S	S	F	S	F	F	S	F
4	S	S	F	S	S	S	S	F	49	S	S	F	S	S	F	F	F
5	S	S	S	F	S	S	S	F	50	S	F	S	F	F	S	S	F
6	S	S	S	S	F	S	S	S	51	S	F	S	S	F	F	S	F
7	S	S	S	S	S	F	S	S	52	S	F	S	S	S	F	F	F
8	S	S	S	S	S	S	F	S	53	S	S	S	F	F	F	S	F
9	F	F	S	S	S	S	S	F	54	S	S	S	S	F	F	F	S
10	F	S	F	S	S	S	S	F	55	F	S	S	F	S	F	S	F
11	F	S	S	F	S	S	S	F	56	F	S	S	F	S	S	F	F
12	F	S	S	S	F	S	S	F	57	F	S	S	S	F	S	F	F
13	F	S	S	S	S	F	S	F	58	S	S	F	F	S	F	S	F
14	F	S	S	S	S	S	F	F	59	S	S	F	F	S	S	F	F
15	S	F	F	S	S	S	S	F	60	S	F	S	F	S	F	S	F
16	S	F	S	F	S	S	S	F	61	S	F	S	F	S	S	F	F
17	S	F	S	S	F	S	S	F	62	S	S	S	F	F	S	F	F
18	S	F	S	S	S	F	S	F	63	S	F	S	S	F	S	F	F
19	S	F	S	S	S	S	F	F	64	S	S	S	F	S	F	F	F
20	S	S	F	F	S	S	S	F	65	F	F	F	F	S	S	S	F
21	S	S	S	F	F	S	S	F	66	F	F	F	S	F	S	S	F
22	S	S	S	S	F	F	S	S	67	F	F	F	S	S	F	S	F
23	S	S	S	S	S	F	F	S	68	F	F	F	S	S	S	F	F
24	S	S	F	S	F	S	S	F	69	F	F	S	F	F	S	S	F
25	S	S	F	S	S	F	S	F	70	F	F	S	F	S	F	S	F
26	S	S	F	S	S	S	F	F	71	F	F	S	F	S	S	F	F
27	S	S	S	F	S	F	S	F	72	F	S	F	F	F	S	S	F
28	S	S	S	F	S	S	F	F	73	F	S	F	F	S	F	S	F
29	S	S	S	S	F	S	F	S	74	F	S	F	F	S	S	F	F
30	F	F	F	S	S	S	S	F	75	S	F	F	F	F	S	S	F
31	F	F	S	F	S	S	S	F	76	S	F	F	F	S	F	S	F
2	F	F	S	S	F	S	S	F	77	S	F	F	F	S	S	F	F
33	F	F	S	S	S	F	S	F	78	F	F	S	S	F	F	S	F
34	F	F	S	S	S	S	F	F	79	F	S	F	S	F	F	S	F
35	S	S	F	S	F	S	F	F	80	S	F	F	S	F	F	S	F
36	F	S	F	F	S	S	S	F	81	F	S	S	F	F	F	S	F
37	F	S	F	S	F	S	S	F	82	S	F	S	F	F	F	S	F
38	F	S	F	S	S	F	S	F	83	S	S	F	F	F	F	S	F
39	F	S	F	S	S	S	F	F	84	F	F	S	S	F	S	F	F
40	S	F	F	F	S	S	S	F	85	F	S	F	S	F	S	F	F
41	S	F	F	S	F	S	S	F	86	S	F	F	S	F	S	F	F
42	S	F	F	S	S	F	S	F	87	F	S	S	F	F	S	F	F
43	S	F	F	S	S	S	F	F	88	S	F	S	F	F	S	F	F
44	F	S	S	F	F	S	S	F	89	S	S	F	F	F	S	F	F
45	F	S	S	S	F	F	S	F	90	F	F	S	S	S	F	F	F
91	F	S	F	S	S	F	F	F	110	S	F	F	F	F	S	F	F
92	S	F	F	S	S	F	F	F	111	F	F	F	S	S	F	F	F

93	F	S	S	F	S	F	F	F		112	F	F	S	F	S	F	F	F
94	S	F	S	F	S	F	F	F		113	F	S	F	F	S	F	F	F
95	S	S	F	F	S	F	F	F		114	S	F	F	F	S	F	F	F
96	F	S	S	S	F	F	F	F		115	F	F	S	S	F	F	F	F
97	S	F	S	S	F	F	F	F		116	F	S	F	S	F	F	F	F
98	S	S	F	S	F	F	F	F		117	S	F	F	S	F	F	F	F
99	S	S	S	F	F	F	F	F		118	F	S	S	F	F	F	F	F
100	F	F	F	F	F	S	S	F		119	S	F	S	F	F	F	F	F
101	F	F	F	F	S	F	S	F		120	S	S	F	F	F	F	F	F
102	F	F	F	S	F	F	S	F		121	F	F	F	F	F	F	S	F
103	F	F	S	F	F	F	S	F		122	F	F	F	F	F	S	F	F
104	F	S	F	F	F	F	S	F		123	F	F	F	F	S	F	F	F
105	S	F	F	F	F	F	S	F		124	F	F	F	S	F	F	F	F
106	F	F	F	F	S	S	F	F		125	F	F	S	F	F	F	F	F
107	F	F	F	S	F	S	F	F		126	F	S	F	F	F	F	F	F
108	F	F	S	F	F	S	F	F		127	S	F	F	F	F	F	F	F
109	F	S	F	F	F	S	F	F		128	F	F	F	F	F	F	F	F

Discussion

The common approach for representing the failure cause information is as shown in Table 2. The MTBF of the 225 kW varies from 24162 to 25380 hours. In the years 1995 – 1997, the larger failure has occurred in the gear box which is 254 hours and the next is rotor. In the years 2001-2003 and 2007 – 2010, the highest failure has occurred in the rotor.

Table 2 Failure data of WTS

LOC NUMBER	YEAR	TOTAL TIME	MTTR						GDT	MTBF
			YAW	ROTOR	BRAKE	GEAR	GENERATOR	TOTAL		
PK1 / 225 kW	1995-1997	26304	19	121	7	254	9	410	1306	24588
	1998-2000	26304	9	60	36	24	123	252	672	25380
	2001-2003	26280	34	258	56	432	12	792	556	24932
	2004-2007	26304	12	14	23	4	21	74	1531	24699
	2007-2010	26304	26	454	15	19	18	532	1610	24162
D24 / 250 kW	1995-1997	26304	12	1466	7	5	13	1503	1306	23495
	1998-2000	26304	18	327	11	821	826	2003	672	23629
	2001-2003	26280	12	78	10	292	248	640	556	25084
	2004-2007	26304	16	48	13	49	4	130	1531	24643
	2007-2010	26304	12	256	8	258	21	555	1610	24139
SP A 2/ 400 kW	1995-1997	26304	14	12	7	5	13	51	1306	24947
	1998-2000	26304	107	1338	14	821	842	3122	672	22510
	2001-2003	26280	15	288	42	12	11	368	556	25356
	2004-2007	26304	31	13	25	6	4	79	1531	24694
	2007-2010	26304	10	139	8	7	14	178	1610	24516

The total MTTR of 250 kW WT varies from 130 to 2003, for 225 kW WT the total MTTR varies from 9 to 123 hours and 400 kW WT has 4 to 842 hours of MTTR. The highest failure in the rotor is obtained as 1466 hours in the years 1995-1998. In 1998-2000, 2001-2003 and 2007-2010, the gear box has a considerable failure of 821 hours, 248 hours and 258 hours. The generator has a failure of 826 hours and 248 hours in the years 1998-2000 and 2001-2003 respectively. From 1998 to 2000, the 400 kW WT had more failures in the rotor, gear and generator which are 1338, 821 and 848 hours respectively.

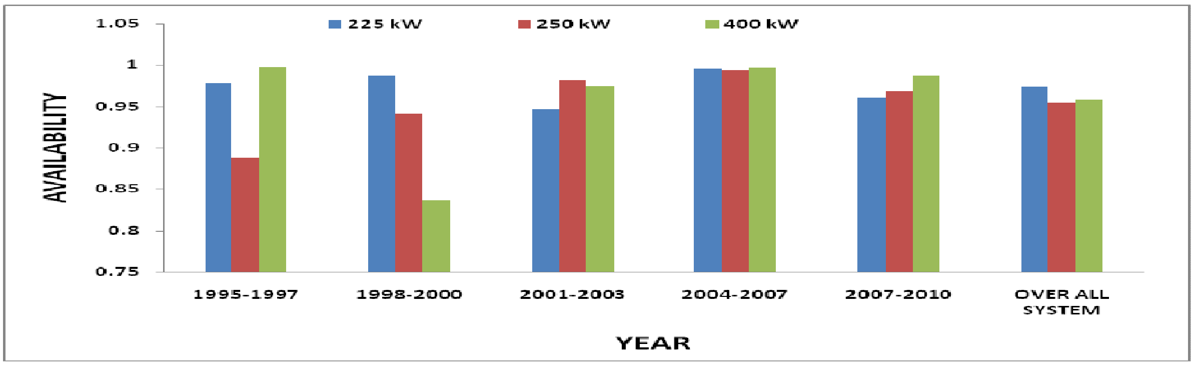

Figure: 3 Availability of WT system

The calculated results of availability from ITEM Toolkit version 8.0.2 for WTs with three years interval and system availability are plotted in a graph as shown in Fig. 3. The system availability of the 225 kW WT for three years interval is varying from 94.657% to 99.551 % and over all availability is obtained as 97.3444%, the availability of the 250 kW WT system is between 88.761 and 99.364 and the overall system availability is 95.441. For 400 kW WT, the range of the availability for three years interval is obtained from 83.691 to 99.731% and the overall system availability is attained as 95.7289%.

Conclusion

The MA analysis is carried out in this paper to compute the availability and performance of the WTs with capacities 225 kW, 250 kW, and 400 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. The WT system behavior is analyzed and represented in 128 possible states. The results for the years 1998-2000 and 2001-2003 show that the failures rates are major in the rotor, gear box and generator and it is exposed that if they are eliminated then the availability could be improved to an extent of 99 percent throughout the life of the WT. The availability of the WT is highly affected during high wind season. It reduces the overall power generation considerably. During low wind period and known Grid down Time, the preventive maintenance (PM) has to be carried out by trained employees to reduce the failures and increase the availability 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.

Reference

[1] P.Wang and D.W. Coit: ieee proceedings of Reliability and Maintainability Symposium, (2005).

[2] Palle Christensen and Gregor Giebel: European Wind Energy Conference (2001) p 63-67.

[3] P. Hu R. Karki R. Billinton: IET Gener. Transm. Distrib., 2009, Vol. 3, Issue. 8, pp. 783–791

[4] Rajesh Karki, Po Hu, and Roy Billinton: IEEE Transactions on Energy Conversion, Vol. 21, No. 2, (2006) p 533- 540.

[5] T.Sunder Selwyn and Dr. R. Kesavan: International Journal of Computer Applications Volume 32– No.4, (2011) p42-49

[6] R.M.Fricks, and K.S.Trivedi: ieee proceedings of Reliability and Maintainability Symposium, (2003) pp: 89 - 95

Key Engineering Materials II
10.4028/www.scientific.net/AMR.488-489

Computation of Availability and Performance of Wind Turbine with Markov Analysis in India

10.4028/www.scientific.net/AMR.488-489.1702