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Availability Assessment of Generating Units of Balimela Hydro Electric Power Station (510 MW) – A Markovian Approach

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Abstract: **-** Reliability and availability of the individual generating units of Balimela Hydro Electric Power Station have been evaluated and presented in this paper from April 2007 to March 2013. The operational data for the above period was collected and analyzed by using Markov model. From the collected data and based on the type of faults faced by each generating unit, different states are defined known as Markov states. The reliability indices such as repair rate (μ), failure rate (λ), mean time to repair (MTTR), mean time to failure (MTTF) and mean time between failures (MTBF) have been determined. The state probabilities for each of these states have also been calculated, and finally reliability and availability have been determined leading to establishing the reasons behind the poor availability.

Keywords: **-** *Markov model, Hydro electric power station, availability, reliability.*

I. INTRODUCTION

Balimela Hydro Electric Power station (BHEP) is Odisha's one of the oldest hydro power station and presently is the second largest hydro power project of the state. The Balimela Reservoir on the river Sileru is situated in the Malkangiri District of Odisha State. The capacity of the Reservoir is 2676 Mm^3. From the reservoir, 50% of water is diverted through a tunnel to Balimela Power House and the balance 50% is let off in the river for utilization by Andhra Pradesh. The rated head of Balimela Power House is 274.5 meters. The Power House has six (06) Generating Units of 60 MW each providing an installed capacity of 360 MW was initially installed between the years 1973 and 1977. Recently two more identical Units of 75 MW each were commissioned during the years 2008 and 2009 increasing the installed capacity up to 510 MW. The units 1 to 6 of BHEP, Balimela (6×60 MW) have been operating for more than 36 years [1].

Table 1: Commissioning dates of generating units of Balimela

Unit No.	Commissioning date	Age(in years)
1	August 14, 1973	40
2	January 25, 1974	40
3	August 24, 1974	39
4	March 26, 1975	38
5	May 7, 1976	37
6	January 5, 1977	37
7	December 23, 2008	5
8	January 23, 2009	5

The objective of this paper is to evaluate the reliability and availability of the older six generating units (i.e. unit no. 1 to 6) so as to conclude regarding necessity of renovation and modernization (R & M).

II. METHODOLOGY AND APPROACH

Reliability may be defined as the probability of a device or system performing its function adequately for the period of time intended under the operating conditions intended [2]. But this definition of reliability is applicable to a particular kind of performance, where a device is successful if it has not failed during its intended time of service. The possibility of repairs after failures and of continued service after repairs is not considered. However, there is a class of devices and systems (e.g. generators) which undergoes repair when failed, then returns to service and is expected to function in this manner indefinitely. Hence it is clear that the reliability of such a device needs to be expressed by a measure different from the one defined above. An index of reliability in such cases is the availability. The availability of a repairable device is defined as the proportion of time, in the long run, that is in or ready for service [2]. To evaluate the reliability and availability of the individual generating units of Balimela Hydro Electric Station, the operational data from April 2007 to March 2013 were collected and analyzed by using Markov model. From the collected data and based on the type of faults faced by each generating unit, different states are defined known as Markov states. Then the reliability indices such as repair rate (μ), failure rate (λ), mean time to repair (MTTR), mean time to failure (MTTF) and mean time between failures (MTBF) have been determined for each of these states.[3]The state probabilities for each of these states are also calculated. Thus reliability and availability are determined subsequently as per their definitions [3].

Hydro Unit Modeling

To model a hydro unit, the states can broadly be classified into up-state and down-state [4].

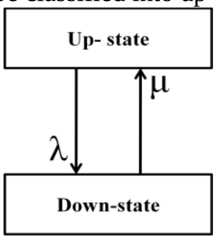


Fig. 1 Two-state model

A unit is said to be in up-state if it is either in or ready for service. It transits from up-state to down-state due to forced or scheduled outages. Forced outage means the shutdown of a generating unit for emergency reasons or a condition in which the generating equipment is unavailable for load due to unanticipated breakdown. Scheduled outage means the shutdown of a generating unit for inspection or maintenance, in accordance with an advance schedule. To carry out Markov model for the generating units it is assumed that the failure and repair rates are exponentially distributed. There is no transition between the scheduled and forced outages. The unit after repairing is immediately returning to up-state. From this, a developed Markov model is given as follows known as three state Markov model [4].

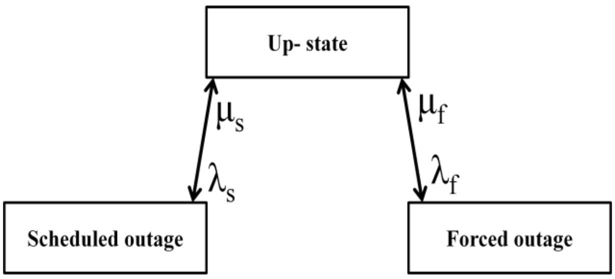


Fig. 2 Three-state Markov model

We can classify events of Hydro-unit and it's down states into:

1. Scheduled outage (Reserve, Preventive maintenance, and overhaul)
2. Generator
3. Governing system (servo motors, wicket gates, speed governor, and etc.)
4. Excitation system
5. Thrust bearing overheat
6. External Effects
7. Main Unit Circuit Breaker
8. Turbine (penstock, spiral case, butterfly valve, turbine bearing, and runner)

More developed model is driven as follows:

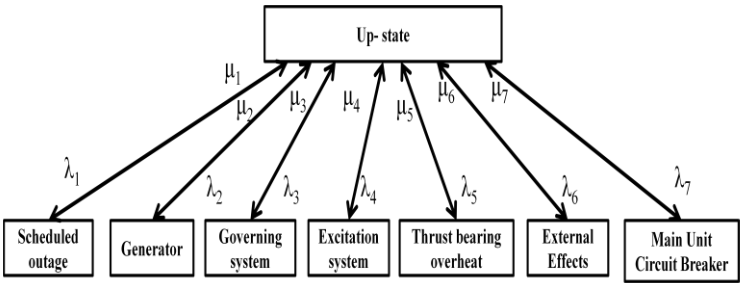


Fig. 3 Developed hydro- unit model

Table 2: State Probability Value

State Number	State Probability	
0	$\mu_1\ \mu_2\ \mu_3\ \mu_4\ \mu_5\ \mu_6\ \mu_7\ \mu_8$ / D	d_0 / D
1	$\lambda_1\ \mu_2\ \mu_3\ \mu_4\ \mu_5\ \mu_6\ \mu_7\ \mu_8$ / D	d_1 / D
2	$\mu_1\ \lambda_2\ \mu_3\ \mu_4\ \mu_5\ \mu_6\ \mu_7\ \mu_8$ / D	d_2 / D
3	$\mu_1\ \mu_2\ \lambda_3\ \mu_4\ \mu_5\ \mu_6\ \mu_7\ \mu_8$ /D	d_3 / D
4	$\mu_1\ \mu_2\ \mu_3\ \lambda_4\ \mu_5\ \mu_6\ \mu_7\ \mu_8$ / D	d_4 / D
5	$\mu_1\ \mu_2\ \mu_3\ \mu_4\ \lambda_5\ \mu_6\ \mu_7\ \mu_8$ / D	d_5 / D
6	$\mu_1\ \mu_2\ \mu_3\ \mu_4\ \mu_5\ \lambda_6\ \mu_7\ \mu_8$ / D	d_6 / D
7	$\mu_1\ \mu_2\ \mu_3\ \mu_4\ \mu_5\ \mu_6\ \lambda_7\ \mu_8$ / D	d_7 / D
8	$\mu_1\ \mu_2\ \mu_3\ \mu_4\ \mu_5\ \mu_6\ \mu_7\ \lambda_8$ / D	d_8 / D
Where D= $d_0+d_1+d_2+d_3+d_4+d_5+d_6+d_7+d_8$		

III. RESULTS

Mean time to repair (mean down time, MTTR) = FOH / N
Mean time to failure (mean up time, MTTF) = SH / N
Mean time between failures (MTBF) = MTTR + MTTF
Repair rate (μ) = 1 / MTTR
Failure rate (λ) = 1 / MTTF
Where, N (Number of failures) - number of times a unit experience forced outage
FOH (forced outage hours) – time in hours during which a unit or major equipment was unavailable due to a forced outage [5]
SH (service hours) – total number of hours the unit was actually operated with breakers closed to the station [5]

According to the definition of reliability the reliability is considered as the probability of the unit without failure [3]. States 0 and 1 are the two states that are without failure and availability is the probability that the unit is in state 0, thus:
Reliability, R = $P_0 + P_1$ and Availability, A = P_0

The reliability and availability for Unit No. 4 have been calculated for the year 2007-08 and presented in Table 3 below.

Table 3: Failure Rates, Repair Rates and State Probabilities of Unit No. 4 of BHEP

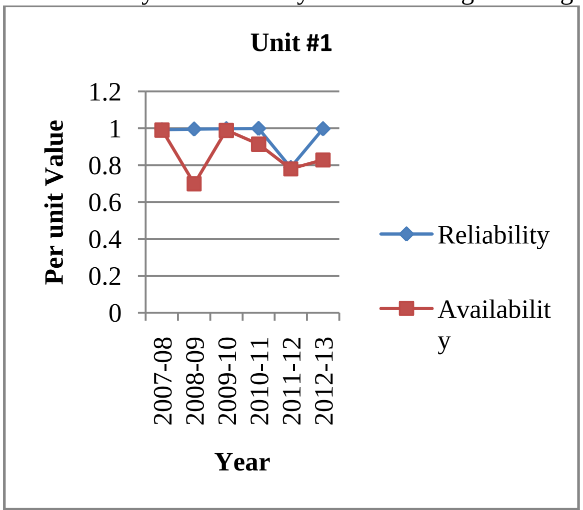
2007-08									
State Number	Basic Event	No. of Occurrence	Total Repair times(hrs)	MTTR in hrs	MTBF in hrs	MTTF in hrs	Repair Rate μ	Failure Rate λ	State Probability
0	Up State								0.9242
1	scheduled Outage	1	520	520	8614	8094	0.0019230	0.0001235	0.0593
2	Generator	4	44.38	11.09	2034.59	2023.5	0.0901306	0.0004941	0.0050
3	Governing System	4	35.28	8.82	2032.32	2023.5	0.1133786	0.0004941	0.0040
4	Excitation System	1	1.5	1.5	8095.5	8094	0.6666666	0.0001235	0.0001
6	External Effects	4	62.35	15.58	2039.08	2023.5	0.0641539	0.0004941	0.0071
Reliability= 0.983612922 Availability= 0.92423531									

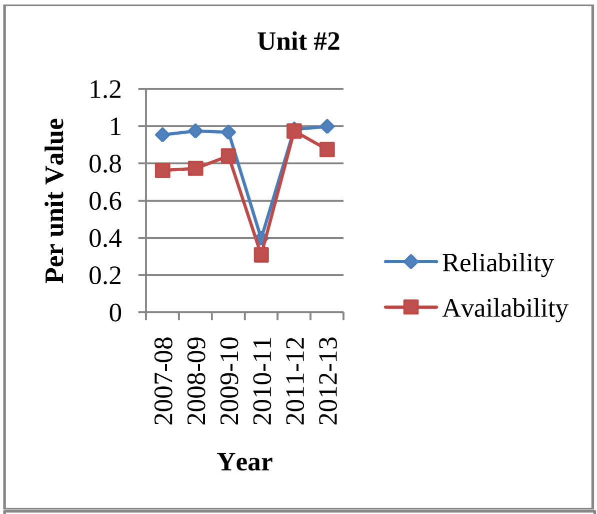
On similar lines reliability and availability of all the six units for the years 2007-08 to 2012-13 (six years) were evaluated and summarized in Table 4.

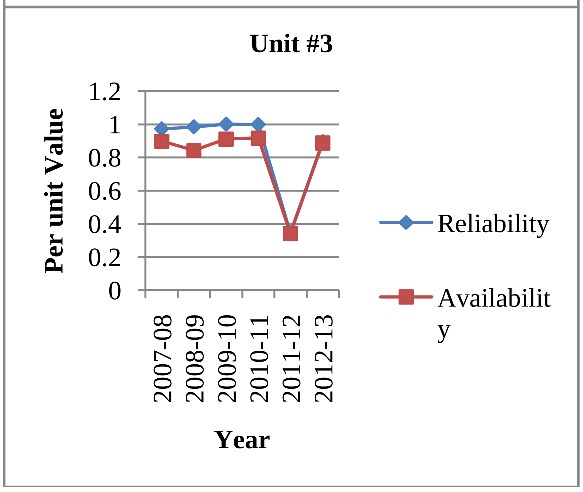
Table 4: Reliability (R) and Availability (A) values for unit no. 1 to 6 of BHEP from 2007 – 2013

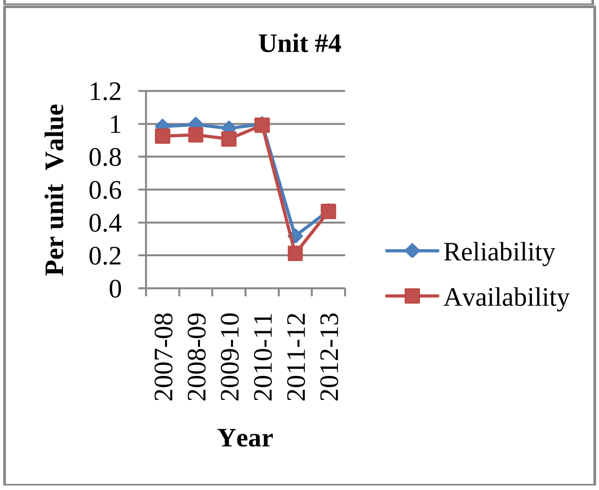
Unit No	2007-08		2008-09		2009-10		2010-11		2011-12		2012-13	
	R	A	R	A	R	A	R	A	R	A	R	A
1	0.9929	0.9918	0.9967	0.6995	0.9986	0.9895	1	0.9147	0.7876	0.7808	0.9982	0.8293
2	0.9531	0.7622	0.9738	0.7730	0.9671	0.8396	0.3963	0.3078	0.9835	0.9736	0.9982	0.8735
3	0.9718	0.8981	0.9833	0.8419	1	0.9111	0.9976	0.9169	0.3450	0.3410	0.8946	0.8873
4	0.9836	0.9242	0.9955	0.9313	0.9721	0.9060	0.9986	0.9902	0.3166	0.2105	0.4705	0.4659
5	0.9938	0.9075	0.9802	0.9769	0.9946	0.9226	0.9954	0.9867	0.4805	0.4750	0.9859	0.9777
6	0.9759	0.8870	0.9925	0.9898	0.9953	0.9099	0.9913	0.9829	0.9971	0.9874	1	0.9602

The availability and reliability curves of the generating units are illustrated below.









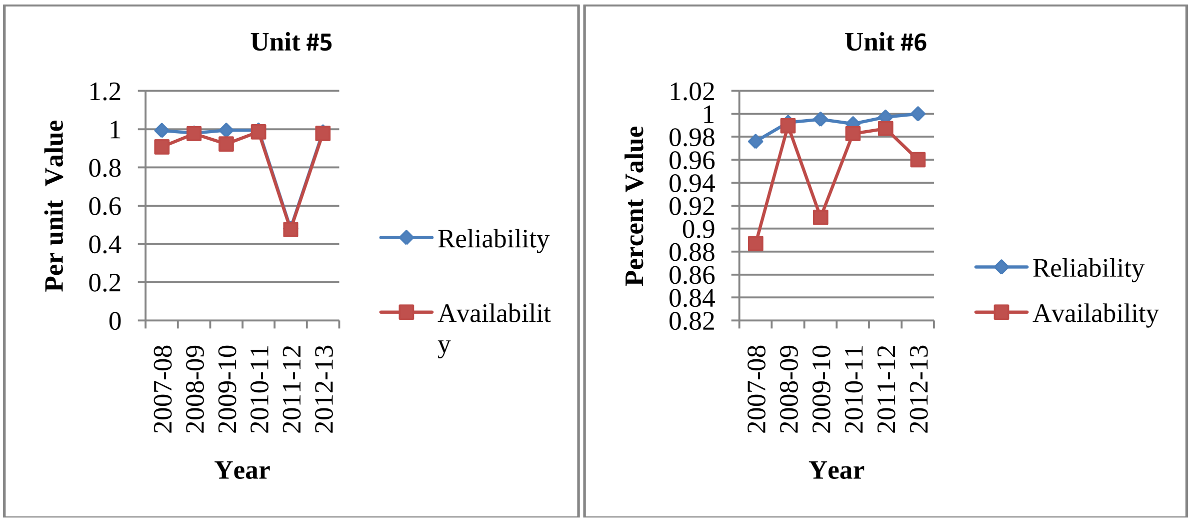


Fig. 4 Availability and Reliability curves

IV. DISCUSSIONS AND CONCLUSIONS

Table 5: Down time in Hrs (D) and Number of occurrence (N) for all down state events from April 2007 to March 2013

Events → / Unit No. ↓	Scheduled outage		Generator		Governing System		Excitation system		Thrust bearing overheat		External effects		Main unit circuit breaker	
	D	N	D	N	D	N	D	N	D	N	D	N	D	N
UNIT #1	4980	41	4	1	4	2	8	1	3261	2	116	10	0	0
UNIT #2	6501	40	505	4	23	2	9	1	6332	2	534	12	0	0
UNIT #3	3469	38	42	1	123	3	0	0	6634	2	230	11	46	4
UNIT #4	2704	30	119	5	36	4	4	2	10517	3	270	14	120	1
UNIT #5	1612	40	149	3	3	1	0	0	4525	1	311	19	0	0
UNIT #6	2059	46	48	1	76	3	0	0	0	0	254	24	42	3

Table 6: Total Forced outage Hours versus Total Scheduled outage Hours and Availability (in %age) considering the entire six years data (i.e. from Apr 2007 to Mar 2013)

UNIT NO.	Total Scheduled Outage hours	Total Forced Outage hours	Availability (in %age)
1	4980	3393	84%
2	6501	7403	74%
3	3469	7075	80%
4	2704	11066	74%
5	1612	4988	87%
6	2059	420	95%

From the analysis, it is clear that the fault that results maximum down time of a unit is the thrust bearing over heat. Apart from this there are other faults which appear on a regular basis are excitation system faults and governing system faults. Even though these faults do not necessarily result in longer down time but they affect the continuity of service.

So to analyze above mentioned faults, a closer look of the system was taken. After going through the details of the site, it was clear that there are many factors which have caused the above mentioned faults. The key points are described below:

1. The speed governing system (electro hydraulic governor) was not working in "auto" mode satisfactorily. Every time there is a failure of the auto governing system, they were switched to manual mode because of non-availability of the spare parts. If in this state (i.e. governor in manual mode) a sudden full load throw

off takes place due to some system disturbance, the unit trips attending the over speed limit. To ensure fast response quick acting digital governors should be employed.

2. The excitation system is of conventional type (i.e. shaft mounted excitation system). Hence, there is more wear and tear requiring frequent maintenance. Since the system has been working for more than 36 years, the response of the AVR (automatic voltage regulator) has become very sluggish resulting in over voltage in case of full load throw-off. Frequent sparking has been also observed at the slip rings. For better control and reliability static excitation system (thyristor type) should be preferred.
3. Forced oil – supply system for the generator thrust bearing is effected by pumping oil through the thrust bearing oil bath via a closed circuit. The closed circuit comprises motor (requiring A.C. supply) driven oil pumps – oil coolers – filters (strainers) –a pressure header – an oil bath of the thrust bearing – over flow oil pipes – drain tank pumps and instrumentation (for checking oil pressure, temperature and levels in the drain tank etc.). Oil is supplied into the thrust bearing bath by means of centrifugal pumps, one which is in operation and the other is a stand-by one. The oil pumps are electrically interlocked in such a way that if one of the pump fails to operate, the stand-by pump starts automatically due to a pulse generated by an electrical contact pressure gauge. In case of failure of A.C. supply to both these motors (i.e. say a system disturbance or failure of grid) there is no alternative arrangement to avail power supply for the station auxiliary instantly. If because of some reason both these pumps fail to operate, another stand-by emergency D.C. Lubricating oil pump operates which is also not reliable and often fails to serve when desired. Hence it would be preferable to have the thrust bearing immersed in an oil bath of adequate volume through which cooling water is circulated for effecting cooling of the lubricating oil. The old babbited thrust bearing segments should be replaced by fluoraplast coated pads to ensure less friction and less bearing oil temperature during running.
4. After observing the above facts, the trends of the availability of the generating units and looking at the age of this hydro electric project it may be an attractive proposition to go for Renovation and Modernization of the generating units to ensure better availability and reliability.

REFERENCES

[1] http://ohpcltd.com/balimela/index.asp?type=index

[2] J. Endrenyi, *Reliability Modeling in Electric Power systems* (A Wiley& Sons, 1980).

[3] M. Sahu and A. Barve, Reliability and Availability Evaluation of PATHRI & CHILLA Hydro Power Station (India) by using Markov model, *International Journal of Electrical, Electronics and Computer Engineering, 1(2),* 2013, 115-122

[4] A.R. Majeed and N.M. Sadiq, Availability & Reliability Evaluation of Dokan Hydro Power Station, *IEEE PES Transmission and Distribution Conference and Exposition,* Latin America, Venezuela, 2006

[5] A.M. Zungeru, A.B. Araoye, B.B. Garegy, A.J. Garba and O.J. Tola, Reliability Evaluation of Kainji Hydro-Electric Power Station in Nigeria, *Journal of Energy Technologies and Policy, Vol.2, No.2,* 2012