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Reliability and Availability Evaluation of PATHRI & CHILLA Hydro Power Station (India) by using Markov Model

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ABSTRACT: This paper presents an evaluation of Markov models used to obtain unit reliability and availability the operational data of Pathri and Chilla power stations (India) for period 2007 - 2012. The most important reliability indices are found namely failure rate (λ), repair rate (μ), MTTR, MTBF, MTTF Through data collection and analysis. The data of each year and for each unit is time scheduled. After tabulating all the data, we classified for each unit the different type of failure taking into account the various sub units and systems. According to the classification we defined Markov states. Failure rate repair rate of all state are found from the classified data. The determination of availability and reliability from their definition is completed.

Keywords: Availability, Reliability, Hydro power station, Markov model.

I. INTRODUCTION

Pathri hydro power station (PHPS) has an installed capacity of 20.4MW.It consists of 3 identical independent unit of 6.8MW capacity per each. PHPS has been constructed on upper Ganga canal at 13 km downstream of holy city, Haridwar, India. All the mechanical equipments were supplied by J.M.Vaith, Germany and electrical equipments by Siemens, Germany. Each unit of PHPS units consists of several subunits such as Turbine, Generator, Excitation system, Speed Governor, Spiral case, etc.

Chilla hydro power station (CHPS) has an installed capacity of 144MW. It consists of 4 identical independent units of 36 MW capacities per each. CHPS is a runoff river scheme constructed under Garhwal Rishikesh Chilla hydel scheme in the river Ganga. It comprises a diversion barrage across the river Ganga at Pashulok 5 km downstream of Rishikesh town. Each unit of CHPS comprises vertical shaft Kaplan turbine of rated head 32.5 meter. There are separate penstocks for each unit.

The objective of "Reliability Evaluation of Hydropower Station (PHPS & CHILLA)" is: To study the Frequency of Scheduled maintenance of each individual generating unit of the station. To Evaluate MTTR, MTBF, MTTF, failure rate, repair rate, probability of occurrence of failure for the components/ subsystems of individual generating unit. To carry out Markov model and State space diagram of both hydro power station. To apply the common concepts of probability to find the overall reliability of Hydro power station.

II. MATERIAL AND METHODOLOGY

The most important reliability indices are found namely failure rate (λ), repair rate (μ), MTTR, MTBF, MTTF Through data collection and analysis. An evaluation of Markov models used to obtain unit reliability and availability the operational data of these stations for period 2007 – 2012. The data of each year and for each unit is time scheduled. After tabulating all the data, we classified for each unit the different type of failure taking into account the various sub units and systems. According to the classification we defined Markov states. Failure rate repair rate, MTTR, MTTF, MTBF of all state are found from the classified data. The determination of availability and reliability from their definition is completed.

A. Modeling

Hydro-Unit Model: To drive the Markov model of a Hydro-unit we assume: The failure and repair rates are exponentially distributed. There are no transition between the scheduled and force outages. The unit after repairing is immediately returning to up state.

From the above definition a developed Markov model is driven as follows:

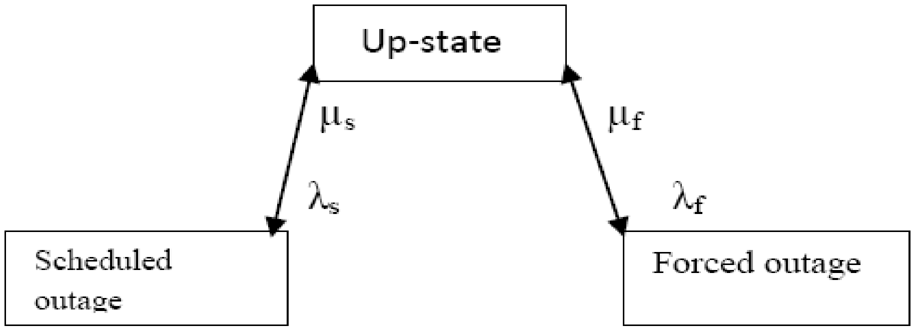

Fig.1 *Three- state Markov model*

We classify events of Hydro-unit and it's down state into:
1. Reserve, Preventive maintenance, and overhaul.
2. Generator.
3. Turbine (inlet gate, penstock, spiral case, butter fly valve, turbine bearing and runner)
4. Excitation system (thyristor, cooling system, equipped transformer, etc…..)
5. Governor system (servo motors, wicket gate, speed governor, etc……)
6. Main Unit Transformer.
7. Main Unit Circuit Breaker.
8. External Effects.

More developed model is driven as follows:

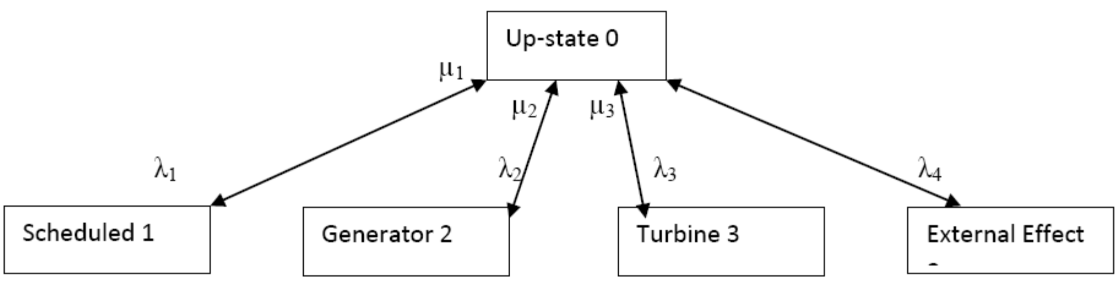

Fig.2 *Developed hydro-unit model*

Plant Modeling: To Model PHPS the three units should be studied together. The number of failure rates and repair rates of a unit for five year and for all the units are taken to determine the plant availability and reliability. Similarly, To Model CHPS the number of failure rates and repair rates of a unit for five year and for all the four units are taken to determine the plant availability and reliability.

The state probabilities are determined by the same ways as for unit modeling. The probability of state 1 is the probability that the three units (PHPS) are up

$$P_1=\mu_1\ \mu_2\ \mu_3/\prod_{i=1}^{3}(\lambda i+\mu i)$$

Probability of state 8 is the probability that all the units are down

$$P_8=\lambda_1\ \lambda_2\ \lambda_3/\prod_{i=1}^{3}(\lambda i+\mu i)$$

Table 1: State Probability Value & Frequency of Encountering States

State Number	State probability		Rate of departure	Frequency of state
0	μ 1μ2μ3μ4μ5μ6μ7μ8 /D	d0/D	λ 1+λ2+ λ3+……+ λ8	(λ1+λ2+ λ3+……+λ8) d0/D
1	λ1μ2μ3μ4μ5μ6μ7μ8 /D	d1/D	μ1	μ1d1/D
2	μ1λ2μ3μ4μ5μ6μ7μ8 /D	d2/D	μ2	μ2d2/D
3	μ1μ2λ3μ4μ5μ6μ7μ8 /D	d3/D	μ3	μ3d3/D
4	μ1μ2μ3λ4μ5μ6μ7μ8 /D	d4/D	μ4	μ4d4/D
5	μ1μ2μ3μ4λ5μ6μ7μ8 /D	d5/D	μ5	μ5d5/D
6	μ1μ2μ3μ4μ5λ6μ7μ8 /D	d6/D	μ6	μ6d6/D
7	μ1μ2μ3μ4μ5μ6λ7μ8 /D	d7/D	μ7	μ7d7/D
8	μ1μ2μ3μ4μ5μ6μ7λ8 /D	d8/D	μ8	μ8d8/D

Where D=d0+d1+d2+d3+d4+d5+d6+d7+d8

The frequency of encountering state 1 is, f1 = (λ1 + λ2+λ3) P1
The frequency of encountering state 8 is, f8 = (μ1 + μ2+ μ3)/ P8
The transition rate matrix of fig.4 is determined by the same way as the unit transition rate matrix. The probability of state 1 is the probability that the four units (CHPS) are up

$$P_1=\mu_1\ \mu_2\ \mu_3\ \mu_4/\prod_{i=1}^{4}(\lambda i+\mu i)$$

Probability of state 16 is the probability that all the units are down

$$P_{16}=\lambda_1\ \lambda_2\ \lambda_3\lambda_4/\prod_{i=1}^{3}(\lambda i+\mu i)$$

The frequency of encountering state 1 is f1 = (λ1 + λ2+λ3+ λ4) P1

The frequency of encountering state 8 is F16 = (μ1 + μ2+ μ3+ μ4)/ P16

RESULTS

Hydro-Unit Modeling: For PHPS and CHPS, The failure rate and repair rates for these states and their probability are shown bellow in table.

For evaluation of reliability and availability we will take the unit-I of PHPS,

$$\text{Availability} = \frac{P0}{P4+P6} = 0.99794$$

According to the definition of reliability is considered as the probability of unit without failure.

Reliability = P_0 +P_3 = 0.996650

Similarly we calculate all unit of availability and reliability of PHPS and CHPS, the result is as shown in Table3 .Failure states are reset into the first repair state and therefore, the transition probabilities out of the failure states and out of the first repair state are identical.

Plant Modeling: PHPS: The maximum number component of state in a three component ,where each component can exist in two states, is 2^3 or 8.This is shown in fig.3 in λ and μ which represents the failure rate and repair rates of component and U and D indicates that the component is up or down respectively. The states to be combined for system success and failure are: 2-out-of-3 system - success = states 1, 2, 3, 4 Failure = states 5, 6,7,8 as shown in Table 5.

CHPS: The maximum number component of state in a four component ,where each component can exist in two states, is 2^4 or 16.This is shown in fig.3 in λ and μ which represents the failure rate and repair rates of component and U and D indicates that the component is up or down respectively. The states to be combined for system success and failure are:

2-out-of-4system-Success = states

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 Failure = states 12, 13, 14, 15, 16

Table 2: Failure Rates, Repair Rates and State Probabilities for PHPS and CHPS

Pathri hydro power station(PHPS) Down States event of hydro unit 1										
State Number	Basic Event	No.of occurrence	Total repair times(hrs)	MTTR in hrs	MTBF in hrs	MTTF in hrs	Repair Rate in μ	Failure Rate in λ	Probability of occurrence	State Probability
0	Up State									0.995421
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine	11	54.2	4.92727	3986.2	3981.255	0.20295	0.00025	0.001236088	0.00122938
4	Excitation system(thyrister,cooling system,equipped transformer,and etc.)	4	9.55	2.3875	10962	10959.61	0.41885	0.00009	0.000217798	0.00021442
6	Main unit transformer	7	26.55	3.79286	6264	6260.207	0.26365	0.00016	0.000605501	0.0006056
			108.22				0.88545	0.00050	0.002059387	
Reliability=0.996650 Availability=0.997940										

Pathri hydro power station(PHPS) Down States event of hydro unit 2										
State Number	Basic Event	No.of occurrence	Total repair times(hrs)	MTTR in hrs	MTBF in hrs	MTTF in hrs	Repair Rate in μ	Failure Rate in λ	Probability of occurrence	State Probability
0	Up State									0.564728
2	Generator	4	31.6	7.9	10962	10954.1	0.12658	0.0000913	0.000721191	0.0038339
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine bearing,and runner)	3	214.25	71.4167	14616	14544.58	0.014	0.0000680	0.00491019	0.028115
6	Main unit transformer	8	267.3	33.4125	5481	5447.588	0.02993	0.0001836	0.006133449	0.4063897
8	External Effect	3	36	12	14616	14604	0.08333	0.0000685	0.000821693	0.00038339
			549.15				0.25385	0.00041	0.012586523	
Reliability=0.971118 Availability=0.9874134										

Pathri hydro power station(PHPS) Down States event of hydro unit 3										
State	Basic Event	No.of occurrence	Total repair times(hrs)	MTTR in hrs	MTBF in hrs	MTTF in hrs	Repair Rate in μ	Failure Rate in λ	Probability of occurrence	State Probability
0	Up State									0.9830485
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine bearing,and runner)	16	119.25	7.45313	2740.5	2733.047	0.13417	0.00037	0.00273	0.00273785
4	Excitation system(thyrister,cooling system,equipped transformer,and etc.)	3	4.2	1.4	14616	14614.6	0.71429	0.00007	0.00010	9.6432E-05
5	Governor system(servo motor,wicket gates,speed governor,and etc)	4	151.15	37.7875	10962	10924.21	0.02646	0.00009	0.00346	0.00033151
8	External Effect	3	32.12	10.7067	14616	14605.29	0.0934	0.00007	0.00073	0.00074211
			306.72				0.96832	0.00059	0.00701	
Reliability=0.985786 Availability=0.99298503										

Table 2 contd…

Chilla hydro power station(CHPS) Down States event of hydro unit 1										
S.No.	**Basic Event**	**No.of occurrence**	**Total repair times(hrs)**	**MTTR in hrs**	**MTBF in hrs**	**MTTF in hrs**	**Repair Rate in µ**	**Failure Rate in λ**	**Probability of occurrence**	**State Probability**
0	Up State									0.97546864
2	Generator	3	3.3	1.1	13080.667	13079.57	0.909091	0.000076	0.00008	0.00008
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine bearing,and runner)	3	11.02	3.6733333	13080.667	13076.99	0.272232	0.000076	0.00028	0.00028156
4	Excitation system(thyrister,cooling system,equipped transformer,and etc.)	1	4.05	4.05	39242	39237.95	0.246914	0.000025	0.00010	0.00010252
5	Governor system(servo motor,wicket gates,speed governor,and etc)	1	0.45	0.45	39242	39241.55	2.222222	0.000025	0.00001	0.00001
8	External Effect	3	2.05	0.6833333	13080.667	13079.98	1.463415	0.000076	0.00005	0.00005
			20.87				5.113874	0.000280	0.000511	
			Availability=0.99943668				Reliability=0.975750198			

Chilla hydro power station(CHPS) Down States event of hydro unit 2										
S.No.	**Basic Event**	**No.of occurrence**	**Total repair times(hrs)**	**MTTR in hrs**	**MTBF in hrs**	**MTTF in hrs**	**Repair Rate in µ**	**Failure Rate in λ**	**Probability of occurrence**	**State Probability**
0	Up State									0.96845838
2	Generator	6	15.08	2.5133333	6540.3333	6537.82	0.397878	0.00015296	0.00038	0.00038369
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine bearing,and runner)	4	15.55	3.8875	9810.5	9806.613	0.257235	0.00010197	0.00040	0.00039548
4	Excitation system(thyrister,cooling system,equipped transformer,and etc.)	4	10.1	2.525	9810.5	9807.975	0.39604	0.00010196	0.00026	0.00025672
5	Governor system(servo motor,wicket gates,speed governor,and etc)	1	3.4	3.4	39242	39238.6	0.294118	0.00003	0.00009	0.00010142
8	External Effect	3	15.2	5.0666667	13080.667	13075.6	0.197368	0.00008	0.00039	0.00040439
			59.33				1.542638	0.00046	0.00151	
			Availability=0.998817854				Reliability=0.968853863			

Chilla hydro power station(CHPS) Down States event of hydro unit 3										
S.No.	**Basic Event**	**No.of occurrence**	**Total repair times(hrs)**	**MTTR in hrs**	**MTBF in hrs**	**MTTF in hrs**	**Repair Rate in µ**	**Failure Rate in λ**	**Probability of occurrence**	**State Probability**
0	Up State									0.97884491
2	Generator	1	1.1	1.1	39242	39240.9	0.909091	0.00003	0.00003	0.00003
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine bearing,and runner)	7	28.35	4.05	5606	5601.95	0.246914	0.00018	0.00072	0.00072806
4	Excitation system(thyrister,cooling system,equipped transformer,and etc.)	1	5.05	5.05	39242	39236.95	0.19802	0.00003	0.00013	0.00015126
5	Governor system(servo motor,wicket gates,speed governor,and etc)	1	1.15	1.15	39242	39240.85	0.869565	0.00003	0.00003	0.00003
8	External Effect	2	8.35	4.175	19621	19616.83	0.239521	0.00005	0.00021	0.00020845
			44				2.46311	0.00031	0.00112	
			Availability=0.999563926				Reliability=0.979572967			

Chilla hydro power station(CHPS) Down States event of hydro unit 4										
S.No.	**Basic Event**	**No.of occurrence**	**Total repair times(hrs)**	**MTTR in hrs**	**MTBF in hrs**	**MTTF in hrs**	**Repair Rate in µ**	**Failure Rate in λ**	**Probability of occurrence**	**State Probability**
0	Up State									0.99490941
3	Turbine(inlet gate,penstock,spiral case,butter fly valve,turbine bearing,and runner)	1	1	1	39242	39241	1	0.00003	0.00003	0.00003
4	Excitation system(thyrister,cooling system,equipped transformer,and etc.)	1	2.34	2.34	39242	39239.66	0.42735	0.00003	0.00006	0.00007
8	External Effect	1	13.25	13.25	39242	39228.75	0.075472	0.00003	0.00034	0.00039728
			16.59					0.00008	0.00042	
		Availability=0.999503465			Reliability=0.99530669					

Table 3: System Availability and Reliability of (PHPS) 2007-12.

UNIT	Availability	Reliability
1	0.9979	0.9967
2	0.9874	0.9711
3	0.9930	0.9858

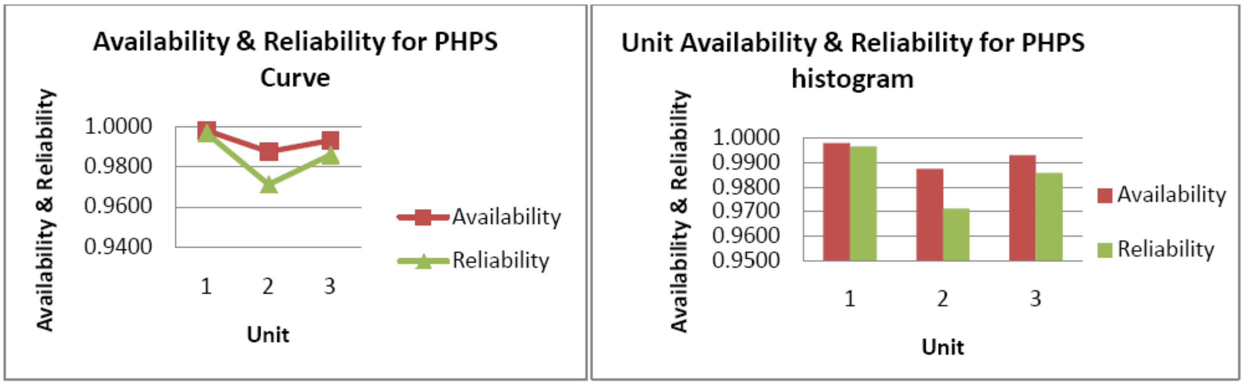

Fig. 3. Availability & Reliability of PHPS.

Table 4: System Availability and Reliability of (CHPS) 2007-12.

UNIT	Availability	Reliability
1	0.9994	0.9758
2	0.9988	0.9689
3	0.9996	0.9796
4	0.9995	0.9953

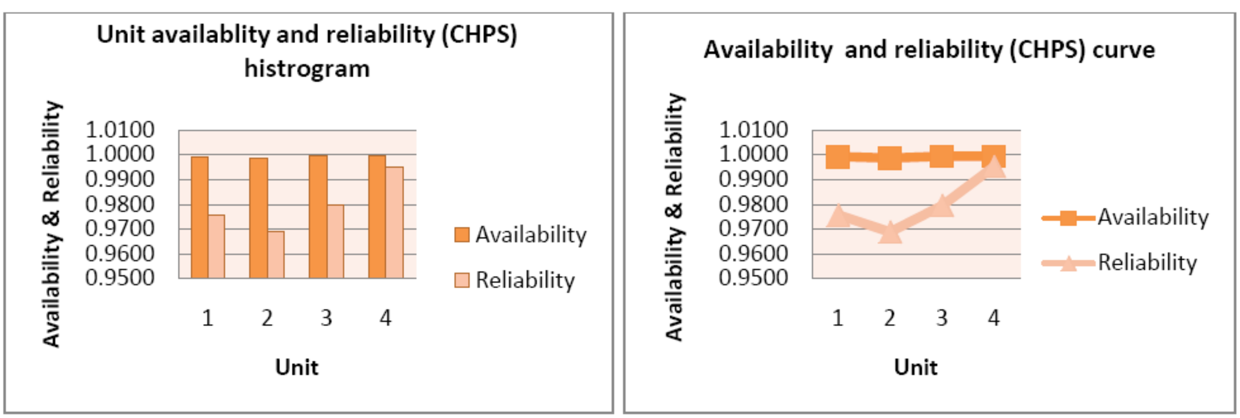

Fig.4. Availability & Reliability of CHPS.

Table 5: PHPS State Probability and Availability, Reliability Determination 2007-12.

State Number	State Probability	Frequency Of State
1	0.335310000	0.000146540
2	0.213010000	0.000056000
3	0.203061000	0.000042600
4	0.211300000	0.000000050
5	0.000000094	0.000000011
6	0.000000096	0.000000117
7	0.000000003	0.000000006
8	0.000000000	0.000000000

2-out-of3 system, State Probability = 0.942681

So, Reliability of PHPS = 0.942681, Availability of PHPS = 0.97012

Table 6: CHPS State Probability and Availability, Reliability Determination 2007-12.

State Number	State Probability	Frequency Of State
1	0.20162000000	0.0001350600000
2	0.10100000000	0.0000302450000
3	0.10400000000	0.0000101580000
4	0.09150000000	0.0000002035600
5	0.13010000940	0.0000000158000
6	0.10030009600	0.0000001430000
7	0.10146000300	0.0000000033000
8	0.10526000000	0.0000000042300
9	0.00913200000	0.0000000002350
10	0.00104500000	0.0000000001145
11	0.00135000000	0.0000000000253
12	0.00231000000	0.0000000000142
13	0.00505100000	0.0000000000113
14	0.00006023000	0.0000000000052
15	0.00001032000	0.0000000000032
16	0.00000000021	0.0000000000001

2-out-of 4 system, State Probability = 0.951120,
3-out-of 4 system, State Probability = 0.007377

So, Reliability of CHPS =0.951120 and Availability of CHPS = 0.960530

DISCUSSION AND CONCLUSION

The weak points that cause poor point reliability and availability for PHPS and CHPS are given in Table 7 & 8.

Table 7: Unit Major Faults That Affect the Reliability Indices for PHPS.

Unit No.	Cause of trip	Down time in Hr due to trip
Unit-1	Turbine (inlet gate, penstock,…etc)	54.2
Unit-2	Main Unit Transformer	267.3
Unit-2	Turbine (inlet gate, penstock,…etc)	214.25
Unit-3	Turbine (inlet gate, penstock,…etc)	119.25
Unit-3	Governor system (servo motors, wicket gates, Speed governor and etc...).	151.15

Table 8: Unit Major Faults That Affect the Reliability Indices for CHPS.

Unit No.	Cause of trip	Down time in Hr due to trip
Unit-1	Turbine (inlet gate, penstock,…etc)	11.02
Unit-2	Turbine (inlet gate, penstock,…etc)	15.55
Unit-3	Turbine (inlet gate, penstock,…etc)	28.35
Unit-3	External Effects	13.25

Our study of the plant availability and reliability that the maintenance program and skill of Engineers and technicians play an important role for improving the performance of the units and increasing the availability and reliability of the units and the power plant.

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