Reliability and Availability Evaluation of Sunkoshi Hydro Power Station

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Abstract: This paper evaluates and presents the reliability and availability of Sunkoshi Hydro Power Station, Nepal, during the period of FY 2009/10 to FY 2013/14. The operational data for the above period is collected and analyzed by using Markov model. Markov states are defined with the collected data and types of the failure faced by each generating units. The most important reliability indices like mean time to repair (MTTR), mean time to failure (MTTF), mean time between failure (MTBF), repair rate (μ), failure rate (λ) have been determined. State probabilities for each of the unit are also calculated and finally reliability and availability of Sunkoshi Hydro Power Station is evaluated.

Keywords: Hydro power; Availability; Reliability; Markov model; Failure rate; Repair rate

1. Introduction

Sunkoshi hydro power station is a run-of-river type power plant with installed capacity of 10.05 Megawatts (MW). It has three numbers of identical units each having capacity of 3.35 MW. The power station is located in Sindhupalchowk district at around of 80 Kilometer (KM) east from capital Kathmandu, Nepal. This station was commissioned in January 1972 with a friendly cooperation of Water Conservancy and Electric Power Ministry of the People's Republic of China and Government of Nepal (GO&M Business, 2013). It is owned by Nepal Electricity Authority (NEA), a solely governmental organization of Nepal**.**

Each unit of SHPS consists of several sub-units such as Headwork, Canal, Trash racks, Turbine, Generator, Power Transformer, Excitation system, Governor, Cooling system etc. The study has also focused on these sub-units that cause the unit failure. The unit failure will affect the availability and reliability of the unit and the power plant.

Availability and reliability evaluation play an important role to know performance, ability, and weakness of each unit. It would help to plan and decide periodical maintenance, minimum replacing or repairing schedules when failure occurs.

2. Methodology and Approach

Reliability is the probability of a device or system performing its purpose adequately for the period of time intended under the operating conditions encountered (Billinton & Allan, 1992). The definition of reliability relates to the ability of a system to continue functioning without failure, i.e., to complete a mission satisfactorily. This interpretation of reliability makes it totally unsuitable as a measure for these continuously operated systems that can tolerate failures. The measure used for such repairable systems which are characteristics of components used in hydro power station like generator, transformer, turbine etc is availability. Availability of a repairable device is defined as the proportion of time, in the long run, that is in or ready for service (Endrenyi, Reliability Modeling in Electric Power Systems, 1980). Availability is also interpreted as the probability of finding the component/device/system in the operating state at some time into the failure.

As there are two main categories of reliability evaluation techniques: analytical and simulation. Analytical techniques represent the system by a mathematical model and evaluate reliability indices by mathematical solutions. Simulation on the other hand, like Monte Carlo simulation methods, estimates the reliability indices by simulating the actual process and random behavior of the system.

This paper has used analytical techniques to evaluate the reliability and availability of individual units of Sunkoshi Hydro Power Station with the operational data from FY 2009/10 to FY 2013/14 of the station and analyzed using Markov model. Different states are defined from the collected data and type of failures occurred in each unit, are Markov states. Then reliability indices like mean time to repair (MTTR), mean time to failure (MTTF), mean time between failure (MTBF), repair rate (μ), failure rate (λ) are evaluated for each of the states. For each state, state probability are then calculated through repair rate and failure rate of the corresponding state.

Hydro Unit Modeling

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

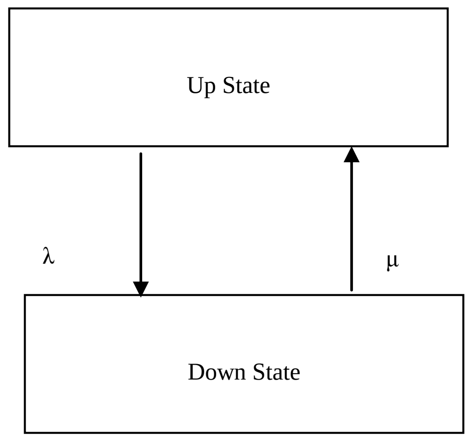

Figure 1: Two-state model (Majeed & Sadiq, 2006)

A unit is said to be in up-state if it is in operating state or in 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 (Sahu & Barve, 2013). 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 (Majeed & Sadiq, 2006).

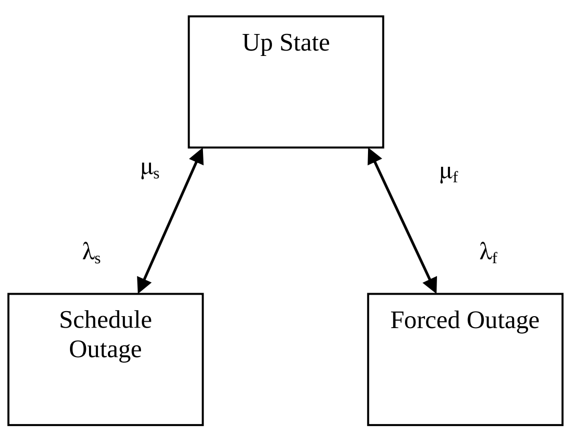

Figure 2: Three State Markov Model (Majeed & Sadiq, 2006)

Markov model has also been used for the availability and reliability evaluation of Dokan Hydro Power Station (Iraq) by defining states, finding failure and repair rates for each units and state probability of each state of the unit, then finally unit and plant reliability (Majeed & Sadiq, 2006).

Most of researches for reliability and availability analysis have used the terms failure rate, repair rate, however they modeled the data in different approaches. To study for the availability analysis of Shiroro Hydro Electric Power Station (Nigeria), it is assumed that exponential model with constant failure rate (Adediran & Jenyo, 1999).

Study of reliability of hydro generator groups for Remeti Hydro Power Plant has performed using Monte Carlo Simulation and compared the result with analytical calculation and concluded Monte Carlo Simulation method can be applied in reliability analysis of hydraulic units (Cristna, Simona, Danut, & Horea, 2011).

For the ease of study, events of hydro-unit and its down states are classified into:

1. Scheduled outage
2. Generator
3. Power Transformer
4. Turbine
5. Governing system
6. Excitation system
7. Civil Works
8. External Effects

Where

Schedule Outage includes Preventive Maintenance (Overhauling, Trashrack Cleaning, Shaftseal works, Spiral casing inspection, Penstock inspection, cooling system etc), Reserve (System outage, T/L maintenance, Load Dispatch Centre's instruction, Flood in river etc) and Lack of water.

Generator includes current transformer (CT), potential transformer (PT), energy meter change etc associated with the generator.

Power Transformer includes power transformer maintenance, gas relay maintenance, Clamp change etc.

Turbine includes guide vane link rod change, shear pin change, head cover repair, Turbine oil change, intake gate maintenance etc.

Excitation includes generator cleaning, carbon brush change, Card change, Relay change etc.

More developed hydro unit model is seen to be as:

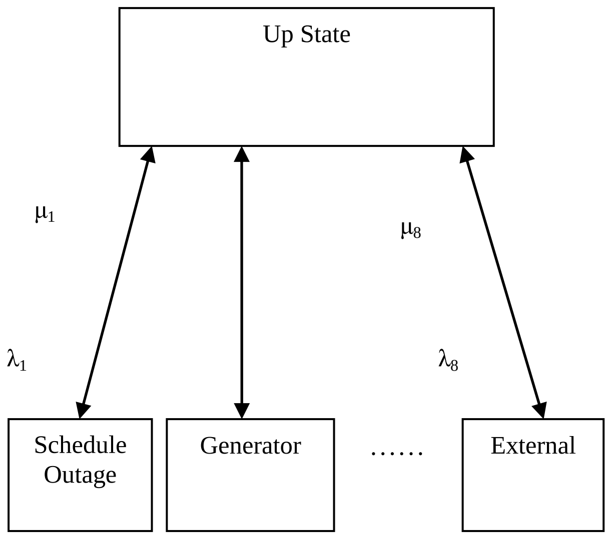

Figure 3: Developed hydro unit model

State probability of the each state is calculated with repair rate (μ) and failure rate (λ) as shown in Table 1 below:

Table 1: 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 $D = d_0+d_1+d_2+d_3+d_4+d_5+d_6+d_7+d_8$		

Calculation adoptions for the indices of reliability are described briefly as the followings (Zungeru, Araoye, & Garegy, 2012):

$$Mean\ time\ to\ repair\ (mean\ down\ time, MTTR) = FOH\ /\ N$$

$$Mean\ time\ to\ failure\ (mean\ up\ time, MTTF) = MTBF - MTTR$$

$$Mean\ time\ between\ failures\ (MTBF) = Total\ Observed\ time\ /\ N$$

$$Frequency = 1\ /\ MTBF$$

$$Repair\ rate\ (\mu) = 1\ /\ MTTR$$

$$Failure\ rate\ (\lambda) = 1\ /\ MTTF$$

Where,

N (Number of failures) - number of times a unit experiences outage

FOH (forced outage hours) – time in hours during which a unit or major equipment is unavailable due to outage.

3. Results

With the operational behavior of the generating unit throughout the year, its model is obtained calculating MTTR, MTBF, MTTF, failure rate, repair rate and then state probability of each state in all units. For demonstration, a case of calculation for FY 2009/10 for unit number 1 is shown below in Table 2, where we see major event other than schedule outage is turbine, having 18.83 hrs of repair time for 4 numbers of failure occurrences. Schedule outage accounts major event in the list of operational data statistics having 863.23 hrs with total number of failure occurred 63 times but schedule outage is the state that is without failure of the unit. Schedule outage is either predefined at the annual outage schedule or at the period of design for unit operation, allocating run of the unit for less energy in the period of dry season (i.e. lack of water) period. Thus schedule outage does not affect on the reliability of the unit but reduces availability of the unit.

According to the definition of reliability, the reliability is considered as the probability of the unit without failure. State 0 and state 1 are the states that are without failure (Dash & Das, 2014). Thus reliability of the unit is:

$$Reliability\ (R) = P0 + P1$$

Again availability is considered as the probability of the unit in operating state that is in state 0. Thus availability of the unit is:

$$Availability\ (A) = P0$$

Thus reliability (R) and availability (A) of unit 1 for the period FY 2066/067 are

Reliability = 0.997180

Availability = 0.899184

On the similar way reliability and availability for all units for each FY are calculated.

Table 2: State probability of Unit 1 for FY 2009/10

State No.	Basic events	No. of occurrence	Total Repair Times (hrs)	State Probability
0	Up state			0.899184
1	Schedule	63	863.23	0.097996
3	Power Transformer	1	2	0.000205
4	Turbine	4	18.83	0.001932
6	Excitation	1	0.42	0.000043
7	Civil Works	2	6.25	0.000640

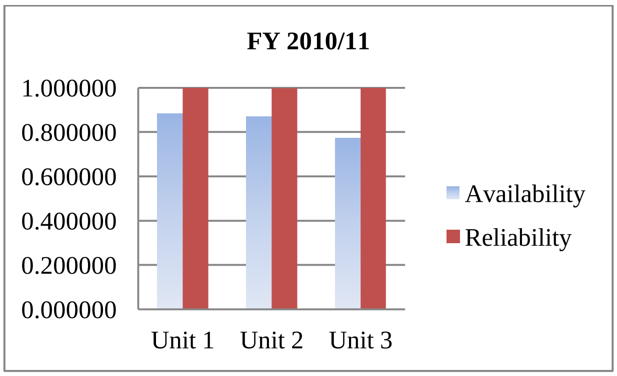

Figure 4: Reliability and Availability of Units for FY 2010/11

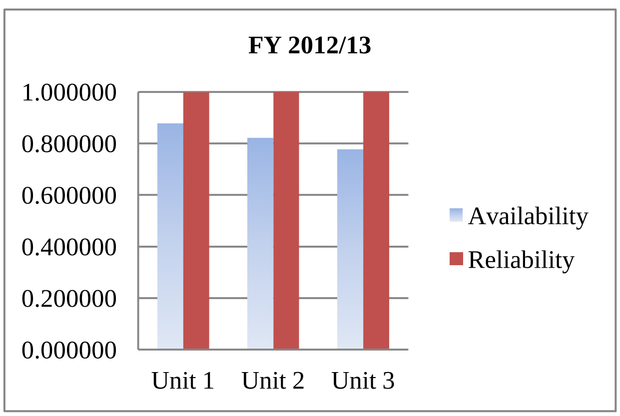

Figure 5: Reliability and Availability of Units for FY 2012/13

Table 3 shows the annual reliability and availability of all three units of SHPS for the period from FY 2009/10 to FY 2013/14 and Table 4 shows individual event and repair hours for all the events for each unit during study period of five years.

Table 3: Annual Unit Reliability and Availability for the FY 2009/10 to 2013/14

FY	Unit 1		Unit 2		Unit 3	
	A	R	A	R	A	R
2009/10	0.899184	0.997180	0.850137	0.997699	0.712577	0.997041
2010/11	0.883924	0.998889	0.870607	0.998250	0.774633	0.998997
2011/12	0.897546	0.997349	0.829932	0.999037	0.851308	0.997086
2012/13	0.877020	0.997839	0.820973	0.999281	0.777121	0.999216
2013/14	0.991306	0.997233	0.845845	0.997312	0.758917	0.997086

Table 4: Individual events and repair hours for all units during FY 2009/10 to FY 2013/14

Basic events	Unit No 1		Unit No 2		Unit No 3	
	No. of occurrence (N)	Total Repair Times (hrs)	No. of occurrence (N)	Total Repair Times (hrs)	No. of occurrence (N)	Total Repair Times (hrs)
Schedule Outage	257	3860.9	451	6799.2	521	9805.9
Generator	3	2.67	1	2.17	1	21.08
Power Transformer	4	4.81	6	5.64	9	8.35
Turbine	20	68.08	15	39.37	11	25.06
Governor					1	5.33
Excitation	3	1.75	4	1.92	3	1.41
Civil Works	5	24.8	6	29.92	5	21.93
External Effects	3	8.41	3	8.01	5	25.99

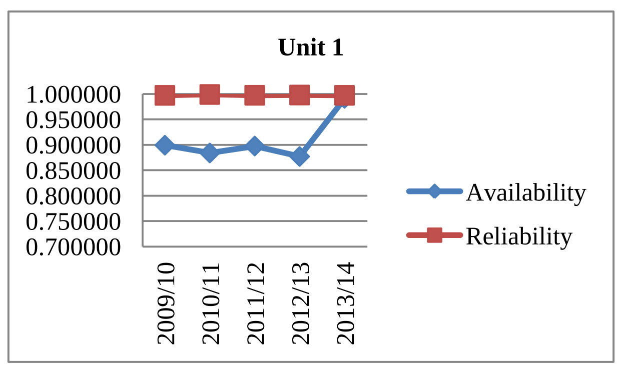

Figure 6: Annual Reliability and Availability of Unit No. 1 for FY 2009/10 to FY 2013/14

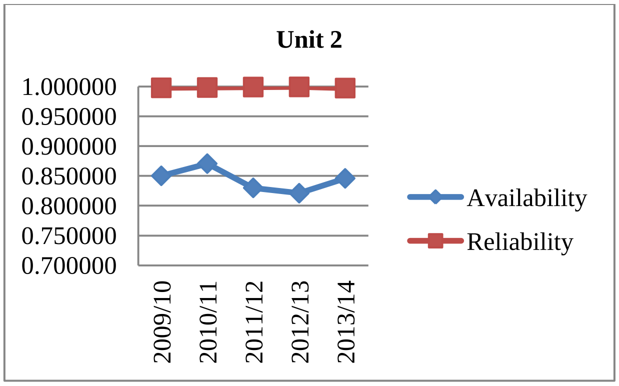

Figure 7: Annual Reliability and Availability of Unit No. 2 for FY 2009/10 to FY 2013/14

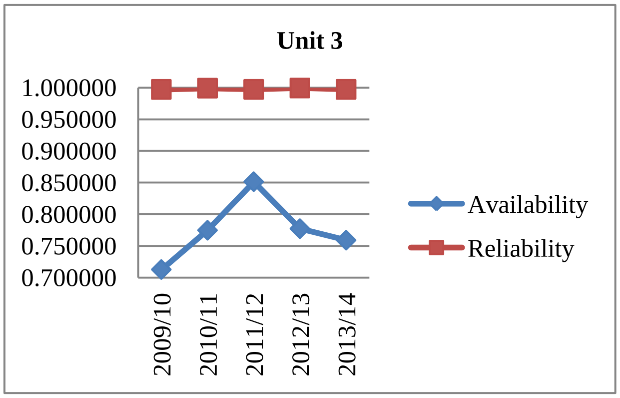

Figure 8: Annual Reliability and Availability of Unit No. 3 for FY 2009/10 to FY 2013/14

4. Discussion and Conclusion

From the analysis of operational data, maximum outage is seen to be schedule in all units. Also the schedule outage is greater in unit 3 than that of unit 2 and that of unit 1. This schedule outage also consists of reserve and idle outages in addition to scheduled preventive maintenance. Schedule outage should have to be of the similar duration in each unit but seen different for the units.

Provision for run of machines in isolation mode is available in unit 1 for the backup supply in station while main transmission system fails. Hence unit 1 has been seen running continuously even in the absence of system in order to get immediate back up supply. Besides, unit 1 has been facing the problem of moving its runner even if its guide vane made closed, due to leakage of water from intake gate and guide vanes. So this unit 1 has run more time in case when the flow is insufficient for all units. This unit 1 has recorded running of 8707.31 hrs on total observed hours of 8784 hrs in FY 2013/14 and seen to have higher availability (0.991306) in that period.

Other than the schedule outage, turbine has forced the machines to have failures more hours. In the study period of five years, turbine has 68.08 hrs for 20 numbers of failure occurrences in unit one, 39.37 hrs for 15 number of occurrences in unit 2 and 25.06 hrs for 11 number of occurrences in unit 3. This event includes the sub events like guide vane link arm change, shear pin change, head cover repair.

Civil works, Generator, Transformer have also some forced outages as 76.65 hrs, 25.92 hrs and 18.8 hrs respectively in the study period of five years. Governor and Excitation outages are seen 5.33 hrs and 5.08 hrs outages respectively during study period in the station.

This station has been using traditional manual approach to clean its trash racks, and much time in rainy season is seen scheduled to clean it. If modern racking machines are used for this cleaning purpose, much time could be saved and would enhance the availability of all units.

Being more than 40 years old power plant, Sunkoshi Hydro Power Station is found to be reliable power plant with having its each unit reliable and having the reliability index of more than 99 % during the study period in all units.

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