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Review of Reliability and Availability Evaluation of MPPGCL Sirmour Hydropower Station using Markov Modelling

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Abstract
Water is one of the best renewable energy sources available, as we are almost totally dependent on the availability of depleting fossil fuels. Being more reliable and cost effective, hydel energy is attracting more investors and entrepreneurs for investing and establishing hydro power plant. Since maintenance and operation of a power plant is very challenging and complicated process, calculating and analysing its compatibility and reliability is very important. This paper introduces Markov reliability model for MPPGCL Sirmour, India by studying the operational data and analysis of all parts of generating unit of the power plant for period of 2010–2015. The availability and reliability of individual unit of power plant is evaluated by taking into account different indices, namely failure rate (λ), repair rate (μ), MTTR, MTTF, MTBF through data collection and tabulating all types of failures for separate analysis. By these evaluations and analyses we can improve reliability of all the components of each unit of power plant. The error of a single sub-unit can affect the annual performance and efficiency of power generation. Thus, Markov modelling technique will help to decrease repair cost and identify sensitive equipment to be replaced. And probably errors can be removed that make more power available at low cost as per given input, and allow a fair step towards energy independence of local community.

Keywords: *Hydro power plant, performance, failure and repair rate, Markov modelling, renewable energy*

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INTRODUCTION
Sirmour Hydro Power Station (SHPS) is a canal based power plant. This hydel power plant was installed by the Madhya Pradesh State Electricity Board (MPSEB), which has now become Madhya Pradesh Power Generation Company Ltd. (MPPGCL). Resource water is received from Bansagar dam. It is located at Deolond, Shahdol District, Madhya Pradesh, India. It is a multipurpose river valley project on Sone River situated in the Ganges basin in Madhya Pradesh, India with both irrigation and 425 MW of hydroelectric power generation [1].

Hydro power station is situated at Sirmour, Rewa District (M.P.). Plant location coordinates are; 24°51′10″N 81°22′21″E. SHPS have installed capacity of 315 MW. It consists of three identical independent units, each having capacity of 105 MW. Its first unit started in September 1991 and second and third unit in August and September 1992. The equipment of power station have been installed by the Bharat Heavy Electricals Ltd. (BHEL) [2].

Particular unit of SHPS consist of several sub-units such as penstock, butter fly valve, spiral case, turbine, generator, excitation system, governor, power transformer, cooling system, etc. This study has focused on faults of these sub-units that cause the whole unit failure and ultimately affects the availability and reliability of the power plant.

Evaluation of reliability and availability of a power station gives better information to know performance, ability and weakness of each unit and also help to plan and decide periodical maintenance, minimum replacing or repairing schedules when failure occurs. It also helps to evaluate MTTR, MTTF, MTBF, failure rate, repair rate, probability of occurrence of failure for the components of each unit.

Reliability

System reliability can be defined as, the probability that a system will perform specified function within prescribed limit, under given environmental conditions, for a specified time.

The intention of designing for reliability is thus to design integrated system with assemblies that effectively fulfil all their required duties [3].

Availability

Availability can be simply defined as, the item's capability of being used over a period of time.

Or

The measure of an item's availability can be defined as, that period in which the item is in a usable state [3].

Maintainability

It is a measure of the repairable condition of an item that is determined by the mean time to repair (MTTR) established through corrective maintenance action. Performance variable relating availability to reliability and maintainability are concerned with the measures of time that subject to equipment failure. These measures are: mean time between failures (MTBF), mean time to failures (MTTF) or mean down time (MDT) and mean time to repair (MTTR) or mean up time (MUT) [3].

Markov Model Fundamentals

For any given system, a Markov model consists of a list of the possible states of that system, the possible transition paths between those states, and the rate parameters of those transitions. In reliability analysis the transitions usually consist of failures and repairs. When representing a Markov model graphically, each state is usually depicted as a bubble, with arrows denoting the transition paths between states, as depicted in the Figure 1 below for a single component that has just two states: healthy and failed [4].

Fig. 1: *State of the System.*

The symbol λ denotes the rate parameter of the transition from State 0 to State 1. In addition, we denote by $P_j(t)$ the probability of the system being in State j at time t. If the device is known to be healthy at some initial time t=0, the initial probabilities of the two states are $P_0(0)=1$ and $P_1(0)=0$. Thereafter the probability of State 0 decreases at the constant rate λ, which means that if the system is in State 0 at any given time, the probability of making the transition to State 1 during the next increment of time dt is λdt [5].

Therefore, the overall probability that the transition from State 0 to State 1 will occur during a specific incremental interval of time dt is given by multiplying:

(1) the probability of being in State 0 at the beginning of that interval, and
(2) the probability of the transition during an interval dt given that it was in State 0 at the beginning of that increment. This represents the incremental change dP_0 in probability of State 0 at any given time, so we have the fundamental relation:

$$dP_0 = -(P_0)(\lambda dt)$$

Dividing both sides by dt, we have the simple differential equation:

$$\frac{dP_0}{dt} = -\lambda P_0, \frac{dP_1}{dt} = \lambda P_0, P_0 + P_1 = 1$$

This signifies that a transition path from a given state to any other state reduces the probability of the source state at a rate equal to the transition rate parameter λ multiplied by the current probability of the state [6]. Now, since the total probability of both states must equal 1, it follows that the probability of State 1 must increase at the same rate that the probability of State 0 is decreasing. Thus the equations for this simple model are:

$$\frac{dP_0}{dt} = -\lambda P_0 \; \frac{dP_1}{dt} = \lambda P_0 \; P_0 + P_1 = 1$$

The solution of these equations, with the initial conditions $P_0(0)=1$ and $P_1(0)=0$, is:

$$P_0(t) = e^{\lambda t} \; P_1(t) = 1 - e^{-\lambda t}$$

The form of this solution explains why transitions with constant rates are sometimes called exponential transitions, because the transition times are exponentially distributed. Also, it's clear that the total probability of all the states is conserved. Probability simply flows from one state to another [7]. It's worth noting that the rate of occurrence of a given state equals the flow rate of probability into that state divided by the probability that the system is not already in that state. Thus in the simple example above the rate of occurrence of State 1 is given by $(\lambda P_0)/(1–P_1)=\lambda$.

Of course, most Markov are more elaborate than the simple example discussed above. The Markov model of a real system usually includes a full-up-state (i.e., the state with all elements operating) and a set of intermediate states representing partially failed condition, leading to the fully failed state, i.e., the state in which the system is unable to perform its design function. The model may include repair transition paths as well as failure transition paths. The analyst defines the transition paths and corresponding rate between the various states, and then writes the system equations whose solution represents the time-history of the system. In general, each transition path between two states reduces the probability of the state it is departing, and increases the probability of the state it is entering, at a rate equal to the transition parameter λ multiplied by the current probability of the source state [8].

The state equation for each state equates the rate of change of the probability of that state (dP/dt) with the probability flow into and out of that state. The total probability flow into a given state is the sum of all transition rates into that state, each multiplied by the probability of the state at the origin of that transition. The probability flow out of the given state is the sum of all transitions out of the state multiplied by the probability of that given state. To illustrate, the flows entering and exiting a typical state from and to the neighbouring states are depicted in Figure 2.

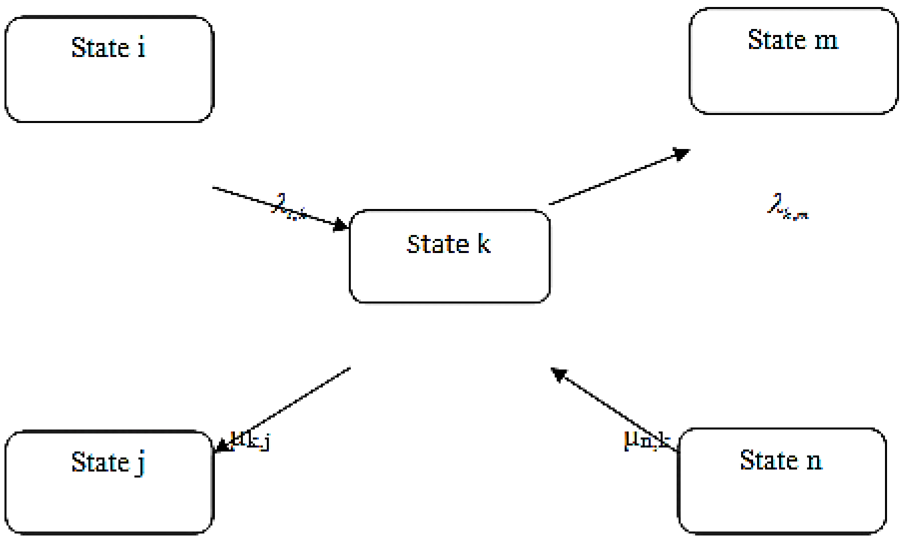

Fig. 2: *Transitions Into and Out of State P_j.*

This is not intended to represent a complete Markov model, but only a single state with some of the surrounding states and transition paths (Figure 2). It's conventional in the field of reliability to denote failure rates by the symbol λ and repair rates by the symbol μ, sometimes with subscripts to designate the source and destination states.

The state equation for State k sets the time derivative of $P_k(t)$ equal to the sum of the probability flows corresponding to each of the transitions into and out of that state. Thus we have:

$$\frac{dP_k}{dx} = \sum_i \lambda_{i,k} P_i + \sum_n \mu_{n,k} P_n - \left(\sum_j \mu_{k,j} + \sum_n \lambda_{k,n} \right) P_K$$

Each state in the model has an equation of this form, and these equations together determine the behaviour of the overall system. In this generic description, we have treated repair transitions as if they occur at constant rates, but, as noted above, actual repairs in real-world applications are usually not characterized by constant rates. Nevertheless, with suitable care, repairs can usually be represented in Markov models as continuous constant rate transitions from one state to another, by choosing each repair rate μ such that 1/μ is the mean time to repair for the affected state [9].

METHODOLOGY

Methods of evaluation of reliability techniques are categorised by two approaches:

1. Analytical, and
2. Simulation.

- Analytical approach gives information about mathematical modelling and evaluates reliability indices by mathematical solution.
- Simulation technique gives information about Monte Carlo simulation methods; they estimate the reliability indices by simulating the actual process and random behaviour of the system.

In this paper, we are using analytical techniques to evaluate the reliability and availability of each unit of Sirmour Hydro Power Station (SHPS). In this paper, we are considering the operational data of the period of 2010–15 of the station and analysed it using Markov model. After collection of data for each year and each unit, we classified for each unit the different types of failures occurred, that classification we defined Markov states. Evaluation of failure rate (λ) repair rate (μ), MTTR, MTTF, MTBF, each of the states are found from the classified data. For each state, state probability are then calculated through repair rate and failure rate of the corresponding state.

MARKOV MODELLING

Unit Modelling

To model a hydro-unit generally according to its mode of operation, it can be divided into up-state and down-state (Figure 3).

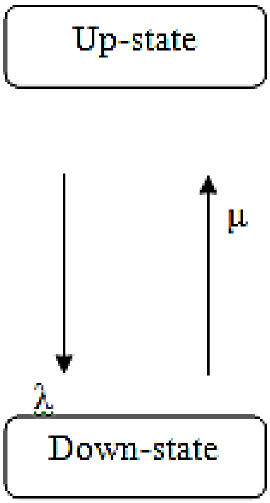

Fig. 3: *Two State Model.*

Up-state and down-state represent repair rate and failure rate in a hydro-unit generation. The hydro-unit is transit from up-state to down-state, either due to force or scheduled outages. To derive the Markov model of a hydro-unit we assume:

1) The failure and repair rates are exponentially distributed.
2) There is no transition between the scheduled and force outages. The unit after repairing is immediately returning to up-state.

The component is in the failed state, the system moves through two states, those before switching and after switching. A model of this process can be constructed by considering such components to have three-state cycles consisting of an operating state, a state between the fault and switching (s state) and a repair state (r state) when the device is isolated for repair. Obviously, the system effects of the s and r states are very different. It should be noted that r states, lasting until repairs are completed, are usually much longer in duration than the s states and, also that there are only very weak restriction as to the time distribution of any of the three states. A system of two independent components i and j with three-state cycles will have a state transition diagram. A developed Markov model can be explained as follows, the given is three-state Markov model (Figure 4).

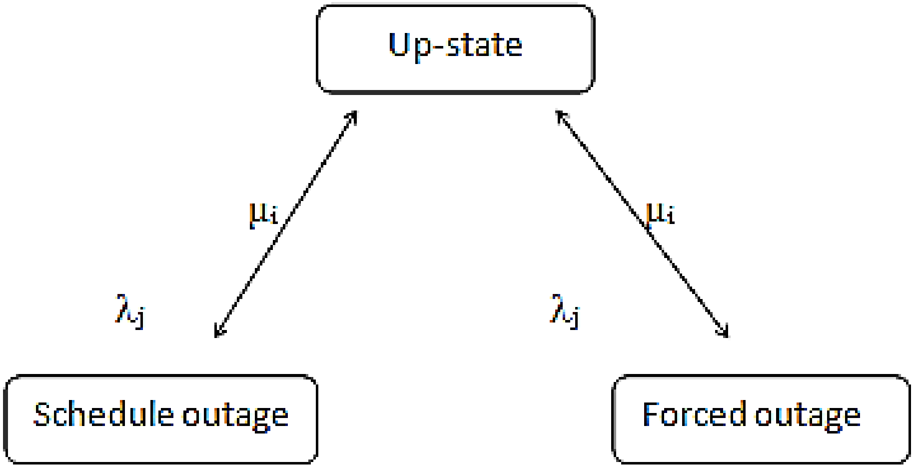

Fig. 4: *Three-State Markov Model.*

The event of hydro-unit in it's down-states, they are divided into two parts (Figure 5):

1. Scheduled outage/planned outage; and
2. Forced outage.

- ➢ Scheduled outage/planned outage:
  - Reserve, preventive maintenance, and overhaul.
- ➢ Force outage:
  - Generator,
  - Turbine (inlet gate, penstock, spiral case, butter fly valve, turbine bearing, and runner),
  - Excitation system (thyristor, cooling system, equipped transformer, etc.),
  - Governor system (servo motors, wicket gates, speed governor, etc.),
  - Main unit transformer,
  - Main unit circuit breaker,
  - External effects.

More developed model is given as follows:

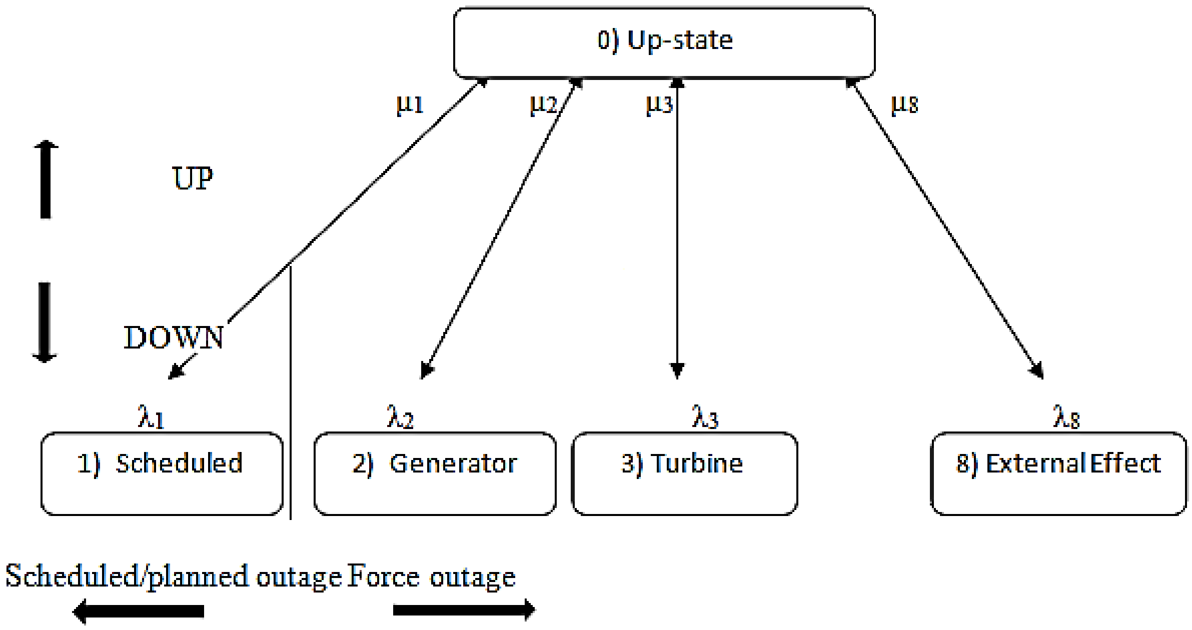

Fig. 5: *Developed Hydro-Unit Model.*

The state transition matrix of Figure 3 is as follows:

$$\begin{bmatrix} -(\lambda_1+\lambda_2+......+\lambda_8) & \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 & \lambda_5 & \lambda_6 & \lambda_7 & \lambda_8 \\ \mu_1 & -\mu_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_2 & 0 & -\mu_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_3 & 0 & 0 & -\mu_3 & 0 & 0 & 0 & 0 & 0 \\ \mu_4 & 0 & 0 & 0 & -\mu_4 & 0 & 0 & 0 & 0 \\ \mu_5 & 0 & 0 & 0 & 0 & -\mu_5 & 0 & 0 & 0 \\ \mu_6 & 0 & 0 & 0 & 0 & 0 & -\mu_6 & 0 & 0 \\ \mu_7 & 0 & 0 & 0 & 0 & 0 & 0 & -\mu_7 & 0 \\ \mu_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\mu_8 \end{bmatrix}$$

Using by repair rate (μ) and failure rate (λ),

we calculated state probability of each state as shown in Table 1.
The state probabilities are as follows**:**

Table 1: *State Probability.*

State No.	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
$D=d_0+d_1+d_2+d_3+d_4+d_5+d_6+d_7+d_8$		

Frequencies of encountering states are taken as in Table 2:

Table 2: *Frequencies of Encountering States.*

State Number	Rate of Departure	Frequency of State
0	$\lambda_1+\lambda_2+........+\lambda_8$	$(\lambda_1+\lambda_2+....+\lambda_8)d_0/D$
1	μ_1	$\mu_1 d_1/D$
2	μ_2	$\mu_2 d_2/D$
3	μ_3	$\mu_3 d_3/D$
4	μ_4	$\mu_4 d_4/D$
5	μ_5	$\mu_5 d_5/D$
6	μ_6	$\mu_6 d_6/D$
7	μ_7	$\mu_7 d_7/D$
8	μ_8	$\mu_8 d_8/D$

Plant Modelling

In this model all the three units of SHPS are studied together. So that the number of failure rates and repair rates of the entire unit for five years are taken into the consideration. They help to determine the plant availability and reliability.

The transition rate matrix of Figure 4 is determined by the same way as for unit transition rate matrix. State probabilities are determined by the same way for unit modelling. When the all the three units are up-state then the probability of State 1 is:

$$P = \mu_1\mu_2\mu_3 / \prod_{i=1}^{3}(\mu_i+\lambda_i)$$

When the entire unit are down-state then the probability of State 8 is:

$$P = \lambda_1\lambda_2\lambda_3 / \prod_{i=1}^{3}(\mu_i+\lambda_i)$$

The frequency of encountering State 1 is:
$f_1=(\lambda_1+\lambda_2+\lambda_3)P_1$

The frequency of encountering State 8 is:
$f_8=(\mu_1+\mu_2+\mu_3)P_8$

Representation of State Space Diagram

The number of states in the state space diagrams increases if the number of units of the power plant increase and as the number of states in which each system component can rise. In the diagram (Figure 6) we represent all the states of all three units under the repair (R) and failed (F) condition.

The number of states in the diagram is 2^3 for a 3-component system in which each state is represented as a 2-state model. In state space diagram, all the system components continuously operate either in series, parallel or series/parallel. In this system very necessary class of systems known as standby systems can also be modelled and analysed using state space diagrams and Markov technique. The state space diagram of the entire three units is as follows:

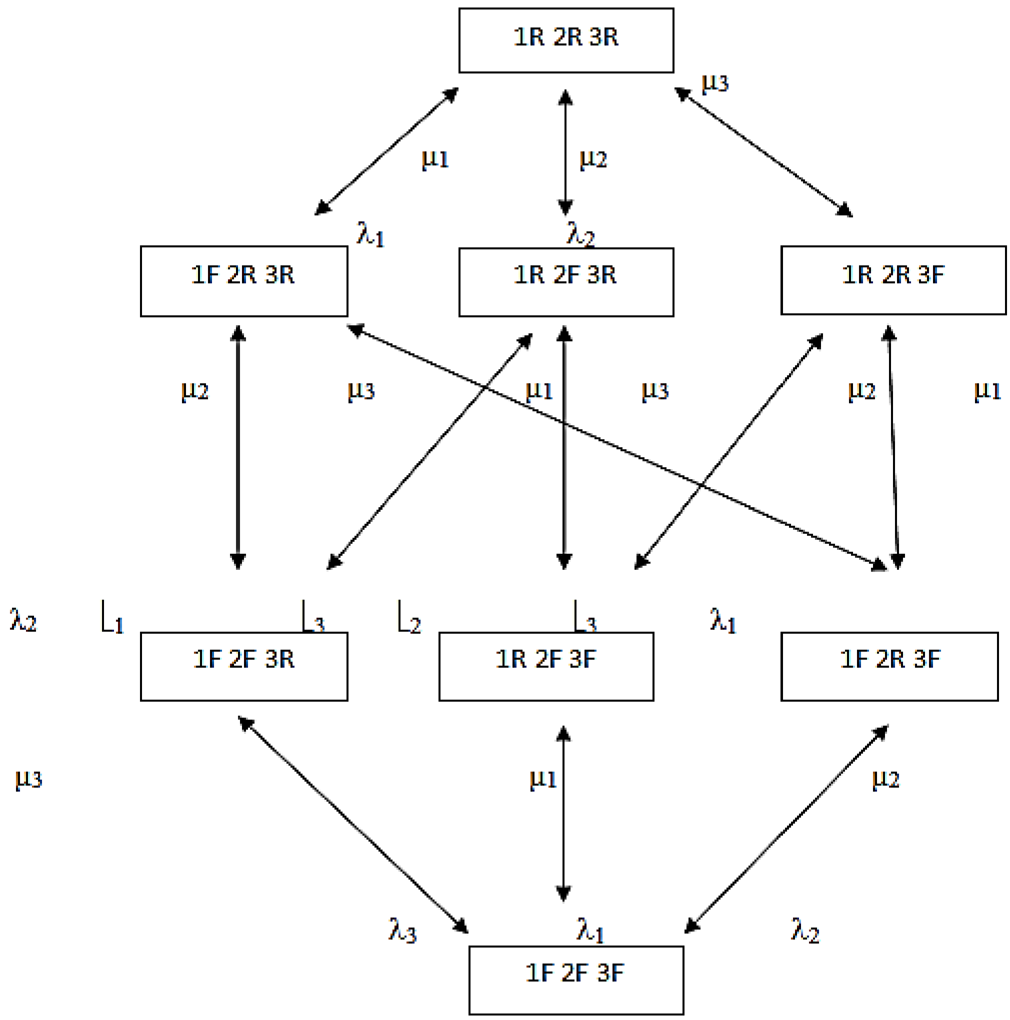

Fig. 6: *State Space Diagram for SHPS.*

If the system performing its work continuously with time without any interruption of failure that system is known as perfect system otherwise it is defective system. In reliability theory that systems are divided into two parts repairable and non-repairable systems.
Where repairable systems denote:

$$MTTF = m = \frac{\sum_{i=1}^{n} m_i}{n} = \frac{1}{\lambda}, MTTR = r = \frac{\sum_{i=1}^{n} r_i}{n} = \frac{1}{\mu}$$

λ=Failure rare
μ=Repair rate

n = *Number of failure*
$\frac{1}{\lambda}$ = *It is a average time till failure it is denoted by m or MTTF*
$\frac{1}{\mu}$ = *It is a average time to repair that denotd by r or MTTR*

System availability is used for reliability calculation of repairable system. Availability is defined as the probability of the system that works properly at any time, under the given conditions, that state is 0. Thus availability of the unit is:

Availability (A)=P_0

Where,
A= System availability,
U= System unavailability,
T= Total working time, and
R= System reliability.
According to the definition of reliability, the systems work without failure. Thus reliability of the unit is:
Reliability (R)=P_0+P_1

CONCLUSION

Today with the growing demand for power consumption due to increase in quality of life and income level, need of power generation is also at hike. For this, maintenance of a power station is the principal need. In this paper we concentrated on detailed evaluation of availability and reliability of each sub-unit of all the three units in THPS-I. For all three units of the plant, the faults or errors in each part over a period of 2010–15 are classified into several categories. and after this classification the reliability indices namely failure rate, repair rate, MTTR, MTTF and MTBF have been calculated by employing the Markov modelling method based on finding probability.

The model was used to determine expected power output along with the outages from all units. Hence we concluded that apart from scheduled outages that were planned for regular maintenance of plant, various other major or minor faults occur that affect the availability and reliability of the plant. The results indicated that increasing repair rates by additional repair crews considerably increased system availability and the expected power outputs. Analysis presented in this paper can be used by operation managers and maintenance engineers to study the systems under consideration for further improvements and thus expenses on those unnecessary repairs and faults can be minimized or removed.

REFERENCES

1. https://en.wikipedia.org/wiki/Bansagar_Dam
2. http://www.mppgenco.nic.in/hydel-generation.html
3. Rudolph Frederick Stapelberg. *Handbook of Reliability, Availability, Maintainability, and Safety in Engineering Design*.
4. *Handbook of Control Systems and Safety Evolution of Reliability*.
5. Majeed AR, Sadiq NM. Availability & Reliability Evaluation of Dokan Hydro Power Station. *IEEE Conf. Proc. Transmission and Distribution*. 2006.
6. Farshad Khosravi, Naziha Ahmad Azli, Ebrahim Babaei. A New Modeling Method for Reliability Evaluation of Thermal Power Plants. *IIIE International Conference on Power and Energy (PECon2010).*
7. Allan RN, Roman J. Reliability Assessment of Generation System Containing Multiple Hydro Power plant Using Simulation Techniques. *IEEE Trans Power Syst.* Aug 1989; 4(3): 1074–1080p.
8. Department of Army, US Army Crops of Engineer. *Reliability Analysis of Hydro Power Equipment*. Technical Letter No. 1110-2-550; 30 May 1997.
9. Billinton R, Hau Chen, Jiaqi Zhou. Individual Generating Station Reliability Assessment. *IEEE Trans Power Syst*. Nov 1999; 14(4): 1238–1244p.

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