

# Modeling and Analysis of Generation System Based on Markov Process with Case Study

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## Abstract

Power system is very complex and tedious task to study the reliability of whole system. In this work we are concentrating only on the reliability evaluation of the generation system. The reliability analysis of the generation system is applied in numerous ways. These ways are differing in time consumption and technology. Compared to simulation technique Markov technique has additional benefits. In this work using Markov process, Frequency and Duration of system, transient and steady-state probabilities are calculated for Bhorka Power Corporation of Gadag.

**Keywords:** Reliability, Adequacy, Generation Model, Load Model, Risk Model, Markov Chain, MTTF

## I. INTRODUCTION

The modern installation is separated into generation system, transmission and distribution system, because it is tedious task to review the entire installation as shown in figure 1. The modeling and analysis of generation system has been worked in this work.

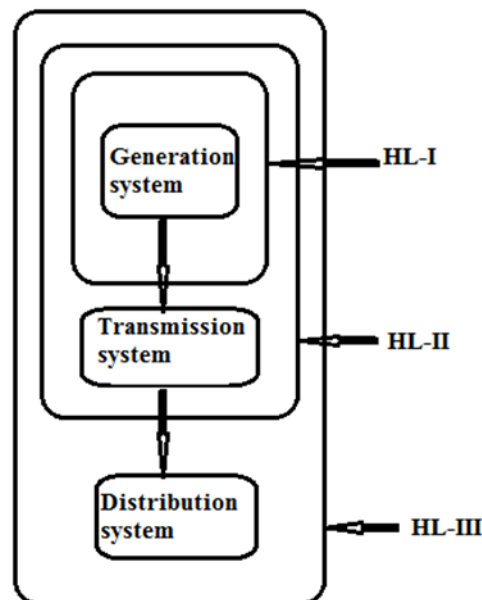


Fig. 1: functional zones and hierarchical levels.

In figure 1 the HL-I explains, the study and analysis of only generation system. HL-II explains, the study and analysis of the both generation and transmission systems. HL-III explains the study and analysis of the generation, transmission and distribution systems. In this work we are focusing on the reliability evaluation of the generation system (HL-I).

Adequacy assessment of the HL-I explains, ability of the generation system capacity to meet load demand. The generation system capacity is estimated with response to only load demand as shown in figure 2 [1][2][3].

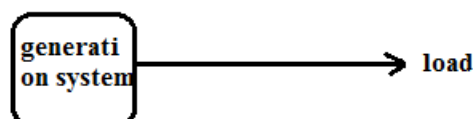


Fig. 2: adequacy assessment of HL-I.

Adequacy assessment of HL-I is carried out by modeling load and generation system separately then these two models are combined. Whenever the generation system is not able to meet the load demand, this value is represented by risk model as reliability index as shown in figure 3.

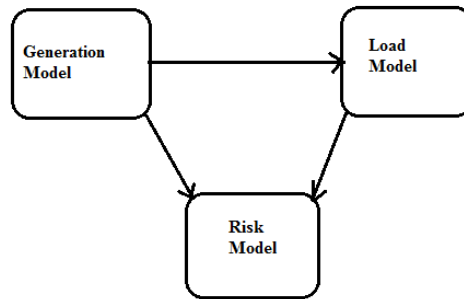


Fig. 3: Reliability Evaluation Of Generation System.

#### A. Generation Model:

The modeling of generation system is done by various methods as deterministic and probabilistic method. Deterministic method does not take into account of facility capacity, failure and repair rates. Probabilistic method is more advance from deterministic method. Monte carlo simulation and analytical methods are two methods in probabilistic method. Simulation needs past history data, errors are more compared to analytical method [1][2][3]

The analysis of the generation system conventionally created by developing the COPT (capacity outage probability table) using capacity units. Minimum cut set methodology, fault tree methodology, event based methodology, state based methodology and Markov ways are various methods obtainable in analytical methodology. Markov method is a lot of advance methodology to research and modeling of the generation system compared to different methods and it is explained in section II [4].

#### B. Load Model:

Load model is formed by using daily or monthly or yearly peak loads via time in seconds or minutes or hours as shown in figure 4. Where  $t_k$  is the time at outage of unit  $k$ ,  $Q_k$  is the outage capacity and [1][2][5].

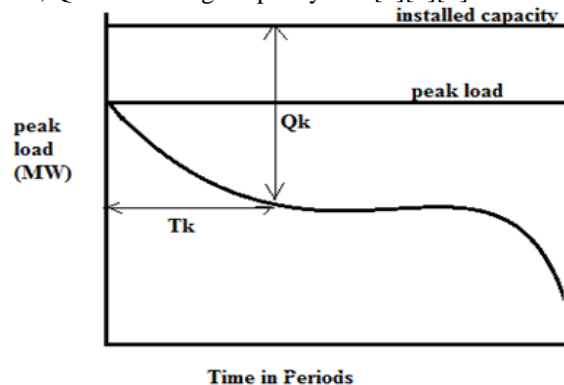


Fig. 4: Load model

#### C. Risk Model:

Risk model is to evaluate the risk indices such as LOLE, LOEE, EENS, Frequency and duration of system etc. In this work we are concentrating on the Frequency and Duration of states and steady state probabilities of the system [3].

#### D. Frequency and Duration of States:

The frequency and duration can be calculated as shown in figure 5 [3].

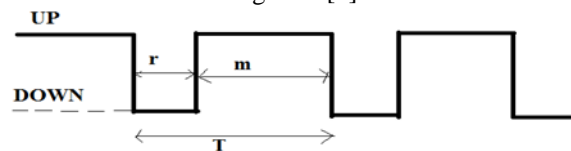


Fig. 5: Mean Time/State Diagram of a Single Component System

$$\begin{aligned} \text{Frequency of encountering State } i &= P(\text{being in State } i) \times (\text{rate of departure from State } i) \\ &= P(\text{not being in State } i) \times (\text{rate of entry into State } i). \end{aligned}$$

$$\text{Mean Duration in State } i, (m_i) = 1/\text{rate of departure from State } i.$$

(eq.1)

Where,

$$m = \text{MTTF} = 1/\lambda$$

$$r = \text{MTTR} = 1/\mu$$

$$T = \text{MTBF} = m + r = 1/f$$

And

$$\text{Availability} = m/(m+r) = m/T = 1/\lambda \cdot T = f/\lambda; \quad \text{Unavailability} = r/(m+r) = r/T = 1/T \cdot \mu = f/\mu$$

## II. MARKOV METHOD

The Markov method is very simple method, it considers failure rate of the system and complex system can be modeled in simple manner by applying semi-Markov method or hidden-Markov method. The Markov method is extremely advance and applicable to all or any engineering application by stating two international standards as IEC61165 and IEC 61508. IEC 61165 provides guidance on the applying of Markov techniques to dependability analysis. The main goal of IEC 61508 is to estimate the probability of failure on demand for the critical system being examined [5][6].

In Markov method the reliability is evaluated by using FOR (Forced Outage Rate), which is also referred as un-availability (U) and it is given by,

$$FOR = \frac{\text{forced outage hours}}{\text{in service hours} + \text{forced outage hours}}$$

$$FOR = \frac{\lambda}{\lambda + \mu}$$

$$A = 1 - FOR$$

Where,

- A = unit availability
- $\lambda$  = unit failure rate
- $\mu$  = unit repair rate
- U = unit unavailability.

Markov model is depicted in two parts as, variety of states and its state transitions between states. The one-component Markov model is shown in figure 6. Where state 1 represents the unit is operating and state 2 represents the unit is failed.

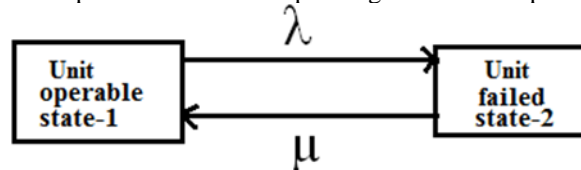


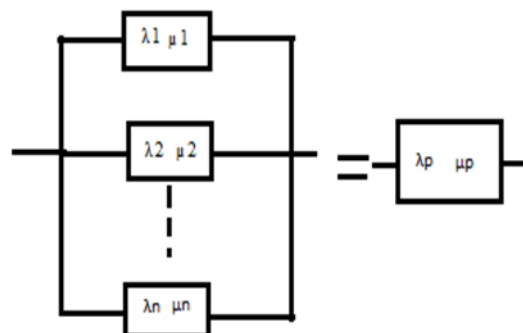
Fig. 6: One-component model of the Markov chain

From figure 6 we can acquire the steady state values for probabilities of every state. Using these values we can predict the behavior of the system. The steady state probabilities can be written as [6][7].

$$P1 = P_{up}, \quad P2 = P_{down}. \quad P1 = \lambda / (\lambda + \mu), \quad P2 = \mu / (\lambda + \mu).$$

### A. Probabilities of the Generation System:

Reliability of the system may be combination of exponential functions that has to be computed in easier manner. If the actual reliability function involving a number of exponential functions this might be approximated to single exponential function. Since exponential distribution is characterized by failure rate, the approach used to estimate the failure rate experimentally for parallel combinations as shown in figure below.



$$Q_p = \prod_{i=1}^n Q_i$$

$$A = 1 - \prod_{i=1}^n Q_i$$

$$\frac{1}{\lambda_p} = \left( \frac{1}{\lambda_1} + \frac{1}{\lambda_2} \dots \dots + \frac{1}{\lambda_n} \right) - \left( \frac{1}{(\lambda_1 + \lambda_2)} + \frac{1}{(\lambda_1 + \lambda_3)} \dots \dots + \frac{1}{(\lambda_1 + \lambda_n)} \right) + \left( \frac{1}{(\lambda_1 + \lambda_2 + \lambda_3)} + \dots \dots \dots + \left( (-1)^{n+1} \frac{1}{\sum \lambda_n} \right) \right) \quad (\text{eq-2})$$

Where,

- A= unit availability
- Qi= unit unavailability of unit i
- Qp= unavailability of parallel units
- $\lambda_p$  =failure rate of parallel units.

The equations of state probabilities are,

$$\begin{aligned} \frac{dP_1}{dt} &= -\lambda P_1(t) + \mu P_2(t) \\ \frac{dP_2}{dt} &= \mu P_1(t) - \lambda P_2(t) \end{aligned} \quad (\text{eq-3})$$

In general,

$$\frac{dP}{dt} = A P(t)$$

Where

- A= stochastic transitional probability matrix.
- P(t)= vector of the state probabilities.

$$A = \begin{bmatrix} -\lambda & \mu \\ \mu & -\lambda \end{bmatrix}$$

Using the transition matrix several reliability indices is obtained like the probability changes of every state with relevance to time, the system steady state probability, and MTTF are quickly obtained. These results can be used in the operation and programming of power system for various interval of  $\Delta t$ .

#### B. Availability of Whole Generation System:

The states of the power system is divided into acceptable W and unacceptable state U, which are W= {P1, P2, P3. P4, P5, P6, P7} U= {P8}. Availability of the system is calculated as,

$$A = \sum_{k=W} P_i(t) = P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t) + P_6(t) + P_7(t) \quad (\text{eq-4})$$

#### C. MTTF- Mean Time to First Failure of the System:

$$A = \begin{bmatrix} B & C \\ D & E \end{bmatrix}$$

Where

- B= 2x2 square matrix, that describes the shift probability between acceptable states of power system.
- C=2x1 matrix, that describes the shift probability from acceptable state to unacceptable state.
- D= 1x3 matrix, that describes the shift probability from unacceptable state to acceptable state.
- E=1x1 matrix, that describes the shift probability between unacceptable states.

If the unacceptable state of power system is set as absorption state i.e D=0 E=1 in (eq-5), a replacement transition matrix of Markov model are established. Therefore, the MTTF is given by

$$MTTF = \int_0^{\infty} A(i) dt = \sum_{i=0}^n q_i \quad (\text{eq-6})$$

Where i=1, 2, 3, 4,..... n= number of states.

The general form of Markov model,

$$\frac{d}{dt} P(t)^T = P(t)^T A$$

Where,

$$P(t)^T = (P_1(t) ; P_2(t) ; P_3(t) ; P_4(t) ; P_5(t) ; P_6(t) ; P_7(t))$$

A= stochastic transitional probability matrix.

$$P(t)^T = \int_0^{\infty} P(t)^T A$$

Let

$$\begin{aligned} q &= \int_0^{\infty} P(t) dt \\ \int_0^{\infty} P(t)^T dt &= q^T \times A \\ P(\infty)^T - P(0)^T &= q^T \times A \\ P(\infty)^T &= (0,0,0,1), \end{aligned}$$

$$\begin{aligned} P(0)^T &= (1,0,0,0,0,0,0) \\ P(\infty)^T &= (0,0,0,0,0,0,1) \\ (-1, 0, 0, 0, 0, 0, 1) &= (q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8)*A \quad (\text{eq-7}) \end{aligned}$$

### III. CASE STUDY

Reliability evaluation is evaluated using a real system BHORUKA POWER CORPORATION GADAG. The generation data has been given in the below table and single-line diagram as shown in figure 7 and One month generation data of the system is shown in table 1.

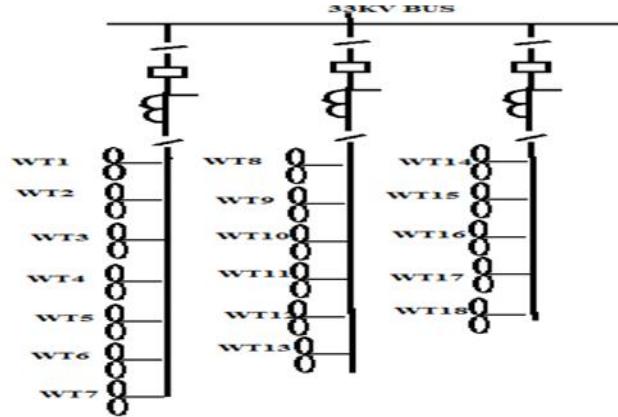


Fig. 7: single line diagram of Bhorka Power Corporation Gadag

Table -1:  
AUGUST-MONTH 2014 REPORT

WT NO	OPERATION hrs	CAPACITY KW	WOTT $\lambda(\text{hr})$	RT $\mu(\text{hr})$	AVAILABILITY (A)
1	666.24	37	72.53	5.23	95.00
2	668.12	48	69.79	6.09	95.60
3	685.13	42	55.62	3.25	97.89
4	689.32	44	54.68	0.00	98.14
5	690.28	38	53.72	0.00	97.46
6	671.15	38	72.85	0.00	96.08
7	668.19	45	69.71	6.10	94.27
8	672.38	42	70.12	1.50	95.61
9	694.14	47	49.86	0.00	98.26
10	675.18	34	68.82	0.00	95.63
11	654.39	39	82.43	7.18	95.85
12	692.34	43	51.66	0.00	97.84
13	696.39	44	47.61	0.00	99.18
14	669.39	40	74.61	0.00	95.01
15	NA	NA	NA	NA	NA
16	689.22	33	54.78	0.00	98.39
17	501.56	36	235.06	7.38	92.07
18	NA	NA	NA	NA	NA
Total	10685.57	650	1183.85	37.53	90.72

### IV. SIMULATION RESULTS

There are three components therefore there will be  $2^3 = 8$  states [8]. The Markov model is obtained by considering three radial lines as three components. It is shown in figure 8. The steady state probabilities of each state are tabulated in table 2. The frequency and duration of each state is tabulated in table 3.

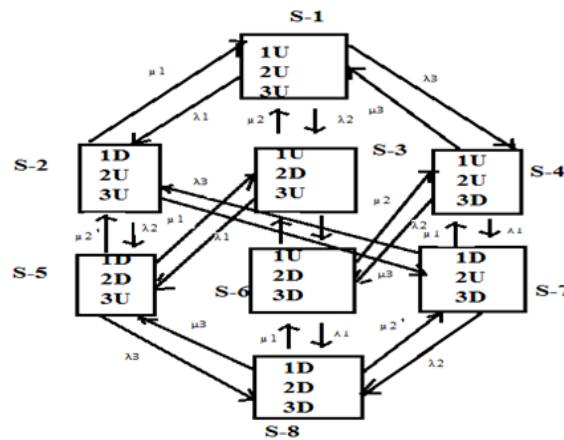


Fig. 8: Markov Model of Bhorkuka Power Corporation.

The state equations are

$$\begin{aligned}\frac{dP_1}{dt} &= -(\lambda_1 + \lambda_2 + \lambda_3)P_1(t) + \mu_1P_2(t) + \mu_2P_3(t) + \mu_3P_4(t) \\ \frac{dP_2}{dt} &= \lambda_1P_1(t) - (\mu_1 + \lambda_2 + \lambda_3)P_2(t) + \lambda_2P_5(t) + \lambda_3P_7(t) \\ \frac{dP_3}{dt} &= \mu_2P_1(t) - (\mu_3 + \lambda_1 + \lambda_3)P_3(t) + \lambda_1P_5(t) + \lambda_3P_6(t) \\ \frac{dP_4}{dt} &= \mu_3P_1(t) - (\mu_3 + \lambda_1 + \lambda_2)P_4(t) + \lambda_2P_6(t) + \lambda_1P_7(t) \\ \frac{dP_5}{dt} &= \mu_2P_2(t) + \mu_1P_3(t) - (\mu_2 + \mu_1 + \lambda_3)P_5(t) + \lambda_3P_8(t) \\ \frac{dP_6}{dt} &= \mu_3P_3(t) + \mu_2P_4(t) - (\mu_1 + \mu_3 + \lambda_2)P_6(t) + \lambda_1P_8(t) \\ \frac{dP_7}{dt} &= \mu_3P_2(t) + \mu_1P_4(t) - (\mu_1 + \mu_3 + \lambda_2)P_7(t) + \lambda_2P_8(t) \\ \frac{dP_8}{dt} &= \mu_3P_4(t) + \mu_1P_5(t) + \mu_2P_6(t) - (\mu_1 + \mu_2 + \mu_3)P_8(t)\end{aligned}$$

In general,

$$\frac{dP}{dt} = A P(t)$$

Where,

$$A = \begin{bmatrix} -(\lambda_1 + \lambda_2 + \lambda_3) & \lambda_1 & \lambda_2 & \lambda_3 & 0 & 0 & 0 & 0 \\ \mu_1 & -(\mu_1 + \lambda_2 + \lambda_3) & 0 & 0 & \lambda_2 & 0 & \lambda_3 & 0 \\ \mu_2 & 0 & -(\mu_3 + \lambda_1 + \lambda_3) & 0 & \lambda_1 & \lambda_3 & 0 & 0 \\ \mu_3 & 0 & 0 & -(\mu_3 + \lambda_1 + \lambda_2) & 0 & \lambda_2 & \lambda_1 & 0 \\ 0 & \mu_2 & \mu_1 & 0 & -(\mu_2 + \mu_1 + \lambda_3) & 0 & 0 & \lambda_3 \\ 0 & 0 & \mu_3 & \mu_2 & 0 & -(\mu_3 + \mu_2 + \lambda_1) & 0 & \lambda_1 \\ 0 & \mu_3 & 0 & \mu_1 & 0 & 0 & -(\mu_1 + \mu_3 + \lambda_2) & \lambda_2 \\ 0 & 0 & 0 & 0 & \mu_3 & \mu_1 & \mu_2 & -(\mu_1 + \mu_2 + \mu_3) \end{bmatrix}$$

Using eq-1 and eq-2 obtained the values as,

$$\begin{aligned}\lambda_1 &= 0.0821/\text{hr} & \mu_1 &= 820.9/\text{hr} \\ \lambda_2 &= 0.07613/\text{hr} & \mu_2 &= 44.706/\text{hr} \\ \lambda_3 &= 0.0277/\text{hr} & \mu_3 &= 0.8804/\text{hr}.\end{aligned}$$

Table -2:

The Steady-State Probabilities of each state are,

State no	Steady-State Probabilities
P1	P1UxP2UxP3U = 0.96775
P2	P1DxP2UxP3D = 0.03044
P3	P1UxP2DxP3U = 1.6479e-3
P4	P1UxP2DxP3D = 5.18505e-5
P5	P1DxP2UxP3U = 9.6786e-5
P6	P1DxP2UxP3D = 3.0452e-6
P7	P1DxP2DxP3U = 1.6481e-7
P8	P1DxP2DxP3D = 5.1856e-9

Table -3:  
Frequency and Duration of states

State no	State probability	Rate of departure from one state to other states	Frequency of encounter from one state to other states	Mean duration of one state to other states (hr)
P1	$P1UxP2UxP3U = 0.9677$	$\lambda1 + \lambda2 + \lambda3 = 0.18593$	$(\lambda1 + \lambda2 + \lambda3)xP1 = 0.1799$	$1/(\lambda1 + \lambda2 + \lambda3) = 5.3783$
P2	$P1DxP2UxP3D = 0.03044$	$\lambda2 + \mu1 + \lambda3 = 1.03863$	$(\lambda2 + \mu1 + \lambda3)xP2 = 0.0316$	$1/(\lambda2 + \mu1 + \lambda3) = 0.9628$
P3	$P1UxP2DxP3U = 1.6479e-3$	$\mu2 + \lambda3 + \lambda1 = 44.8158$	$(\mu2 + \lambda3 + \lambda1)xP3 = 0.0738$	$1/(\mu2 + \lambda3 + \lambda1) = 0.0223$
P4	$P1UxP2DxP3D = 5.18505e-5$	$\mu3 + \lambda2 + \lambda1 = 45.6685$	$(\mu3 + \lambda2 + \lambda1)xP4 = 2.3679e-3$	$1/(\mu3 + \lambda2 + \lambda1) = 0.02189$
P5	$P1DxP2UxP3U = 9.6786e-5$	$\mu2 + \mu1 + \lambda3 = 821.0038$	$(\mu2 + \mu1 + \lambda3)xP5 = 0.07946$	$1/(\mu2 + \mu1 + \lambda3) = 1.2180e-3$
P6	$P1DxP2UxP3D = 3.0452e-6$	$\mu3 + \mu2 + \lambda1 = 821.8565$	$(\mu3 + \mu2 + \lambda1)xP6 = 2.5027e-3$	$1/(\mu3 + \mu2 + \lambda1) = 1.21675e-3$
P7	$P1DxP2DxP3U = 1.6481e-7$	$\mu3 + \mu1 + \lambda2 = 865.6337$	$(\mu3 + \mu1 + \lambda2)xP7 = 1.4272e-4$	$1/(\mu3 + \mu1 + \lambda2) = 1.1552e-3$
P8	$P1DxP2DxP3D = 5.1856e-9$	$\mu3 + \mu2 + \mu1 = 866.4864$	$(\mu3 + \mu2 + \mu1)xP8 = 4.4933e-6$	$1/(\mu3 + \mu2 + \mu1) = 1.1540e-3$

## V. CONCLUSION

The modeling and analysis of Bhoruka Power Corporation of Gadag using Markov model has resulted that the steady state probability of states is decreasing. Frequency and duration values of each state has resulted that, frequency and duration values are decreases as state increases. The frequency and duration of state-1 is highest and state-8 is lowest. Complexity will increases by considering de-rated states but it gives same results of Three-component model values by neglecting very low values.

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