Research Article

Cost-benefit analysis of two- identical cold standby system subject to non-availability of water resulting failure to produce hydroelectric power and failure due to non-availability of coal to produce thermal power

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Abstract

Introduction: A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle. The greatest variation in the design of thermal power stations is due to the different fossil fuel resources generally used to heat the water. Some prefer to use the term energy center because such facilities convert forms of heat energy into electrical energy. Certain thermal power plants also are designed to produce heat energy for industrial purposes of district heating, or desalination of water, in addition to generating electrical power. **Thermal Power:** Thermal power is the "largest" source of power in India. There are different types of Thermal power plants based on the fuel used to generate the steam such as coal, gas, Diesel etc. About 75% of electricity consumed in India are generated by thermal power plants. **Coal:** More than 51% of India's commercial energy demand is met through the country's vast coal reserves. Public sector undertaking NTPC and several other state level power generating companies are engaged in operating coal based Thermal Power Plants. Apart from NTPC and other state level operators, some private companies are also operating the power plants. As on July 31, 2010, and as per the Central Electricity Authority the total installed capacity of Coal or Lignite based power plants in India are 87,093.38 MW. Hydro accounted for 16 percent of global electricity consumption, and 3,427 terawatt-hours of electricity production in 2010, which continues the rapid rate of increase experienced between 2003 and 2009. Hydropower is produced in 150 countries, with the Asia-Pacific region generated 32 percent of global hydropower in 2010. China is the largest hydroelectricity producer, with 721 terawatt-hours of production in 2010, representing around 17 percent of domestic electricity use. Brazil, Canada, New Zealand, Norway, Paraguay, Austria, Switzerland, and Venezuela have a majority of the internal electric energy production from hydroelectric power. Paraguay produces 100% of its electricity from hydroelectric dams, and exports 90% of its production to Brazil and to Argentina. Norway produces 98–99% of its electricity from hydroelectric sources. There are now three hydroelectric plants larger than 10 GW: the Three Gorges Dam in China, Itaipu Dam across the Brazil/Paraguay border, and Guri Dam in Venezuela. Water and coal play an important and pivotal role in producing hydroelectric and thermal power respectively. Non-availability of water results failure to produce hydroelectric power and non-availability of coal results failure to produce thermal power. Reliability is a measure of how well a system performs or meets its design requirements. It is hence the prime concern of all scientists and engineers engaged in developing such a system.. In this paper we have taken two types of failures (1) FNAWH - non-availability of water resulting failure to produce Hydroelectric Power (2) FNACT- non-availability of coal to **Produce thermal power:** When the main unit fails due to non-availability of coal then cold standby system becomes operative. Non-availability of coal cannot occur simultaneously in both the units and after failure the unit undergoes very costly repair facility immediately. Applying the regenerative point technique with renewal process theory the various reliability parameters MTSF, Availability, Busy period, Benefit-Function analysis have been evaluated.

Keywords: Cold Standby, FNAWH- non-availability of water resulting failure to produce Hydroelectric Power, FNACT- non-availability of coal to produce thermal power, first come first serve, MTSF, Availability, Busy period, Cost-Benefit analysis.

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Received Date: 25/09/2014 Accepted Date: 07/10/2014

How to site this article: Ashok Kumar Saini. Cost-benefit analysis of two- identical cold standby system subject to non-availability of water resulting failure to produce hydroelectric power and failure due to non-availability of coal to produce thermal power. *International Journal of Statistika and Mathemtika* Aug-Oct 2014; 11(3): 214-220. http://www.statperson.com(accessed 07 October 2014)

Access this article online	
Quick Response Code:	Website: www.statperson.com
	DOI: 08 October 2014

INTRODUCTION

India was the 7th largest producer of hydroelectric power in 2008 after Norway: 114 TW h and 3.5% the world total in 2008.The potential for hydroelectric power **in** India is one of the greatest in the world. India is endowed with economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor. In addition, 6,780 MW in terms of installed capacity from Small, Mini, and Micro Hydel schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. It is the most widely used form of renewable energy. India is blessed with immense amount of hydro-electric potential and ranks 5th in terms of exploitable hydro-potential on global scenario. The present installed capacity is approximately **39,788.40 MW** which is 17.39% of total electricity generation in India. The public sector has a predominant share of 97% in this sector. Stochastic behaviour of systems operating under changing environments has widely been studied. Dhillon, B.S. and Natesan, J. (1983) studied outdoor power systems in fluctuating environment. Kan Cheng (1985) has studied reliability analysis of a system in a randomly changing environment. Jinhua Cao (1989) has studied a man machine system operating under changing environment subject to a Markov process with two states. The change in operating conditions viz. fluctuations of voltage, corrosive atmosphere, very low gravity etc. may make a system completely inoperative. Severe environmental conditions can make the actual mission duration longer than the ideal mission duration. In this paper we have taken two types of failures (1) **FNAWH- failure due to non-availability of water resulting failure to produce Hydroelectric Power** (2) **FNACT- non-availability of coal to produce thermal power**. When the main operative unit **fails due to FNACT- non-availability of coal to produce thermal power** then cold standby system becomes operative. **Non-availability of coal to produce thermal power** cannot occur simultaneously in both the units and after failure the unit undergoes repair facility of very high cost in case of **FNACT- non-availability of coal to produce thermal power** immediately. The repair is done on the basis of first fail first repaired.

Assumptions

1. $F_1(t)$ and $F_2(t)$ are general failure time distributions due to **non-availability of water resulting failure to produce Hydroelectric power** and **Non-availability of coal to produce thermal power.** The repair is of two types -Type -I, Type-II with repair time distributions as $G_1(t)$ and $G_2(t)$ respectively.
2. The **Non-availability of coal to produce thermal power** is non-instantaneous and it cannot come simultaneously in both the units.
3. Whenever the there is availability of coal the unit works as normal as before. But as soon as there occur **Non-availability of coal to produce thermal power** of magnitude beyond the specified range of the unit the operation of the unit stops automatically.
4. The repair starts immediately after the **Non-availability of coal to produce thermal power** of beyond specified of the unit are over and works on the principle first fail first repaired basis.
5. The repair facility does no damage to the units and after repair units are as good as new.
6. The switches are perfect and instantaneous.
7. All random variables are mutually independent.
8. When both the units fail, we give priority to operative unit for repair.
9. Repairs are perfect and failure of a unit is detected immediately and perfectly.
10. The system is down when both the units are non-operative.

SYMBOLS FOR STATES OF THE SYSTEM

$F_1(t)$ and $F_2(t)$ are the **failure time distribution** due to **non-availability of water resulting failure to produce Hydroelectric power** and failure due to **Non-availability of coal to produce thermal power** respectively $G_1(t)$, $G_2(t)$ – repair time distribution Type -I, Type-II due to **non-availability of water resulting failure to produce hydroelectric power** and failure due to **Non-availability of coal to produce thermal power** respectively

Superscripts: O, CS, FNAWH, FNACT

Operative, Cold Standby, Failure due to non**-availability of water resulting failure to produce hydroelectric power**, failure due to **Non-availability of coal to produce thermal power** respectively

Subscripts: nawhf, nactf, actf, ur, wr, uR

Non-availability of water resulting failure to produce hydroelectric power, Non-availability of coal to produce thermal power failure, availability of coal to produce thermal power failure, under repair, waiting for repair, under repair continued from previous state respectively

Up states: 0, 1, 2;

Down states: 3, 4

Regeneration point – 0, 1, 2

Notations

M_i (t) System having started from state I is up at time t without visiting any other regenerative state

A_i (t) state is up state as instant t

R_i (t) System having started from state I is busy for repair at time t without visiting any other regenerative state.

B_i (t) the server is busy for repair at time t.

H_i (t) Expected number of visits by the server for repairing given that the system initially starts from regenerative state i

States of the System

0(O_{nactf}, CS_{nactf})

One unit is operative and the other unit is cold standby and there is no Non-availability of coal to produce thermal power failure in both the units.

1($SOFNACT_{actf, ur,}$ O_{nactf})

The operating unit fails due to Non-availability of coal to produce thermal power and is under repair immediately of very costly Type- II and standby unit starts operating with availability of coal to produce thermal power.

2($FNAWH_{nactf, nawf, ur}$, O_{nactf})

The operative unit fails to produce hydroelectric power due to FNAWH resulting from non-availability of water and undergoes repair of type I and the standby unit becomes operative with no availability of coal to produce thermal power.

3($FNACT_{actf,uR}$, $FNAWH_{nactf, nawf,wr}$)

The first unit fails due to Non-availability of coal to produce thermal power and under very costly Type-II repair is continued from state 1 and the other unit fails to produce hydroelectric power due to FNAWH resulting from non-availability of water and is waiting for repair of Type -I.

4($FNACT_{act,uR}$, $FNACT_{act,wr}$)

The one unit fails due to Non-availability of coal to produce thermal power is continues under repair of very costly Type - II from state 1 and the other unit also fails due to Non-availability of coal to produce thermal power is waiting for repair of very costly Type- II.

5($FNAWH_{nactf, nawf, uR}$, $FNACT_{act, wr}$)

The operating unit fails to produce hydroelectric power due to non-availability of water (FNAW H mode) and under repair of Type - I continue from the state 2 and the other unit fails due to Non-availability of coal to produce thermal power is waiting for repair of very costly Type- II.

6($FNAWH_{nactf,nawf,uR}$, $FNAWH_{nactf,nawf,wr}$)

The operative unit fails to produce hydroelectric power due to FNAWH resulting from non- availability of water and under repair continues from state 2 of Type –I and the other unit is also failed to produce hydroelectric power due to FNAWH resulting from non-availability of water and is waiting for repair of Type-I and there is no availability of coal to produce thermal power.

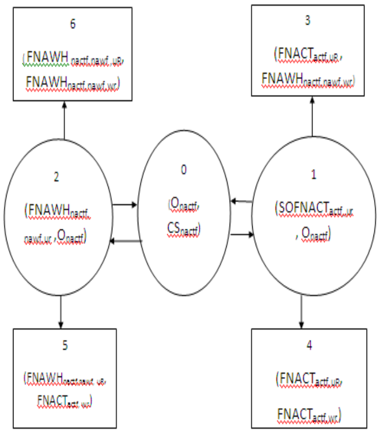

Figure 1: The State Transition Diagram

● Regeneration point - states 0, 1, 2. ○ Up State ▭ Down State

TRANSITION PROBABILITIES

Simple probabilistic considerations yield the following expressions:

$p_{01} = \int_0^{\infty} \overline{F}_2(t)dF_1(t)$, $p_{02} = \int_0^{\infty} \overline{F}_1(t)dF_2(t)$

$p_{10} = \int_0^{\infty} \overline{F}_2(t)dG_1(t)$, $p_{13} = p_{11}^{(3)} = p_{11}^{(4)} = \int_0^{\infty} \overline{G}_1(t)dF_2(t)$

$p_{25} = p_{22}^{(5)} = p_{22}^{(6)} = \int_0^{\infty} \overline{G}_2(t)dF_1(t)$

clearly

$p_{01} + p_{02} = 1,$

$p_{10} + p_{13} = (p_{11}^{(3)}) + p_{14} = (p_{11}^{(4)}) = 1,$

$p_{20} + p_{25} = (p_{22}^{(5)}) + p_{26} = (p_{22}^{(6)}) = 1$ (1)

And mean sojourn time is

$\mu_0 = E(T) = \int_0^{\infty} P[T > t]dt$ (2)

Mean Time to System Failure

$Ø_0(t) = Q_{01}(t)[s]\, Ø_1(t) + Q_{02}(t)[s]\, Ø_2(t)$

$Ø_1(t) = Q_{10}(t)[s]\, Ø_0(t) + Q_{13}(t) + Q_{14}(t)$

$Ø_2(t) = Q_{20}(t)[s]\, Ø_0(t) + Q_{25}(t) + Q_{26}(t)$ (3-5)

We can regard the failed state as absorbing

Taking Laplace-Stiljes transform of eq. (3-5) and solving for

$ø_0^*(s) = N_1(s) / D_1(s)$ (6)

where

$N_1(s) = Q_{01}^*[\, Q_{13}^*(s) + Q_{14}^*(s)\,] + Q_{02}^*[\, Q_{25}^*(s) + Q_{26}^*(s)\,]$

$D_1(s) = 1 - Q_{01}^* Q_{10}^* - Q_{02}^* Q_{20}^*$

Making use of relations (1) and (2) it can be shown that $ø_0^*(0) = 1$, which implies that $ø_0^*(t)$ is a proper distribution.

$$\text{MTSF} = E[T] = \frac{d}{ds} ø_0^*(s) \Big|_{s=0} = (D_1'(0) - N_1'(0)) / D_1(0)$$

$$= (\mu_0 + p_{01}\mu_1 + p_{02}\mu_2) / (1 - p_{01}p_{10} - p_{02}p_{20})$$

where

$\mu_0 = \mu_{01} + \mu_{02},\ \mu_1 = \mu_{10} + \mu_{13} + \mu_{14}$

$\mu_2 = \mu_{20} + \mu_{25} + \mu_{26}$

AVAILABILITY ANALYSIS

Let $M_i(t)$ be the probability of the system having started from state I is up at time t without making any other regenerative state. By probabilistic arguments, we have

The value of $M_0(t)$, $M_1(t)$, $M_2(t)$ can be found easily.

The point wise availability $A_i(t)$ have the following recursive relations

$A_0(t) = M_0(t) + q_{01}(t)[c]A_1(t) + q_{02}(t)[c]A_2(t)$

$A_1(t) = M_1(t) + q_{10}(t)[c]A_0(t) + q_{11}^{(3)}(t)[c]A_1(t) + q_{11}^{(4)}(t)[c]A_1(t),$

$A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) + [q_{22}^{(5)}(t)[c] + q_{22}^{(6)}(t)]\,[c]A_2(t)$ (7-9)

Taking Laplace Transform of eq. (7-9) and solving for $\hat{A}_0(s)$

$\hat{A}_0(s) = N_2(s) / D_2(s)$ (10)

Where

$N_2(s) = \hat{M}_0(s)(1 - \hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s))\,(1 - \hat{q}_{22}^{(5)}(s) - \hat{q}_{22}^{(6)}(s)) + \bar{q}_{01}(s)\,\hat{M}_1(s)$
$[\,1 - \hat{q}_{22}^{(5)}(s) - \hat{q}_{22}^{(6)}(s)] + \hat{q}_{02}(s)\,\hat{M}_2(s)(1 - \hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s))$

$D_2(s) = (1 - \hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s))\,\{\,1 - \hat{q}_{22}^{(5)}(s) - \hat{q}_{22}^{(6)}(s)\,)[1 - (\hat{q}_{01}(s)\,\hat{q}_{10}(s))(1 -$
$\hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s))]$

The steady state availability

$$A_0 = \lim_{t\to\infty}[A_0(t)] = \lim_{s\to 0}[s\,\hat{A}_0(s)] = \lim_{s\to 0}\frac{s\,N_2(s)}{D_2(s)}$$

Using L' Hospitals rule, we get

$$A_0 = \lim_{s\to 0}\frac{N_2(s)+s\;N_2{}'(s)}{D_2{}'(s)} = \frac{N_2(0)}{D_2{}'(0)} \qquad (11)$$

The expected up time of the system in (0, t] is

$$\lambda_u(t) = \int_0^{\infty} A_0(z)\,dz \text{ So that } \bar{\lambda}_u(s) = \frac{\ddot{A}_0(s)}{s} = \frac{N_2(S)}{SD_2(S)} \qquad (12)$$

The expected down time of the system in (0, t] is

$$\lambda_d(t) = t - \lambda_u(t) \text{ So that } \bar{\lambda}_d(s) = \frac{1}{s^2} - \bar{\lambda}_u(s) \qquad (13)$$

The expected busy period of the server when there is FNAWH-failure due to non-availability of water resulting not to produce hydroelectric power in (0, t]

$R_0(t) = q_{01}(t)[c]R_1(t) + q_{02}(t)[c]R_2(t)$

$R_1(t) = S_1(t) + q_{01}(t)[c]R_1(t) + [q_{11}^{(3)}(t) + q_{11}^{(4)}(t)[c]R_1(t),$

$R_2(t) = q_{20}(t)[c]R_0(t) + [q_{22}^{(6)}(t)+q_{22}^{(5)}(t)][c]R_2(t)$ (14-16)

Taking Laplace Transform of eq. (14-16) and solving for $\bar{R}_0(s)$

$\bar{R}_0(s) = N_3(s) / D_3(s)$ (17)

where

$N_3(s) = \hat{q}_{01}(s)\,\hat{S}_1(s)$ and

$D_3(s) = (1 - \hat{q}_{11}^{(3)}(s) - \hat{q}_{11}^{(4)}(s)) - \hat{q}_{01}(s)$ is already defined.

In the long run, $R_0 = \dfrac{N_3(0)}{D_3{}'(0)}$ (18)

The expected period of the system under FACT-failure resulting from non- availability of coal to produce thermal power in (0, t].

$$\lambda_{rv}(t) = \int_0^{\infty} R_0(z)\,dz \text{ So that } \bar{\lambda}_{rv}(s) = \frac{\hat{R}_0(s)}{s}$$

The expected Busy period of the server when there is Non-availability of coal to produce thermal power in (0, t]

$B_0(t) = q_{01}(t)[c]B_1(t) + q_{02}(t)[c]B_2(t)$

$B_1(t) = q_{01}(t)[c]B_1(t) + [q_{11}^{(3)}(t) + q_{11}^{(4)}(t)]\,[c]B_1(t),$

$B_2(t) = T_2(t) + q_{02}(t)[c]\,B_2(t) + [q_{22}^{(5)}(t) + q_{22}^{(6)}(t)]\,[c]B_2(t)$

$T_2(t) = e^{-\lambda_1 t}G_2(t)$ (19- 21)

Taking Laplace Transform of eq. (19-21) and solving for $\overline{B_0}(s)$

$\overline{B_0}(s) = N_4(s) / D_2(s)$ (22)

where

$N_4(s) = \hat{q}_{02}(s)\hat{T}_2(s))$

And $D_2(s)$ is already defined.

In steady state, $B_0 = \frac{N_4(0)}{D_2'(0)}$ (23)

The expected busy period of the server for repair in (0, t] is

$\lambda_{ru}(t) = \int_0^\infty B_0(z)dz$ So that $\overline{\lambda_{ru}}(s) = \frac{\hat{B}_0(s)}{s}$ (24)

The expected number of visits by the repairman for repairing the non-identical units in (0, t]

$H_0(t) = Q_{01}(t)[s][1+ H_1(t)] + Q_{02}(t)[s][1+ H_2(t)]$

$H_1(t) = Q_{10}(t)[s]H_0(t)] + [Q_{11}^{(3)}(t)+ Q_{11}^{(4)}(t)] [s]H_1(t),$

$H_2(t) = Q_{20}(t)[s]H_0(t) + [Q_{22}^{(5)}(t) +Q_{22}^{(6)}(t)] [c]H_2(t)$ (25-27)

Taking Laplace Transform of eq. (25-27) and solving for $H_0^*(s)$

$H_0^*(s) = N_6(s) / D_3(s)$ (28)

In the long run, $H_0 = \frac{N_6(0)}{D_3'(0)}$ (29)

COST-BENEFIT ANALYSIS

The Cost-Benefit analysis of the system considering mean up-time, expected busy period of the system under Non-availability of coal to produce thermal power when the units stops automatically, expected busy period of the server for repair of unit under non-availability of water resulting not to produce Hydroelectric power, expected number of visits by the repairman for unit failure.

The expected total Benefit-Function incurred in (0, t] is

C (t) = Expected total revenue in (0, t]

- expected total repair cost in (0, t] due to Non-availability of coal to produce thermal power failure
- expected total repair cost repairing the units in (0,t] due to FNAWH- failure due to non-availability of water resulting not to produce hydroelectric power
- expected busy period of the system under Non-availability of coal to produce thermal power when the units automatically stop in (0,t]
- expected number of visits by the repairman for repairing of non-identical the units in (0,t]

The expected total cost per unit time in steady state is

$C = \lim_{t\to\infty}(C(t)/t) = \lim_{s\to 0}(s^2 C(s))$

$= K_1A_0 - K_2R_0 - K_3B_0 - K_4H_0$

Where

K_1: revenue per unit up-time,

K_2: cost per unit time for which the system is under repair of type- I

K_3: cost per unit time for which the system is under repair of type-II

K_4: cost per visit by the repairman for units repair.

CONCLUSION

After studying the system, we have analyzed graphically that when the failure rate due to non-availability of water resulting not to produce hydroelectric power and failure rate due to Non-availability of coal to produce thermal power increases, the MTSF and steady state availability decreases and the Cost-Benefit function decreased as the failure increases.

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Source of Support: None Declared
Conflict of Interest: None Declared