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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 BIOMASS ENERGY

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ABSTRACT

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-based materials which are specifically called lignocellulosic biomass. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of bio fuel. Conversion of biomass to bio fuel can be achieved by different methods which are broadly classified into: *thermal*, *chemical*, and *biochemical* methods. Wood remains the largest biomass energy source to date; examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including bio fuels. Industrial biomass can be grown from numerous types of numerous types of plants, including, switch grass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo, and a variety of tree species, ranging from eucalyptus to oil palm (palm oil).Hydroelectricity is the term referring to electricity generated by hydropower the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy, accounting for 16 percent of global electricity generation – 3,427 terawatt-hours of electricity production in 2010 and is expected to increase about 3.1% each year for the next 25 years. Water plays an important and pivotal role in producing hydroelectric power. Non-availability of water results failure to produce hydroelectric 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) FNAW- non-availability of water resulting failure to produce Hydroelectric Power (2) FNABM-failure due to Non-availability of biomass energy. 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, FNAW- non-availability of water resulting failure to produce Hydroelectric Power, FNABM-failure due to Non-availability of biomass energy, first come first serve, MTSF, Availability, Busy period, Cost-Benefit analysis

INTRODUCTION

Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Rotting garbage, and agricultural and human waste, all release methane gas—also called "landfill gas" or "biogas." Crops, such as corn and sugar cane, can be fermented to produce the transportation fuel, ethanol. Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats. Also, biomass to liquids (BTLs) and cellulosic ethanol are still under research.

There is a great deal of research involving algal, or algae-derived, biomass due to the fact that it's a non-food resource and can be produced at rates 5 to 10 times faster than other types of land-based agriculture, such as corn and soy. Once harvested, it can be fermented to produce bio fuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen.

The biomass used for electricity generation varies by region. Forest by-products, such as wood residues, are common in the United States. Agricultural waste is common in Mauritius (sugar cane residue) and Southeast Asia (rice husks). Animal husbandry residues, such as poultry litter, are common in the UK. Hydropower is produced in 150 countries, with the Asia-Pacific region generating 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.

The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity. The average cost of electricity from a hydro plant larger than 10 megawatts is 3 to 5 U.S. cents per kilowatt-hour. It is also a flexible source of electricity since the amount produced by the plant can be changed up or down very quickly to adapt to changing energy demands. Stochastic behavior of systems operating under changing environments has widely been studied. Dhillon BS. and Natesan J. (1983) studied an 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) FNAW: Failure due to non-availability of water resulting failure to produce Hydroelectric Power.

(2) FNABM: Failure due to Non-availability of biomass energy. When the main operative unit fails then cold standby system becomes operative. After failure the unit undergoes repair facility of very high cost in case of FNABM-failure due to Non-availability of biomass energy immediately. Failure due to non-availability of water resulting failure to produce hydroelectric power may disrupt the whole life style. 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 biomass energy. 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 biomass energy is non-instantaneous and it cannot be available simultaneously in both the units.
3. Whenever there is sufficient availability of biomass energy for the unit, it works as normal as before. But as soon as there is not sufficient availability of biomass energy the operation of the unit stops automatically.
4. The repair starts immediately after detecting the failure due to Non-availability of biomass energy 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 $F_2(t)$ – the failure time distribution due to non-availability of water resulting failure to produce Hydroelectric power and failure due to Non-availability of biomass energy 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 biomass energy respectively

Superscripts O, CS, FNAW, FNABM

Operative, Cold Standby, Failure due to non-availability of water resulting failure to produce hydroelectric power , failure due to Non-availability of biomass energy respectively

Subscripts nawf, abm, nabm ur, wr, uR

Non-availability of water resulting failure to produce hydroelectric power, availability of biomass energy, Non-availability of biomass energy , 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_{nabm}, CS_{nabm})

One unit is operative and the other unit is cold standby and there are no Non-availability of biomass energy failures in both the units.

1($SOFNABM_{nabm, ur}$, O_{abm})

The operating unit fails due to Non-availability of biomass energy and is under repair immediately of very costly Type- I and standby unit starts operating with availability of biomass energy.

2($FNAW_{nabm, nawf, ur}$, O_{abm})

The operative unit fails to produce hydroelectric power due to FNAW resulting from non-availability of water and undergoes repair of type II and the standby unit becomes operative with availability of biomass energy.

3($FNABM_{nabm,uR}$, $FNAW_{nabm ,nawf, wr}$)

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

4($FNABM_{nabm,uR}$, $FNABM_{nabm,wr}$)

The one unit fails due to Non-availability of biomass energy is continues under repair of very costly Type - I from state 1 and the other unit also fails due to Non-availability of biomass energy. is waiting for repair of very costly Type- I.

5($FNAW_{nabm,\ nawf,\ uR}$, $FNABM_{nabm,\ wr}$)

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

6($FNAW_{nabm,nawf,uR}$, $FNAW_{nabm,nawf,wr}$)

The operative unit fails to produce hydroelectric power due to FNAW resulting from non- availability of water and under repair continues from state 2 of Type –II and the other unit is also failed to produce hydroelectric power due to FNAW resulting from non-availability of water and is waiting for repair of Type-II and there is no Non-availability of biomass energy.

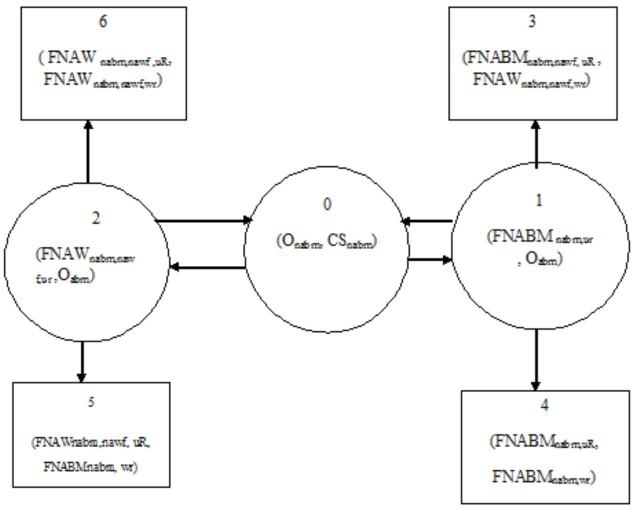

Figure 1: The State Transition Diagram

● Regeneration point -states 0, 1, 2

⬭ Up State

☐ Down State

Transition Probabilities

Simple probabilistic considerations yield the following expressions:

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

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

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

Clearly

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

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

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

And mean sojourn time are

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

MEAN TIME TO SYSTEM FAILURE

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

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

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

We can regard the failed state as absorbing

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

$$ø_0^*(s) = N_1(s) \ / \ D_1(s) \qquad (6)$$

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

$$MTSF = E[T] = \frac{d}{ds}\ ø_0^{*}(s)\ \Big|_{s=0}$$

$$= (D_1'(0) - N_1'(0)) \ / \ D_1(0)$$

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

where

$\mu_0 = \mu_{01} + \mu_{02}$, $\mu_1 = \mu_{10} + \mu_{13} + \mu_{14}$ $\quad \mu_2 = \mu_{20} + \mu_{25} + \mu_{26}$

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 $\hat{A}_0(s)$

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

where

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

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

The steady state availability

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

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

$$\lambda_u(t)= \int_0^t A_0(z)\,dz \text{ So that } \hat{\lambda}_u(s) = \frac{\hat{A}_0(s)}{s} = \frac{N_2(s)}{sD_2(s)} \qquad (12)$$

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

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

The expected busy period of the server when there is FNAW-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 $\hat{R}_0(s)$

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

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, $\qquad R_0 = \dfrac{N_3(0)}{D_2'(0)} \qquad (18)$

The expected period of the system under FNAW-failure resulting from non-availability of water causes not to produce hydroelectric power in (0,t] is

$\lambda_{rv}(t) = \int_0^\infty R_0(z)dz$ So that $\overline{\lambda_{rv}}(s) = \frac{\hat{R}_0(s)}{s}$

The expected Busy period of the server when there is Non-availability of biomass energy 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 $\overline{B_0}(s)$

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

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 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 $H_0^*(s)$

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

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

The expected total cost per unit time in steady state is

$$C = \lim_{t\to\infty}(C(t)/t) = \lim_{s\to 0}(s^2C(s))$$
$$= K_1A_0 - K_2R_0 - K_3B_0 - K_4H_0$$

Where

$K_1 \rightarrow$ Revenue per unit up-time,

$K_2 \rightarrow$ Cost per unit time for which the system is under repair of type- I

$K_3 \rightarrow$ Cost per unit time for which the system is under repair of type-II

$K_4 \rightarrow$ 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 biomass energy increases, the MTSF and steady state availability decreases and the Cost-Benefit function decreased as the failure increases.

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