ANALYSIS OF BENEFIT OF A PLANT CONSISTING OF STEAM AND GAS TURBINE WITH TWO TYPES OF REPAIRMAN

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Abstract: A reliability model of a plant having steam and gas turbine is carried out by two types of repairman (ordinary and expert). Each unit of the system may have three stages i.e. up state, down state or failed state. At initial stage both turbine are operative. When the system's gas turbine fails it goes down to the state, while when the steam turbine fails to be remain in upstate, only the gas turbine works if when power's buyer is too generous. Reliability is improved through regenerative point technique by using semi-Markov process. Through various reliability parameters profit have been calculated and analyzed using graphical illustrations.

Key Words: Plant consisting of steam and gas turbine, Operative State, Failed State, Semi-Markov Process, Technique of Regenerative Point

I. Introduction:

In today's era of global competition and liberalization, it becomes challenge to Indian industries to meet international standards, which can be achieved by producing reliable products. Various reliability models of single unit, two unit or multi-unit models have been studied by several researchers, involving [1-4]. Tuteja and Taneja [5-6] talk over several types of rates like failure and repair rates. Relative study of two-unit systems is made by Taneja and Singh [7] and Taneja and Malhotra [8]. Taj and Taneja [9] presented analysis of reliable system of single machine subsystem of a cable plant with six maintenance categories. Kumar, Gupta and Taneja [10] and Batra and Taneja [11] analyzed reliability under standby units. Rajesh, Taneja and Prasad [12] presented reliability and availability analysis for a three unit plant having gas turbine with seasonal effect and FCFS repair pattern. Manocha and Taneja [13] developed two unit system with arbitrary distributions.

In present paper we try to examine the benefit analysis of a plant consisting of steam and gas turbine under two types of repairman. At initial stage both turbine are operative. When the system's gas turbine fails it goes down to the state, while when the steam turbine fails to be remain in upstate, only the gas turbine works if when power's buyer is too generous. When we work in a situation where the only gas turbine is operative is said to be in single cycle; when steam and gas turbine both are operative then it is said to be in combined cycle. In this model, two types of repairman are used. Hence, there are two possibilities the ordinary repairman can repair completely or not. If not then we call the expert repairman he repairs the failed unit completely.

Other Assumptions for the model

- After every completely repair, the unit we get is reasonable as newly one.
- Random variables are independent.
- When both units fails, system fails.
- When system works with only gas turbine it is in single cycle.
- If turbine fails then firstly ordinary repairman repair the turbine, if not possible by ordinary repairman then expert repairman repair the turbine.

II. Notations

O_{gt} : Gas turbine is in operation

O_{st} : Steam turbine is in operation

u_{rgt1} : Ordinary repairman repairing the gas turbine

u_{rgt2} : Expert repairman repairing the gas turbine

u_{rst1} : Ordinary repairman repairing the steam turbine

u_{rst2} : Expert repairman repairing the steam turbine

d_{gt} : Down mode of gas turbine

d_{st} : Down mode of steam turbine

U_{Rst1} : Steam turbine under repair continued from existing state by ordinary repairman

U_{Rst2} : Steam turbine under repair continued from existing state by expert repairman

λ : Gas turbine failure rate

α : Steam turbine failure rate

a : Probability of completely repair the failed unit by ordinary repairman

b : Probability of not completely repairing the failed unit by ordinary repairman

p : Probability of requisition of electricity and the willingness of customer to pay more than the usual rates

q : 1-p i.e. the probability of unwillingness of customer to pay the more than the usual rates

$g_1(t)$, $G_1(t)$: p.d.f and c.d.f repair time by ordinary repairman when he repairs gas turbine

$g_2(t)$, $G_2(t)$: p.d.f and c.d.f repair time when ordinary repairman repairs steam turbine

$g_3(t)$, $G_3(t)$: p.d.f and c.d.f repair time when expert repairman repairs gas turbine

$g_4(t)$, $G_4(t)$: p.d.f and c.d.f repair time when expert repairman repairs steam turbine

III. State Transition Diagram and Transition Probabilities

The state transition diagram in Fig.1 articulate that 0, 1, 2, 3, 4, 5, 6 and 9 are regenerative juncture and thus 0, 1, 2, 3, 4, 5, 6 and 9 are regenerative states. And 7, 8 and 9 are failed states. State 1, 3, 4, and 6 are down states as operable unit is put to down mode. State 2 and 5 are in upstate in single cycle.

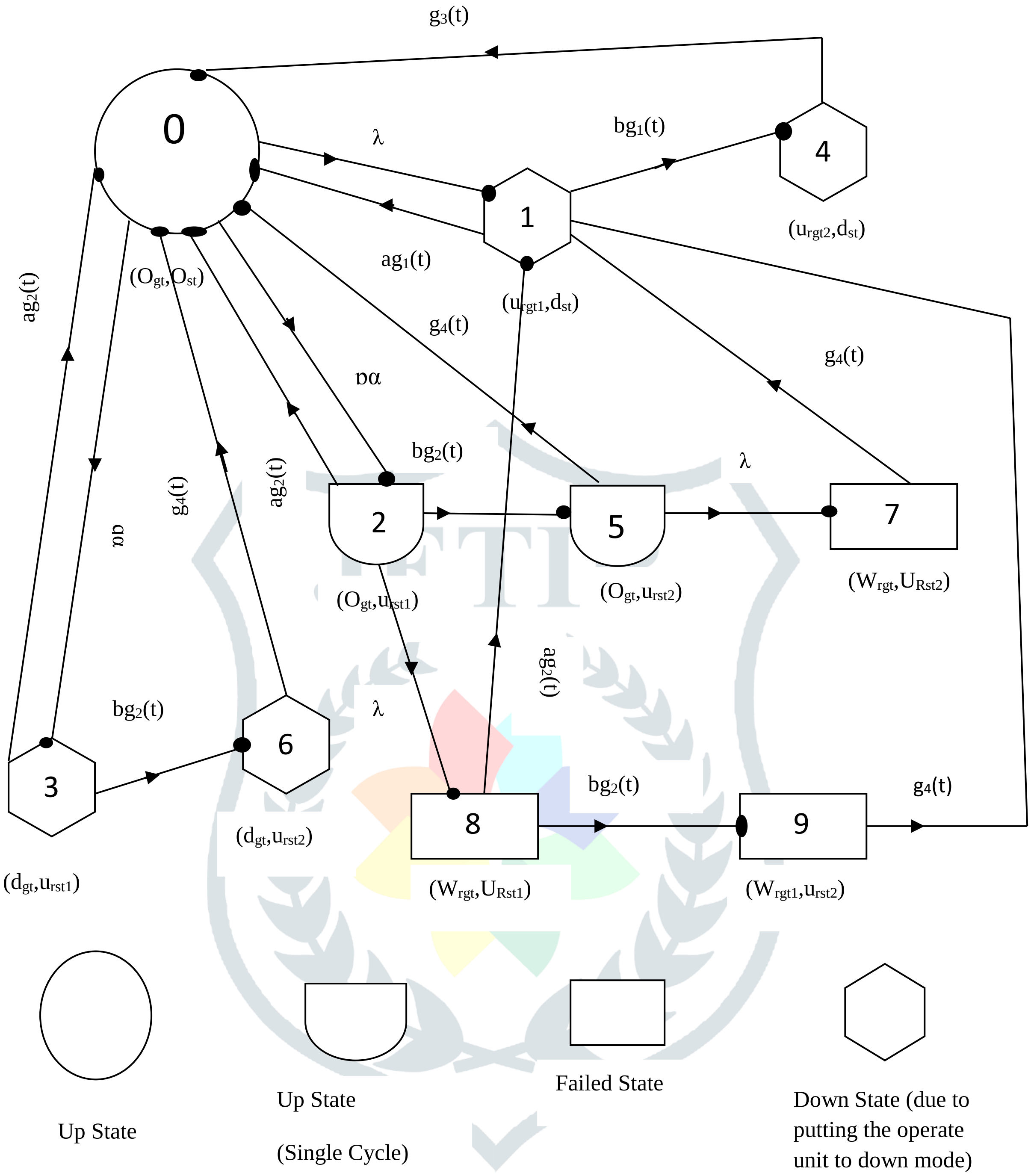

Fig.2.1 State Transition Diagram

The probabilities of transition :

$dQ_{01}(t) = e^{-(\lambda+\alpha)t}\,dt$, $dQ_{02}(t) = p\alpha\, e^{-(\lambda+\alpha)t}\,dt$, $dQ_{03}(t) = p\alpha\, e^{-(\lambda+\alpha)t}\,dt$, $dQ_{10}(t) = ag_1(t)dt$,

$dQ_{14}(t) = bg_1(t)dt$, $dQ_{25}(t) = bg_2(t)e^{-\lambda t}dt$, $dQ_{20}(t) = ag_2(t)e^{-\lambda t}dt$, $dQ_{21}^{(8)}(t) = [\lambda e^{-\lambda t}\copyright 1]ag_2(t)dt$,

$dQ_{29}^{(8)}(t) = [\lambda e^{-\lambda t}\copyright 1]bg_2(t)dt$, $dQ_{28}(t) = \lambda e^{-\lambda t}\,dt$, $dQ_{30}(t) = ag_2(t)dt$, $dQ_{36}(t) = bg_2(t)dt$,

$dQ_{40}(t) = g_3(t)dt$, $dQ_{50}(t) = g_4(t)e^{-\lambda t}dt$, $dQ_{51}^{(7)}(t) = [\boldsymbol{\lambda} e^{-\lambda t}\copyright 1]g_4(t)dt$,

$dQ_{57}(t) = \boldsymbol{\lambda} e^{-\lambda t}\,dt$, $dQ_{60}(t) = g_4(t)dt$, $dQ_{71}(t) = g_4(t)dt$, $dQ_{91}(t) = g_4(t)dt$

and $p_{ij} = \lim_{t\to\infty} Q_{ij} = \lim_{s\to 0} Q_{ij}^{**}(s)$ are given as

$p_{01} = \frac{\lambda}{\lambda+\alpha}$, $p_{02} = \frac{p\alpha}{\lambda+\alpha}$, $p_{03} = \frac{q\alpha}{\lambda+\alpha}$, $p_{14} = b$, $p_{10} = a$, $p_{25} = b\, g_2^*(\lambda)$

$p_{20} = a\, g_2^*(\lambda)$, $p_{21}^{(8)} = a - a\, g_2^*(\lambda)$, $P_{29}^{(8)} = b - b\, g_2^*(\lambda)$, $p_{28} = 1 - g_2^*(\lambda)$

$p_{30} = a$, $p_{36} = b$, $p_{40} = 1$, $p_{50} = g_4^*(\lambda)$, $p_{57} = 1 - g_4^*(\lambda)$

$p_{51}^{(7)} = 1 - g_4^*(\lambda)$, $p_{60} = 1$, $p_{71} = 1$, $p_{91} = 1$

From these, following can be verified

$p_{01}+p_{02}+p_{03} = 1$, $p_{10}+p_{14} = 1$, $p_{20}+p_{25}+p_{21}^{(8)}+p_{29}^{(8)} = 1$, $p_{20}+p_{28}+p_{25} = 1$

$p_{30}+p_{36} = 1$, $p_{40} = 1$, $p_{50}+p_{57} = 1$, $p_{50}+p_{51}^{(7)} = 1$, $p_{60} = 1$, $p_{71} = 1$, $p_{91} = 1$

"The mean sojourn time(μ_i) in the regenerative state 'i' is defined as the same time of stay in that state before transition to any other state". The sojourn in the regenerative state 'i' is denoted by T, then

$$\mu_i = E(T) = P_r(T > t)$$

$$\mu_0 = \frac{1}{\lambda+\alpha}, \quad \mu_1 = -\, g_1^{*'}(0), \quad \mu_2 = \frac{1}{\lambda} - \frac{g_2^*(\lambda)}{\lambda}, \quad \mu_3 = -\, g_2^{*'}(0), \quad \mu_4 = -\, g_3^{*'}(0)$$

$$\mu_5 = \frac{1}{\lambda}\left[1 - g_4^*(\lambda)\right], \quad \mu_6 = -\, g_4^{*'}(0), \quad \mu_9 = -\, g_4^{*'}(0)$$

IV. Reliability and Mean Time to System Failure

To generate the MTSF, we consider failed states as consuming states. Probabilistic indication are used for the recursive relation of $\phi_i(t)$. At any time t the reliability is :

R(t) = inverse Laplace transform of (1- ϕ_0^{**}(s) / s),

where ϕ_0^{**}(s) is the Laplace-Stieltjes Transform of Φ_0(t).

MTSF of system start from state '0' is given by

$$T_0 = \lim_{s\to 0} \frac{1 - Q_0^{**}(s)}{s} = \frac{N}{D}$$

$N = \mu_0 + p_{01}\mu_1 + p_{01}p_{14}\mu_4 + p_{03}(p_{36}\mu_6 + \mu_3) + p_{02}(K_2 + p_{25}K_5)$

and $D = p_{02}(1 - p_{20} - p_{25}p_{50})$

V. Availability Analysis at Full Capacity

"The availability of a system is defined as the probability that the system is operating and provides service when requested". A_i(t) is the probability of unit entering into up state at time t by using probabilistic argument, assuming the unit penetrate into regenerative states i at t=0, and the Laplace transform of availability A_0(t) is :

$$A_0^*(s)=\frac{N_1(s)}{D_1(s)}$$

where, $N_1(s) = M_0^*(s)$

$$D_1(s)=1-q_{01}^*(s)q_{10}^*(s)-q_{02}^*(s)q_{20}^*(s)-q_{03}^*(s)q_{30}^*(s)-q_{10}^*(s)q_{02}^*(s)q_{21}^{(8)*}(s)-q_{02}^*(s)q_{25}^*(s)q_{50}^*(s)$$
$$-q_{40}^*(s)q_{01}^*(s)q_{14}^*(s)-q_{60}^*(s)q_{36}^*(s)q_{03}^*(s)-q_{10}^*(s)q_{02}^*(s)q_{25}^*(s)q_{51}^{(7)*}(s)$$
$$-q_{02}^*(s)q_{40}^*(s)q_{14}^*(s)q_{21}^{(8)*}(s)-q_{10}^*(s)q_{02}^*(s)q_{29}^{(8)*}(s)q_{91}^*(s)-q_{40}^*(s)q_{02}^*(s)q_{14}^*(s)q_{25}^*(s)q_{51}^{(7)*}(s)-q_{91}^*(s)q_{29}^{(8)*}(s)q_{40}^*(s)q_{02}^*(s)q_{14}^*(s)$$

The availability at full capacity at steady state is given by

$$A_0=\lim_{s\to 0}(sA_0^*(s))=\frac{N_1}{D_1}$$

where, $N_1 = \mu_0$

$D_1=\mu_0+p_{01}\mu_1+p_{01}p_{14}\mu_4+p_{03}\mu_3+p_{03}p_{36}\mu_6+p_{02}[K_3+\mu_1(p_{21}^{(8)}+p_{25}p_{51}^{(7)})+p_{14}\mu_4(p_{21}^{(8)}+p_{29}^{(8)}+p_{25}p_{51}^{(7)})+p_{29}^{(8)}(\mu_6+\mu_1)+K_8+p_{25}\mu_6]$

Similarly, Availability in Single Cycle $A_0^{(s)} = \frac{N_{11}}{D_1}$

$N_{11} = \mu_2 - p_{25}\mu_5$

D_1 = is already described above

VI. Analysis of Busy Period by the Ordinary Repairman, I

$B_i^I(t)$ = Probability that the repairman is buzy at the moment when the system penetrate into regenerative state i at t=0, the Laplace transform of $B_0^I(t)$ is :

$$B_0^{I*}(s)=\frac{N_2(s)}{D_1(s)}$$

$$N_2(s)=w_1^*(s)\left[q_{01}^*(s)+q_{02}^*(s)q_{21}^{(8)*}(s)+q_{02}^*(s)q_{25}^*(s)+q_{51}^{(7)*}(s)+q_{91}^*(s)q_{02}^*(s)q_{29}^{(8)*}(s)\right]+q_{02}^*(s)w_2^*(s)+q_{03}^*(s)w_3^*(s)$$

$D_1(s)$ = is already described above

The time fraction in steady state in which system is under repair is

$$B_0^I=\lim_{s\to 0}(sB_0^{I*}(s))=\frac{N_2}{D_1}$$

where, $N_2 = \mu_1[p_{01}+p_{02}-p_{02}p_{20}+p_{51}^{(7)}]+p_{02}\mu_2+p_{03}\mu_3$

D_1 = is already described above

Similarly, Busy Period Analysis by the Expert Repairman, II $B_0^{II}(s)=\lim_{s\to 0}(sB_0^{II*}(s))=\frac{N_{21}}{D_1}$

$N_{21}=p_{02}p_{25}\mu_5+\mu_6(p_{03}p_{36}+p_{02}p_{29}^{(8)})-\mu_4[p_{01}p_{14}+p_{02}p_{14}(p_{21}^{(8)}+p_{29}^{(8)}+p_{25}p_{51}^{(7)})]$

D_1 = is already specified above

VII. Number of Expected Visits of the Ordinary Repairman, I

$V_i^I(t)$ = number of expected visits by the ordinary repair man in (0, t], when the unit starts from the regenerative state i at t=0, the Laplace transform of $V_0^I(t)$ is:

$$V_0^{I**}(s)=\frac{N_3(s)}{D_1(s)}$$

$N_3(s) = Q_{01}^{**}(s)+Q_{02}^{**}(s)+Q_{03}^{**}(s)$

$D_1(s)$ = is defined already

Visits number per unit time in steady state is given by

$$V_0^I = \lim_{s\to 0}(sV_0^{I*}(s)) = \frac{N_3}{D_1}$$

$N_3 = 1$

D_1 = is already described above

Similarly, Number of Expected Visits of the Expert Repairman, II $V_0^{II} = \dfrac{N_{31}}{D_1}$

$N_{31} = p_{03}p_{36}+p_{01}p_{14}+p_{02}(p_{25}+p_{29}^{(8)})+p_{02}p_{14}(p_{21}^{(8)}+p_{29}^{(8)}+p_{25}p_{51}^{(7)})$

D_1 = is already defined above

VIII. Cost- Benefit Analysis

The total profit run into steady state of the system is given by

Profit = $C_0A_0+C_{01}A_{01}-C_{11}B_0-C_{12}B_{01}-C_{21}V_0-C_{22}V_{01}$

C_0 = Yield per unit time when system's work is in full capacity

C_{01} = Yield per unit time when system's work is in single cycle

C_{11} = Expenditure per unit time when an ordinary repairman repair

C_{12} = Expenditure per unit time when expert repairman repair

C_{21} = Expenditure per visit of the ordinary repairman

C_{22} = Expenditure per visit of the expert repairman

IX. Numerical Results for Particular Cases

$g_1(t) = \alpha_1 e^{-\alpha_1 t}$, $g_2(t) = \alpha_2 e^{-\alpha_2 t}$, $g_3(t) = \alpha_3 e^{-\alpha_3 t}$, $g_4(t) = \alpha_4 e^{-\alpha_4 t}$, $p_{01}= \dfrac{\lambda}{\lambda+\alpha}$, $p_{02} = \dfrac{p\alpha}{\lambda+\alpha}$,

$p_{03} = \dfrac{(1-p)\alpha}{\lambda+\alpha}$, $p_{14} = a$, $p_{10} = 1-a$, $p_{25} = \dfrac{(1-a)\alpha_2}{\lambda+\alpha_2}$, $p_{29}^{(8)} = \dfrac{(1-a)\lambda}{\lambda+\alpha_2}$, $p_{20} = \dfrac{a\alpha_2}{\lambda+\alpha_2}$,

$p_{21}^{(8)} = \dfrac{a\lambda}{\lambda+\alpha_2}$, $p_{28} = \dfrac{\lambda}{\lambda+\alpha_2}$, $p_{30} = a$, $p_{36} = 1-a$, $p_{40} = 1$, $p_{50} = \dfrac{\alpha_4}{\lambda+\alpha_4}$, $p_{60} = 1$

$p_{57} = \dfrac{\lambda}{\lambda+\alpha_4}$, $p_{71} = 1$, $p_{51}^{(7)} = \dfrac{\lambda}{\lambda+\alpha_4}$, $p_{91} = 1$, $\mu_0 = \dfrac{1}{\lambda+\alpha}$, $\mu_1 = \dfrac{1}{\alpha_1}$, $\mu_2 = \dfrac{1}{\alpha_2+\lambda}$,

$\mu_3 = \dfrac{1}{\alpha_2}$, $\mu_4 = \dfrac{1}{\alpha_3}$, $\mu_5 = \dfrac{1}{\alpha_4+\lambda}$, $\mu_6 = \dfrac{1}{\alpha_4}$, $\mu_9 = \dfrac{1}{\alpha_4}$ $K_2 = \dfrac{1}{\alpha_2+\lambda}$,

$K_3 = \dfrac{a}{\alpha_2}+\dfrac{(1-a)\alpha_2}{(\lambda+\alpha_2)^2}$, $K_5 = \dfrac{1}{\alpha_4+\lambda}$, $K_8 = \dfrac{(1-a)}{\alpha_2}-\dfrac{(1-a)\alpha_2}{(\lambda+\alpha_2)^2}$

X. GRAPHICAL ANALYSIS

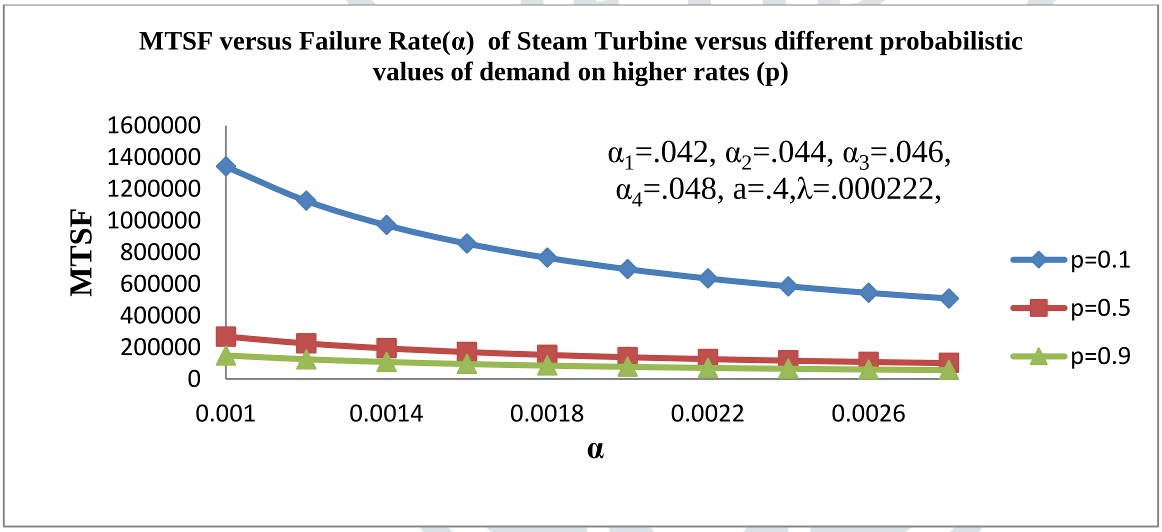

Fig.2

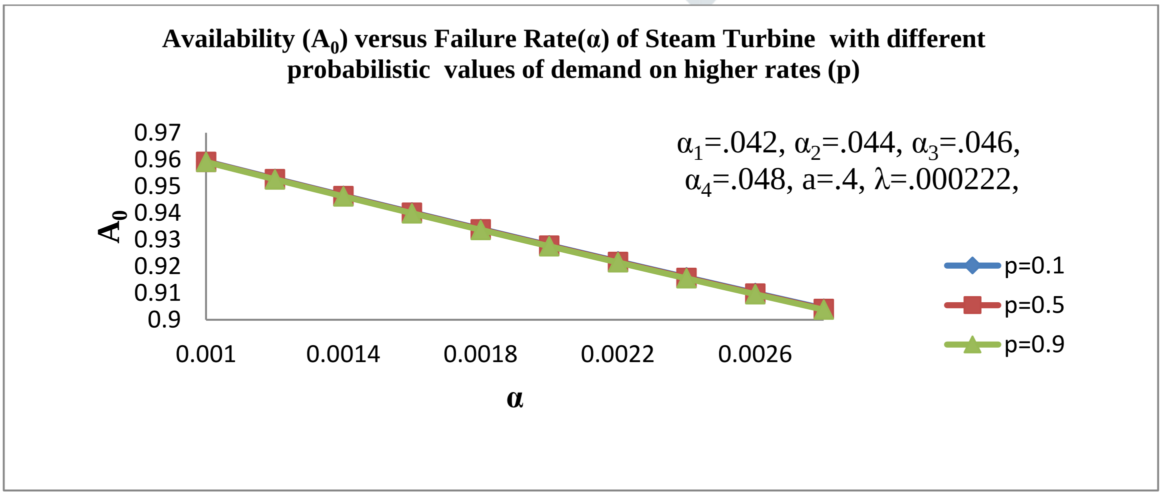

Fig.3

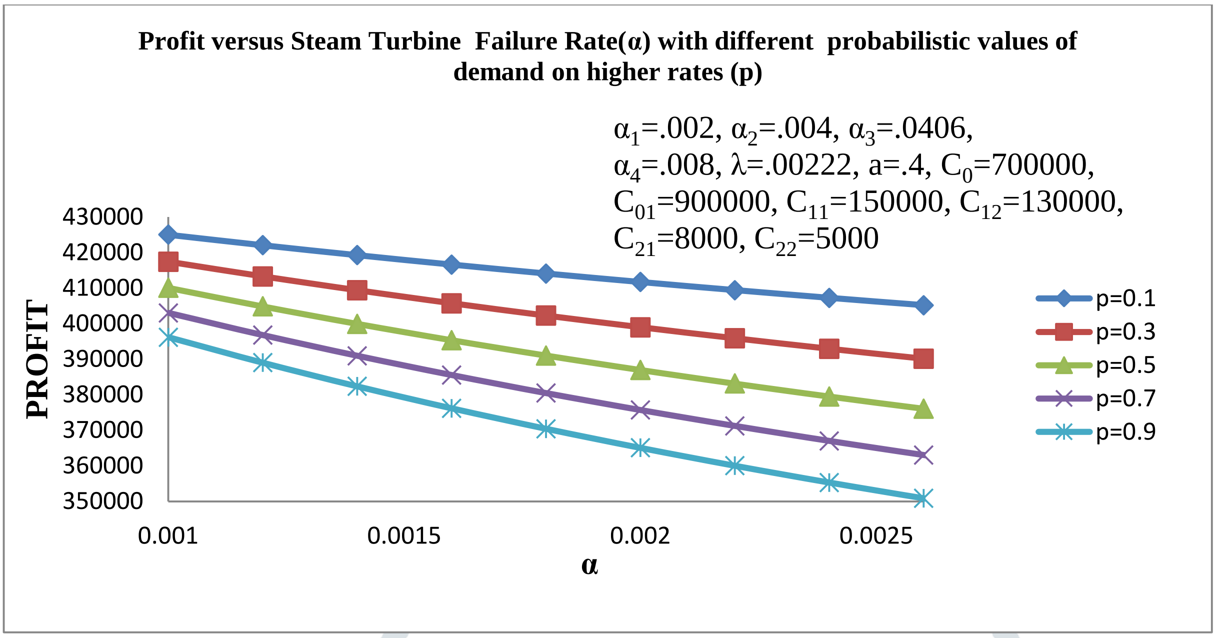
Profit versus Steam Turbine Failure Rate(α) with different probabilistic values of demand on higher rates (p)
α1=.002, α2=.004, α3=.0406, α4=.008, λ=.00222, a=.4, C0=700000, C01=900000, C11=150000, C12=130000, C21=8000, C22=5000
PROFIT
430000
420000
410000
400000
390000
380000
370000
360000
350000
0.001
0.0015
0.002
0.0025
α
p=0.1
p=0.3
p=0.5
p=0.7
p=0.9

Fig. 4

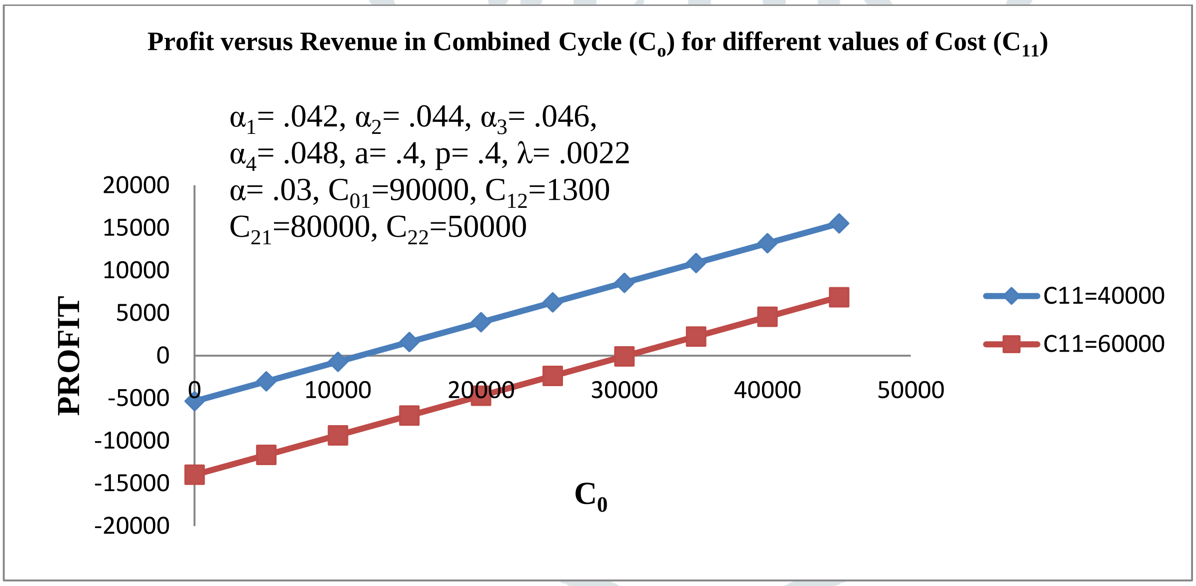
Profit versus Revenue in Combined Cycle (Co) for different values of Cost (C11)
α1= .042, α2= .044, α3= .046, α4= .048, a= .4, p= .4, λ= .0022
α= .03, C01=90000, C12=1300
C21=80000, C22=50000
PROFIT
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
0
10000
20000
30000
40000
50000
C0
C11=40000
C11=60000

Fig.5

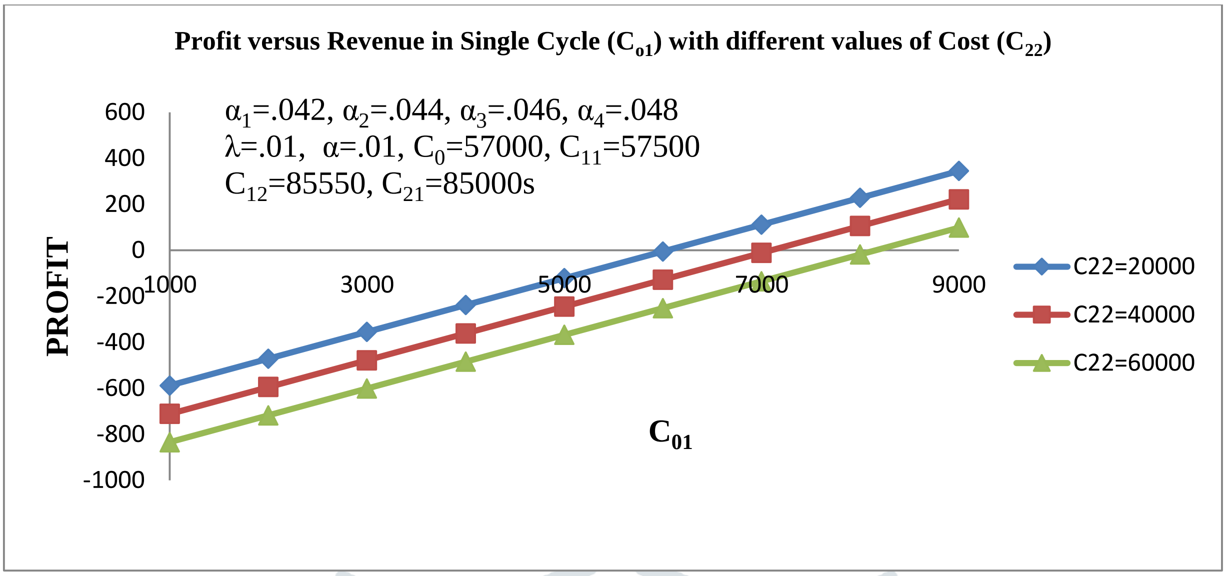

Fig.6

XI. Conclusion Remarks

From the cases we talked above, we can calculate the mean time to system failure, availability, and profit of the system as reliability measures. The graphical representation discussed above for the particular cases are drawn in fig. [2-6]. Fig.2 clearly shows when values of the steam turbine failure rate (α) increases MTSF get decreased. Also fig.3 depicts that with raise in values of steam turbine failure rate (α) with different values of requisition on higher payment (p) availability (A_0) decreases and there is negligible change in availability (A_0). From fig.4 we can conclude that when steam turbine failure rate (α) increases profit decreases for small probabilistic values (p) and fig.5 and fig.6 denote as the revenue cost per unit increases the profit increases.

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