A Reliability Model on an APFC System with Three Stages of Working with Respect to Variation in Power Factor

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Abstract

The present paper deals with the reliability and profit analysis of an automatic power factor controller (APFC) system with three stages of working with respect to variation in power factor. Power factor may vary and result into three categories: controlled, partially controlled and uncontrolled power factor. Due to poor power factor system, many industries have to face many problems like electric loads, energy loads and fuse replacement like. So, there is need to accurate/ appropriate these problems. Study of APFC system, therefore, is of great importance. In the present study, the system is initially operative with controlled factor, then it may transit to the mode where the power factor is partially controlled and vice versa. Also, from the partially controlled power factor mode, the system may transit to a mode of uncontrolled power factor and vice versa. If the system fails, there is need to detect the type of failure by inspection. The type of failure may be 'Fuse blown off' or 'Transformer burnt' or 'Programme problem' or 'output relay faulty'. After repair/replacement on failure, the system goes back to the same controlling mode as was existing at the time of failure. Various measures of system effectiveness have been obtained by making use of regenerative point technique. Graphs have been plotted to draw interesting conclusions related to the revenue per unit up time, loss per unit time during which the power factor remains uncontrolled/partially controlled.

Keywords:- Automatic Power Factor Control (APFC) System, Controlled/Partial Controlled/Uncontrolled Power factor, Measures of System effectiveness, Regenerative point technique.

Introduction

In this present era, the main objective of the industries is the optimization of available resources to obtain the maximum profit. Reliability modeling can be of great use for fulfilling this objective. A large number of researchers including [1-6] have widely studied the concept the Reliability for one or more units systems considering variety of situations. Bhatia et al [4] discussed the probabilistic analysis of an automatic power factor controller (APFC). Some typical examples of such modern systems include transformers, fluorescent lighting. AC induction motors. Are/induction furnaces etc, which draw not only active power (KW) from the supply but also inductive reactive power (KV Ar). Also, apparent power (KVA) is combination of active and reactive power. Power factor is the ratio of active power to apparent power. The low power factor is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all the element of power system. The power factor should be as close to unity as possible which may otherwise lead to energy losses and big penalty.

Bhatia et al. [ ] discussed the model with variation in power factor considering two stages of working i.e. one with power factor controlled and the other with power factor uncontrolled. But, the situation may be there with three stages of working i.e. power factor controlled, power factor partial controlled, and power factor uncontrolled. Normally, if the power factor of APFC is ≥ 0.9 then the system is said to be working with power factor controlled whereas if it lies between 0.85-0.9, then the system is said to work with power factor partial controlled and if it is <0.8 then it is the stage of power factor uncontrolled.

Keeping the above three stages of working, we, in the present paper develop a reliability model on Automatic power factor controller (APFC) panel because the problem of power factor correction/ maintenance of electrical loads is a basic problem which is common to all industrial companies using the information collected by [4]. The system is initially operative with controlled factor, then it may transit to the mode where the power factor is partially controlled and vice versa. Also, from the partially controlled power factor mode, the system may transit to a mode of uncontrolled power factor and vice versa. If the system fails, there is need to detect the type of failure by inspection. The type of failure may be 'Fuse blown off' or 'Transformer burnt' or 'Programme problem' or 'output relay faulty'. After repair/replacement on failure, the system goes back to the same controlling mode as was existing at the time of failure.

The system is analyzed by making use of regenerative point techniques. Various measures of system effectiveness are obtained such as mean time to system failure (MTSF), availability when power factor is controlled, availability when power factor is partial controlled, availability when power factor is not controlled, busy period of type 1 repair, busy period of type II repair, busy period of type III repair, busy period of type IV repair, expected number of visits of the repairman, expected number of fuse replacement, expected number of transformer replacement. The profit incurred to the system is also evaluated and graphical study is also done.

Graphs have been plotted to draw interesting conclusions related to the revenue per unit up time, loss per unit time during which the power factor remains uncontrolled/partially controlled.

From the data/information gathered from an industry, used from [4] and assumed (near to actual one) if not provided by any source; the estimates of rates, costs and probabilities are obtains as :

- Estimated value of failure rate (λ) = 0.001 per hour
- Estimated value of rate with which power factor changes from controlled mode to partial controlled mode (β_{11})=0.015 per hours
- Estimated value of rate with power factor changes from partial controlled mode to controlled mode (β_{12}) = 0.2
- Estimated value of rate with power factor changes from partial controlled mode to uncontrolled mode (γ_{11})=0.005
- Estimated value of rate with power factor changes from uncontrolled mode to partial controlled mode (γ_{12})=0.3
- Probability of failure of type I (p_1) = 0.3
- Probability of failure of type II (p_2) = 0.2
- Probability of failure of type III (p_3) = 0.4
- Probability of failure of type IV (p_4) = 0.1
- Expected cost of fuse replacement (C_1) = 50 INR
- Expected cost of transformer replacement (C_2) = 150 INR
- Expected cost of visit of repairman (C_3) = 1000 INR

Nomenclature

λ	Constant rate of failure
β_{11}	Rate with which power factor changes from controlled mode to partial controlled mode
β_{12}	Rate with which power factor changes from partial controlled mode to controlled mode
γ_{11}	Rate with which power factor changes from partial controlled mode to uncontrolled mode
γ_{12}	Rate with which power factor changes from uncontrolled mode to partial controlled mode
$f_1(t)$, $I(t)$	p.d.f. and c.d.f. of inspection time
p_1	probability of failure of type I (Fuse blown off)
p_2	probability of failure of type II (Transform burnt)
p_3	probability of failure of type III (Programming Problem)
p_4	probability of failure of type IV (output relay faulty)
$f_1(t)$,$F_1(t)$	p.d.f. and c.d.f. of failure of type I with controlled power factor
$f_2(t)$,$F_2(t)$	p.d.f and c.d.f. of failure of type II controlled power factor
$f_3(t)$,$F_3(t)$	p.d.f. and c.d.f. of failure of type III controlled power factor
$f_4(t)$,$F_4(t)$	p.d.f. and c.d.f. of failure of type IV controlled power factor Laplance convolution
$h_{12}(t)$,$H_{12}(t)$	p.d.f. and c.d.f. of the time which includes repair of type I failure as well as conversion of power factor from uncontrolled mode.
$h_{22}(t)$,$H_{22}(t)$	p.d.f. and c.d.f. of the time which includes repair of type II failure as well as conversion of power factor from uncontrolled mode.
$h_{32}(t)$,$H_{32}(t)$	p.d.f. and c.d.f. of the time which includes repair of type III failure as well as conversion of power factor from uncontrolled mode.
$h_{42}(t)$,$H_{42}(t)$	p.d.f. and c.d.f. of the time which includes repair of type IV failure as well as conversion of power factor from uncontrolled mode to controlled mode.
$g_{12}(t)$,$G_{12}(t)$	p.d.f. and c.d.f. of the time which includes repair of type I failure as well as conversion of power factor from partial controlled mode.
$g_{22}(t)$,$G_{22}(t)$	p.d.f. and c.d.f. of the time which includes repair of type II failure as well as conversion of power factor from partial controlled mode
$g_{32}(t)$,$G_{32}(t)$	p.d.f. and c.d.f. of the time which includes repair of type III failure as well as conversion of power factor from partial controlled mode
$g_{42}(t)$,$G_{42}(t)$	p.d.f. and c.d.f. of the time which includes repair of type IV failure as well as conversion of power factor from partial controlled mode
Op	the unit is operative
C	power factor controlled
$\overset{\square}{C}$	power factor partial controlled
$\overline{C}$	power factor not controlled
F	unit is under inspection on failure

F_{r1}	the main unit is under repair in case of type I (fuse blown off)
F_{r2}	the main unit is under repair in case of type II (transformer burnt)
F_{r3}	the main unit is under repair in case of type III (programming problem)
F_{r4}	the main unit is under repair in case of type IV (output relay faulty)
C_0	revenue per unit up time
C_{21}	cost per unit up time for which the repairman is busy for repairing the unit having failure of type I
C_{22}	cost per unit time for which the repairman is busy for repairing the unit having failure of type II
C_{23}	cost per unit up time for which the repairman is busy for repairing the unit having failure of type III
C_{24}	cost per unit up time for which the repairman is busy for repairing the unit failure of type IV
C_1	cost per fuse replacement
C_2	cost per transformer replacement
C_3	cost per visit of the repairman
$L\overset{\square}{C}$	Loss per unit time when power factor is partial controlled
$L\overline{C}$	Loss per unit time when power factor is not controlled
$\overline{AC_0}$	Steady state availability – this is the probability that the system is in up state when power factor is not controlled
$A\overset{\square}{C}_0$	Steady state availability – this is the probability that the system is in up state when power factor is partial controlled
BF_0	probability that the repairman is busy for the repair of type-I failure at instant t; given that the system entered regenerative state i at t=0
BT_0	probability that the repairman is busy for the repair of type-II failure at instant t; given that the system entered regenerative state i at t=0
BP_0	probability that the repairman is busy for the repair of type-III failure at instant t; given that the system entered regenerative state i at t=0
BO_0	probability that the repairman is busy for the repair of type-IV failure at instant t; given that the system entered regenerative state i at t=0
V_0	expected number of visits of the repairman in (0,t]; given that the system entered regenerative state i at t=0
FR_0	expected number of fuse replacements at instant t;given that the system started from the regenerative state i at t=0
TR_0	expected number of transformer replacements;given that the system started from the regenerative state i at t=0

State Transition Diagram

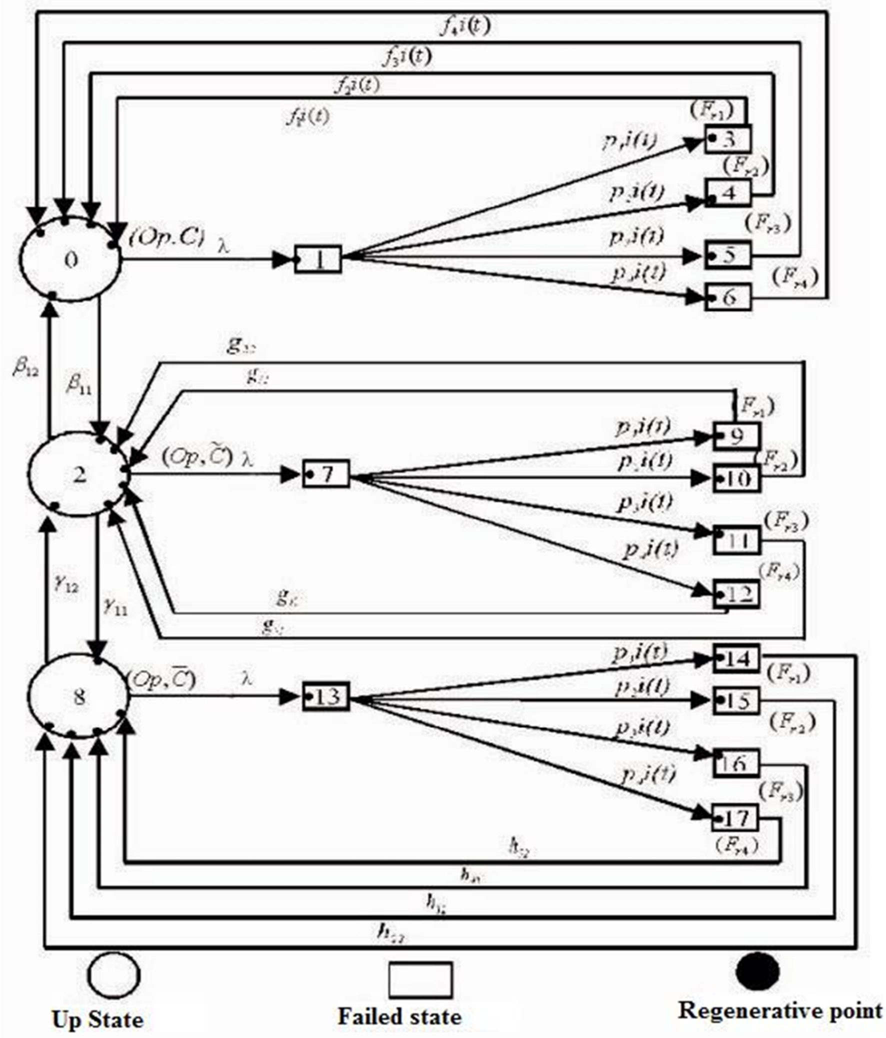

Fig. 1

Model Description & Assumptions

1. Initially the system is operative with controlled power factor.
2. Mode of Power factor may get changed from controlled to partial controlled, partially controlled to uncontrolled and vice-versa.
3. Failure times are assumed to follow an exponential distribution, whereas the others follow arbitrary distributions.
4. After repair, the system becomes as good as new.
5. All the random variables area independent.

Transition Probability and Mean Sojourn Time

The transition diagram showing various states of transition of system are shown in Fig 1 the entry into the states 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16&17 are regenerative state to regenerative state are given below:

$dQ_0, (t) = \beta_{11} e^{-(\lambda+\beta_{11})t} dt$
$dQ_{02}^{(t)} = \lambda\, e^{-(\lambda+\beta_{11})t\, dt}$
$dQ_{20}^{(t)} = \beta_{12} e^{-(\lambda+\beta_{12}+\gamma_{11})t} dt$
$dQ_{27}^{(t)} = \lambda\, e^{-(\lambda+\beta_{12}+\gamma_{11})t}\ dt$
$dQ_{28}^{(t)} = \gamma_{11} e^{-(\lambda+\beta_{12}+\gamma_{11})t}\ dt$
$dQ_{82}^{(t)} = \gamma_{12} e^{-(\lambda+\gamma_{12})t}\ dt$
$dQ_{8,13}^{(t)} = \lambda\, e^{-(\lambda+\gamma_{12})t}\ dt$
$dQ_{30}^{(t)} = f_1^{(t)\, dt}$
$dQ_{40}^{(t)} = f_2^{(t)\, dt}$
$dQ_{50}^{(t)} = f_3^{(t)\, dt}$
$dQ_{60}^{(t)} = f_4^{(t)\, dt}$
$dQ_{92}^{(t)} = g_{12}^{(t)\, dt}$
$dQ_{10,2}^{(t)} = g_{22}^{(t)\, dt}$
$dQ_{11,2}^{(t)} = g_{32}^{(t)\, dt}$
$dQ_{12,2}^{(t)} = g_{42}^{(t)\, dt}$
$dQ_{14,8}^{(t)} = h_{12}^{(t)\, dt}$
$dQ_{15,8}^{(t)} = h_{22}^{(t)\, dt}$
$dQ_{16,8}^{(t)} = h_{32}^{(t)\, dt}$
$dQ_{17,8}^{(t)} = h_{42}^{(t)\, dt}$
$dQ_{13}^{(t)} = p_1\, i(t)\, dt = dQ_{79}(t) = dQ_{13,14}(t)$

$dQ_{14}^{(t)} = p_2\, i(t)\, dt = dQ_{7,10}(t) = dQ_{13,15}(t)$ $dQ_{15}^{(t)} = p_3\, i(t)\, dt = dQ_{7,11}(t) = dQ_{13,16}(t)$
$dQ_{16}^{(t)} = p_4\, i(t)\, dt = dQ_{7,12}(t) = dQ_{13,17}(t)$
The non zero element p_{ij} can be obtained by $p_{ij} = \lim_{s \to 0} q_{ij}^{*}(s)$ such tha

$p_{01}+p_{02} = 1$
$p_{13}+p_{14}+p_{15}+p_{16} = 1$
$p_{20}+p_{27}+p_{28} = 1$
$p_{30}+p_{40=}+p_{50=}+p_{60} = 1$
$p_{92}+p_{10,2}+p_{11,2}+p_{12,2} = 1$
$p_{14,8}+p_{15,8}+p_{16,8}+p_{17,8} = 1$
$p_{79}+p_{7,10}+p_{7,11}+p_{7,12} = 1$
$p_{13,14}+p_{13,15}+p_{13,16}+p_{13,17} = 1$

The mean sojourn times (μ_i) in the regenerative state i is defined as the time to stay in that state before transition to any other state.
If T denotes the stay time in the regenerative state *i*, then:

$$\mu_i = E(T) = P(T>y)$$

$$\mu_0 = \frac{1}{\lambda + \beta_{11}} \quad \mu_1 = \int_0^\infty t \; i(t)dt = \mu_7 = \mu_{13} \quad \mu_2 = \frac{1}{\lambda + \beta_{12} + y_{11}} \quad \mu_3 = \int_0^\infty t \; f_1(t)dt$$

$$\mu_4 = \int_0^\infty t \; f_2(t)dt \quad \mu_5 = \int_0^\infty t \; f_3(t)dt \quad \mu_6 = \int_0^\infty t \; f_4(t)dt \quad \mu_8 = \frac{1}{\lambda + y_{12}} \quad \mu_9 = \int_0^\infty t \; g_{12}(t)dt$$

$$\mu_{10} = \int_0^\infty t \; g_{22}(t)dt \quad \mu_{11} = \int_0^\infty t \; g_{32}(t)dt \quad \mu_{12} = \int_0^\infty t \; g_{42}(t)dt \quad \mu_{14} = \int_0^\infty t \; h_{12}(t)dt \quad \mu_{15} = \int_0^\infty t \; h_{22}(t)dt$$

$$\mu_{16} = \int_0^\infty t \; h_{32}(t)dt \quad \mu_{17} = \int_0^\infty t \; h_{42}(t)dt$$

The unconditional mean time taken by the system to transit to any regenerative state *i* when time is counted from the epoch of entrance into state is mathematical stated as :

$$m_{ij} = \int_0^\infty t \; dQ_{ij}(t) = -q_{ij}(0)$$

Also

$$m_{01} + m_{02} = \mu_0;\; m_{13} + m_{14} + m_{15} + m_{16} = \mu_1;\; m_{20} + m_{27} + m_{28} = \mu_2;\; m_{30} = \mu_3$$

$$m_{40} = \mu_4;\; m_{50} = \mu_5;\, m_{60} = \mu_6;\; m_{79} + m_{7,10} + m_{7,11} + m_{7,12} = \mu_7;\, m_{82} + m_{8,13} = \mu_8$$

$$m_{92} = \mu_9;\; m_{10,2} = \mu_{10};\; m_{11,2} = \mu_{11};\; m_{12,2} = \mu_{12};\; m_{17,2} = \mu_{17}$$

$$m_{13,14} + m_{13,15} + m_{13,16} + m_{13,17} = \mu_{13};\, m_{14,8} = \mu_{14};\, m_{15,2} = \mu_{15};\, m_{16,2} = \mu_{16}$$

Measures of System Effectiveness

Considering the failed state as absorbing state and using the probabilistic arguments used for regenerative process, we obtained the recursive relation for mean time to system failure (MTSF), availability when power factor is controlled, availability when power factor is partial controlled, availability when power factor is not controlled, busy period for repair of type I, type II, type III, and type IV failure, expected number of visits of the repairman, expected number of fuse replacements, expected number of transformer replacements. Then employing Laplace/Laplace Stieltj's Transforms of these recursive relations, the steady state solution for the above mentioned measures of system effectiveness are obtained as under:

Mean time to system failure = N/D
Availability when power factor controlled (AC_0) = N_1/D_1
Availability when power factor partial controlled (AC_0) = N_2/D_1
Availability when power factor uncontrolled ($\overline{AC_0}$) = N_2/D_1
Busy Period of type – I repair (BF_0) = N_4/D_1
Busy Period of type – II repair (BT_0) = N_5/D_1
Busy Period of type – III repair (BP_0) = N_6/D_1
Busy Period of type – IV repair (BO_0) = N_4/D_1
Expected Number of Visits of Repair man (V_o) = N_8/D_1
Expected Number of Fuse Replacement (FR_o) = N_9/D_1
Expected Number of Transformer Replacement (PR_o) = N_{10}/D_1
where
$N = \mu_0 + p_{o1}\mu_1$, $D = 1 - p_{01}\, p_{10}$
$N1 = p_{02}\, p_{82}\, \mu_0$,
$D_1 = p_{20}\, p_{82}\, \mu_0 + p_{82}\, p_{20}\, \mu_1 + p_{02}\, p_{82}\, \mu_2 + p_{01}\, p_{13}\, p_{82}\, p_{20}\, \mu_3 + p_{01}\, p_{14}\, p_{82}\, p_{20}\, \mu_4 + p_{01}\, p_{15}\, p_{82}\, p_{20}\, \mu_5 + p_{01}\, p_{15}\, p_{82}\, p_{20}$

$\mu_6 + p_{02}\, p_{27}\, p_{82}\, \mu_7 + p_{02}\, p_{28}\, \mu_8 + p_{02}\, p_{27}\, p_{82}\, p_{79}\, \mu_9 + p_{02}\, p_{27}\, p_{7,10}\, p_{82}\, \mu_{10} + p_{02}\, p_{27}\, p_{7,11}\, p_{82}\, \mu_{11} + p_{02}\, p_{7,12}\, p_{82}\, \mu_{12} + p_{02}\, p_{28}\, p_{8,13}\, \mu_{13} + p_{02}\, p_{28}\, p_{8,13}\, p_{13,14}\, \mu_{14} + p_{02}\, p_{28}\, p_{8,13}\, p_{13,15}\, \mu_{15} + p_{02}\, p_{28}\, p_{8,13}\, p_{13,16}\, \mu_{16} + p_{02}\, p_{28}\, p_{8,13}\, p_{13,17}\, \mu_{17}$,
$N_2 = p_{02}\, p_{82}\, \mu_2$, $N_3 = p_{02}\, p_{28}\, \mu_8$,
$N_4 = p_{01}\, p_{13}\, p_{20}\, \mu_8 + p_{02}\, p_{27}\, p_{79}\, p_{82}\, \mu_9 + p_{28}\, p_{8,13}\, p_{13,14}\, \mu_{14}$,
$N_5 = p_{01}\, p_{14}\, p_{20}\, p_{82}\, \mu_4 + p_{02}\, p_{27}\, p_{7,10}\, p_{82}\, \mu_{10} + p_{28}\, p_{8,13}\, p_{13,15}\, \mu_{15}$,
$N_6 = p_{01}\, p_{15}\, p_{20}\, p_{82}\, \mu_5 + p_{02}\, p_{27}\, p_{7,11}\, p_{82}\, \mu_{11} + p_{28}\, p_{8,13}\, p_{13,16}\, \mu_{16}$,
$N_7 = p_{01}\, p_{16}\, p_{20}\, p_{82}\, \mu_5 + p_{02}\, p_{27}\, p_{7,12}\, p_{82}\, \mu_{12} + p_{28}\, p_{8,13}\, p_{13,17}\, \mu_{17}$,
$N_8 = p_{01}\, p_{20}\, p_{02}\, (p_{27}\, p_{82} + p_{28})$,
$N_9 = p_{01}\, p_{13}\, p_{20} + p_{02}\, [p_{27}\, p_{79}\, p_{82} + p_{28}\, p_{8,13}\, p_{13,14}]$,
$N_{10} = p_{01}\, p_{24}\, p_{82} + p_{02}\, [p_{27}\, p_{7,10}\, p_{82} + p_{28}\, p_{8,13}\, p_{13,15}]$

Profit Analysis

At steady state, the expected total profit (P) per unit time incurred to the system is given by:
Profit (P_3) = $C_0 (AC_0 + A\tilde{C}_0) - C_{21}\, BF_0 - C_{22}\, BT_0 - C_{23}\, BP_0 - C_{24}\, BO_0 - C_1\, FR_0 - C_2\, PR_0 - C_3\, V_0 - (L\tilde{C})(A\tilde{C}) - (\overline{LC})(\overline{AC}_0)$
Particular Case;
$f_1(t) = \alpha_1 e^{-\alpha_1} t$, $f_2(t) = \alpha_2 e^{-\alpha_2} t$, $f_3(t) = \alpha_3 e^{-\alpha_3} t$, $f_4(t) = \alpha_4 e^{-\alpha_4} t$, $g_{12}(t) = \beta_{22} e^{-\beta_{22}} t$, $g_{22}(t) = \beta_{32} e^{-\beta_{32}} t$, $g_{32}(t) = \beta_{42} e^{-\beta_{42}} t$ $g_{42}(t) = \beta_{52} e^{-\beta_{52}} t$, $h_{12}(t) = \gamma_{22} e^{-\gamma_{22}} t$, $h_{22}(t) = \gamma_{32} e^{-\gamma_{32}} t$,
$h_{32}(t) = \gamma_{42} e^{-\gamma_{42}} t$, $h_{42}(t) = \gamma_{52} e^{-\gamma_{52}} t$, $i(t) = \int e^{-\delta t}$

Using the values of the parameters as mentioned under the heading of Introduction in this paper as
$p_1=0.3$, $p_2=0.2$, $p_3=0.4$, $p_4=0.1$, $\alpha_1=4$, $\alpha_2 = 2$, $\alpha_3 = 6$, $\alpha_4 = 10$, $\beta_{11} = 0.015$, $\beta_{12} = 0.2$, $\beta_{22} = 2.5$, $\beta_{32} = 1.75$, $\beta_{42} = 4$, $\beta_{52} = 6.5$, $\alpha_{11} = 0.005$, $\alpha_{12} = 0.3$, $\alpha_{22} = 2.5$, $\alpha_{32} = 0.25$, $\alpha_{42} = 2$, $\alpha_{52} = 3$, $\delta = 6$, $\lambda = 0.001$, $L\overline{C} = 500$, $L\overline{C} = 300$, $C_1=50$, $C_2 = 250$, $C_3 = 1000$, $C_{21} = 100$, $C_{22} = 150$, $C_{23} = 50$, $C_{24} = 75$;

The following values of various measures of system effectiveness are obtained:

1. Mean Time To System Failure (MTSF)=1002.669Hours
2. Availability when Power Factor is controlled(AC_0)=0.908497
3. Availability when Power Factor is partial controlled($A\tilde{C}_0$)=0.048723
4. Availability when Power Factor is not controlled($\overline{A}C_0$)=0.000792
5. Busy Period of Type I repair(BF_0)=0.000077445
6. Busy Period of Type II repair(BT_0)=0.000101
7. Busy Period of Type III repair(BP_0)=0.00006825
8. Busy Period of Type IV repair(BO_0)=0.0000103
9. Expected number of Visits of repairman(v_0)=0.00124
10. Expected number of Fuse Replacement(FR_0)=0.0003
11. Expected number of Transformer Replacement(TR_0)=0.0002
12. Profit incurred to the system(P)=941.668

Graphical Interpretation (Conclusion)

Various graphs have been plotted but all the graphs have not been shown here to avoid wastage of space and to avoid repetition of similar interpretation. However, the users of such systems may plot any other suitable graph as per their requirement and on the basis of the data available to them and may draw important conclusion and as a result may take important decision regarding profitability of the system. some of the plotted graphs are shown as follows:

Fig. 2 depicts the behaviour of MTSF with different values of λ. MTSF decreases with increases the value of λ.

Fig. 3 depicts the behaviour of profit(P) with respect to loss($\tilde{L}C$) due to partial controlled power factor for different values of the rate (β_{12}) with which power factor changes from partial controlled mode to controlled mode. It can be concluded that the profit (P) decreases with increases the value of ($\tilde{L}C$) and higher values for higher value of β_{12}. It can also be noticed that if β_{12}=0.2 then P>or=or<0 according as $\tilde{L}C$ >or=or<326.7.So, for the model to be beneficial, $\tilde{L}C$ should be <325 if β_{12}=0.2.
Similarly, for β_{12}=0.3and β_{12}=0.4,the values for $\tilde{L}C$ should be lesser than 420.31and 504.47 respectively.

Fig. 4 shows the behaviour of profit(P) with respect to cost (C_2) per replacement of the transformer for different values of cost (C_3) per visit of repairman. It is obvious from the graph that the profit decreases with the increase in the values of cost (C_2). It can also be noticed that if C_3=2100 then P>or=or<0according as C_2 <or >4378.89. So, for the model to be beneficial, C_2 should be < 4378.89 if C_3=2100. Similarly, for C_3=2140and C_3=2180, the values for C_2 should be lesser than 4002.44 and 3507.97, respectively.

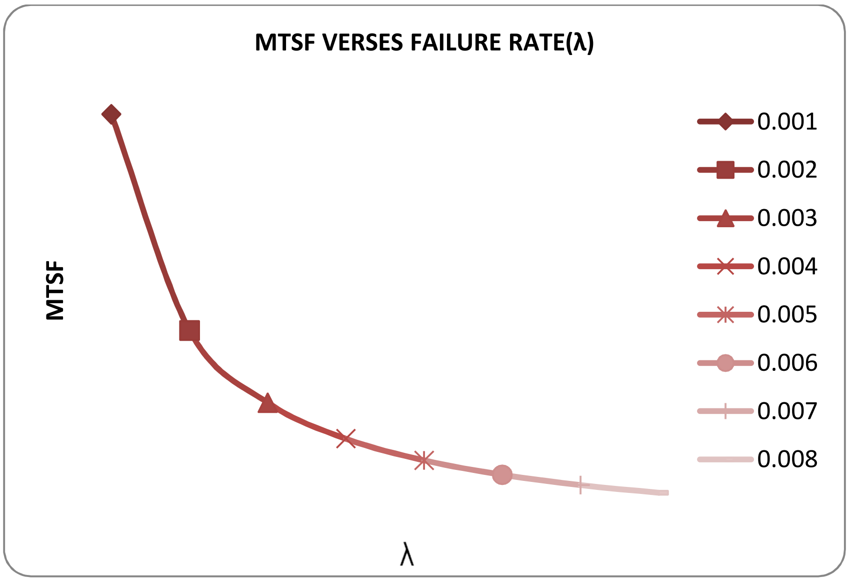

Fig. 2

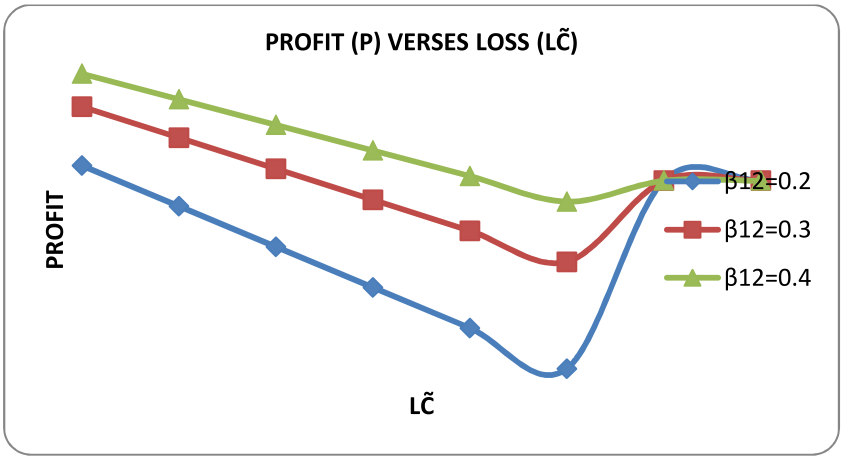

Fig. 3

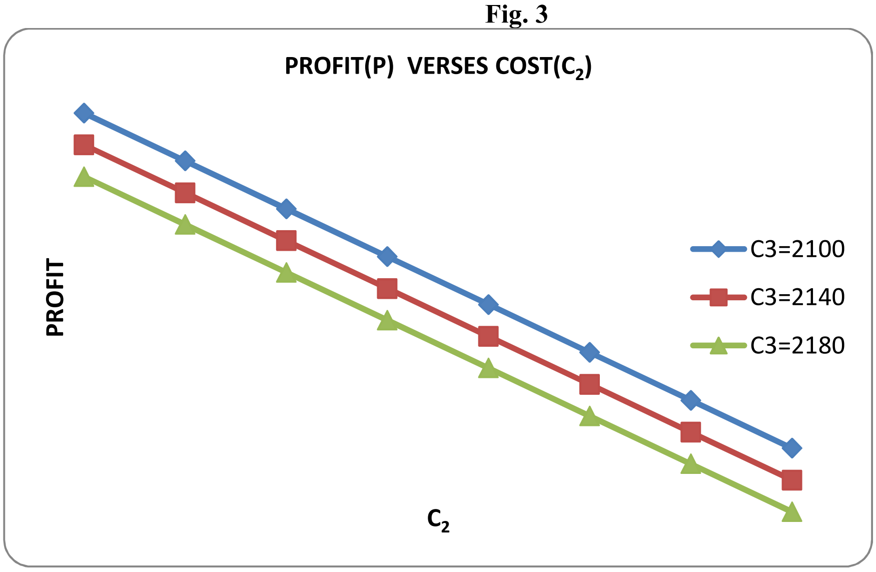

Fig. 4

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