Ability Assesment of A Solar PV System Integrated with Greenhouse

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Abstract

In this paper, the author deals with the ability assessment of a solar photovoltaic (PV) system integrated with greenhouse. The power produced from the solar PV system has been used to operate the required heating/cooling equipments inside the greenhouse. The block diagram of solar PV system has been shown in fig 1-(a). The authors have been used supplementary variables technique to mathematical formulation of the model. The difference-differential equations of various flow states are then solved subjected to Laplace transform. The reliability function, availability function and M.T.T.F have obtained. Steady-state behavior of the system and a particular case (when repairs follow exponential time distribution) have also been computed to improve practical utility of the model. A numerical example together with its graphical illustration has also appended in the end to highlight important results of the study.

Keywords' : *Reliability assessment, Markovian analysis, Laplace transform, MTTF, Steady state behavior*

1. INTRODUCTION

The whole system under consideration consists of four main subsystems A, B, C, and E, connected in series. Subsystem A is a solar panel and produced DC power from sunlight. Subsystem B is a charge controller and it controls the charging of batteries. Subsystem C is a battery bank and stores the DC power produced by the solar panel. Here, in this model, the subsystem C has two units, namely C_1 and C_2 in standby redundancy. Originally, one battery bank C_1 works and on failure of C_1 we can online standby battery bank C_2 by the help of imperfect switching device D. In last, the subsystem E is an inverter and it converts 3.0KVA DC power to 220V/50Hz AC power. The flow of states for this system has been shown in fig-1(b).

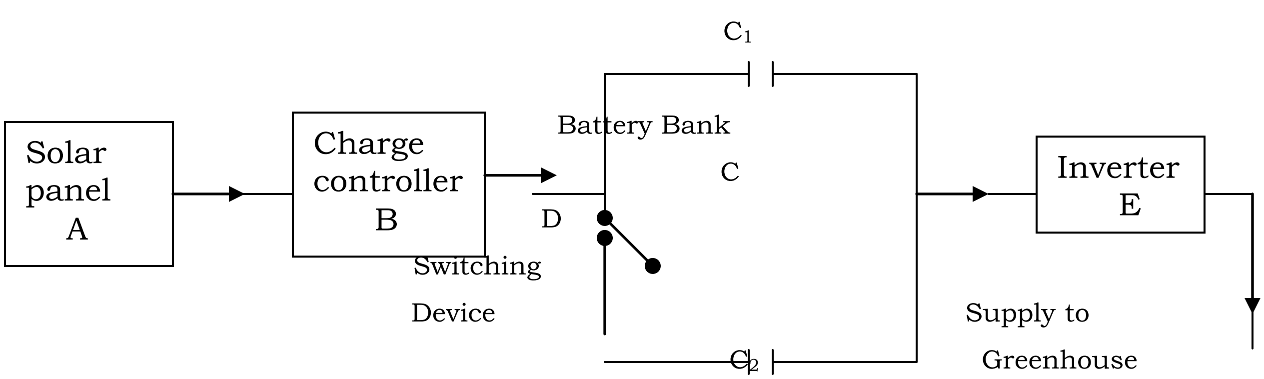

Fig-1 (a): Block Diagram of Solar PV System

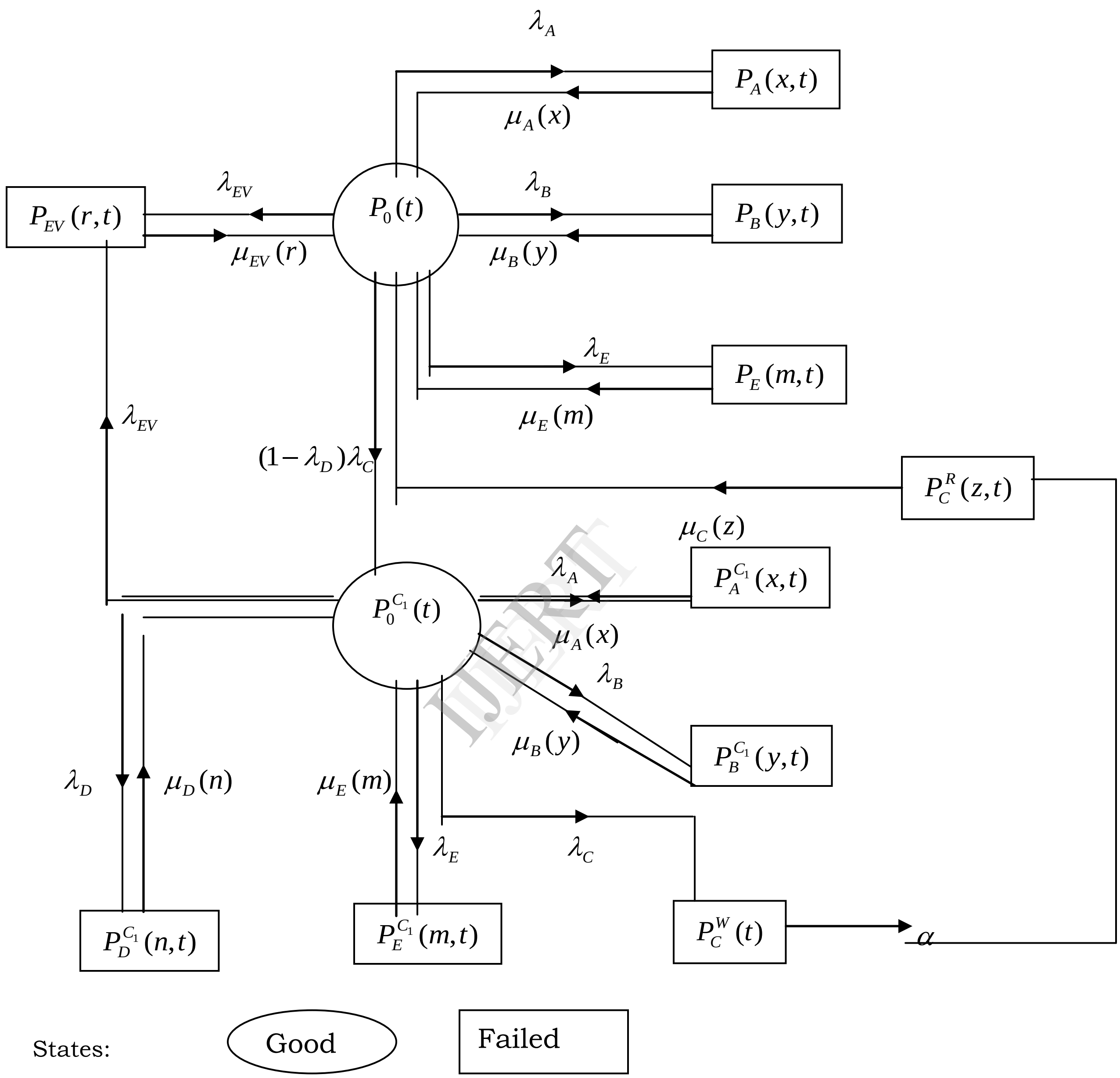

Fig-1 (b): Flow of states

2. ASSUMPTIONS

The following assumptions have been associated with this model:

(i.) Initially at t=0, all the subsystems and the system as a whole is operable.

(ii.) Repair to subsystem C has given only if its both units are failed. In this case, the system has to wait for repair otherwise repair facilities are always available.

(iii.) The whole system can also fail due to environmental reasons.
(iv.) Failures are S-independent and nothing can fail from a failed state.
(v.) Repairs are perfect i.e., after repair components work as new.
(vi.) All failures follow exponential time distribution whereas all repairs follow general time distribution.

3. NOMANCLATURE

$P_0(t) / P_0^{C_1}(t)$	Pr {At time t, system is operable while unit C_1 is working/failed}.
$P_i(j,t)\Delta / P_i^{C_1}(j,t)\Delta$	Pr {At time t, system is failed due to failure of i^{th} subsystem and elapsed repair time lies in the interval $(j, j+\Delta)$ while unit C_1 is working /failed}.
$P_C^W(t)$	Pr {At time t, system is failed due to failure of subsystem C and is waiting for repair}.
$P_C^R(z,t)\Delta$	Pr {At time t, system is ready for repair of subsystem C and elapsed repair time lies in the interval $(z, z+\Delta)$}.
$P_{EV}(r,t)\Delta$	Pr {At time t, system is failed due to environmental reasons and elapsed repair time lies in the interval $(r, r+\Delta)$}.
$\overline{P}(s)$	Laplace transform of function $P(t)$.
$S_i(x)$	$\mu_i(x)\exp.\left\{-\int \mu_i(x)dx\right\}$, $\forall$ *i* and *x*.
M.T.T.F.	Mean time to failure.
λ_i	Failure rate of i^{th} subsystem.
λ_{EV}	Failure rate due to environmental reasons.
$\mu_i(j)\Delta$	First order probability that i^{th} subsystem will be repaired in the time interval $(j, j+\Delta)$, conditioned that it was not repaired up to the time *j*.

4. FORMULATION OF MATHEMATICAL MODEL

Probability considerations and limiting procedure yield the following set of difference-differential equations governing the behaviour of considered system, which is continuous in time and discrete in space:

$$\left(\frac{d}{dt}+\lambda_A+\lambda_B+\lambda_E+\lambda_{EV}+(1-\lambda_D)\lambda_C\right)P_0(t)=\int_0^\infty P_A(x,t)\mu_A(x)dx + \int_0^\infty P_B(y,t)\mu_B(y)dy + \int_0^\infty P_E(m,t)\mu_E(m)dm + \int_0^\infty P_{EV}(r,t)\mu_{EV}(r)dr\int_0^\infty P_C^R(z,t)\mu_C(z)dz \quad \ldots(1)$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_A(x)\right]P_A(x,t)=0 \quad \ldots(2)$$

$$\left[\frac{\partial}{\partial y}+\frac{\partial}{\partial t}+\mu_B(y)\right]P_B(y,t)=0 \quad \ldots(3)$$

$$\left[\frac{\partial}{\partial m}+\frac{\partial}{\partial t}+\mu_E(m)\right]P_E(m,t)=0 \quad \ldots(4)$$

$$\left(\frac{d}{dt}+\lambda_A+\lambda_B+\lambda_E+\lambda_C+\lambda_D+\lambda_{EV}\right)P_0^{C_1}(t)=\lambda_C(1-\lambda_D)P_0(t)+\int_0^\infty P_A^{C_1}(x,t)\mu_A(x)dx$$ …(5)

$$+\int_0^\infty P_B^{C_1}(y,t)\mu_B(y)dy+\int_0^\infty P_E^{C_1}(m,t)\mu_E(m)dm+\int_0^\infty P_D^{C_1}(n,t)\mu_D(n)dn$$

$$\left[\frac{\partial}{\partial x}+\frac{\partial}{\partial t}+\mu_A(x)\right]P_A^{C_1}(x,t)=0$$ …(6)

$$\left[\frac{\partial}{\partial y}+\frac{\partial}{\partial t}+\mu_B(y)\right]P_B^{C_1}(y,t)=0$$ …(7)

$$\left[\frac{\partial}{\partial m}+\frac{\partial}{\partial t}+\mu_E(m)\right]P_E^{C_1}(m,t)=0$$ …(8)

$$\left[\frac{\partial}{\partial n}+\frac{\partial}{\partial t}+\mu_D(n)\right]P_D^{C_1}(n,t)=0$$ …(9)

$$\left[\frac{\partial}{\partial t}+\alpha\right]P_C^{W}(t)=\lambda_C\ P_0^{C_1}(t)$$ …(10)

$$\left[\frac{\partial}{\partial z}+\frac{\partial}{\partial t}+\mu_C(z)\right]P_C^{R}(z,t)=0$$ …(11)

$$\left[\frac{\partial}{\partial r}+\frac{\partial}{\partial t}+\mu_{EV}(r)\right]P_{EV}(r,t)=0$$ …(12)

Boundary conditions are :

$$P_A(0,t)=\lambda_A\ P_0(t)$$ …(13)

$$P_B(0,t)=\lambda_B\ P_0(t)`$$ …(14)

$$P_E(0,t)=\lambda_E\ P_0(t)$$ …(15)

$$P_A^{C_1}(0,t)=\lambda_A\ P_0^{C_1}(t)$$ …(16)

$$P_B^{C_1}(0,t)=\lambda_B\ P_0^{C_1}(t)$$ …(17)

$$P_D^{C_1}(0,t)=\lambda_D\ P_0^{C_1}(t)$$ …(18)

$$P_E^{C_1}(0,t)=\lambda_E\ P_0^{C_1}(t)$$ …(19)

$$P_C^{R}(0,t)=\alpha\ P_C^{W}(t)$$ …(20)

$$P_{EV}(0,t)=\lambda_{EV}\left[\mathrm{P}_0(t)+P_0^{C_1}(t)\right]$$ …(21)

Initial conditions are:

$P_0(0)=1,$ otherwise all state probabilities at t=0 are zero. …(22)

5. SOLUTION OF THE MODEL

Taking Laplace transforms of equations (1) through (21) subjected to initial conditions (22) and then on solving them one by one, we obtain the following Laplace transforms of various transition-state (depicted in fig-1b) probabilities:

$$\overline{P}_0(s)=\frac{1}{\mathrm{B}(s)}$$ …(23)

$$\overline{P}_A(s)=\frac{\lambda_A}{B(s)}D_A(s) \qquad \ldots(24)$$

$$\overline{P}_B(s)=\frac{\lambda_B}{B(s)}D_B(s) \qquad \ldots(25)$$

$$\overline{P}_E(s)=\frac{\lambda_E}{B(s)}D_E(s) \qquad \ldots(26)$$

$$\overline{P}_0^{C_1}(s)=\frac{\lambda_C(1-\lambda_D)}{A(s)B(s)} \qquad \ldots(27)$$

$$\overline{P}_A^{C_1}(s)=\frac{\lambda_A\lambda_C(1-\lambda_D)}{A(s)B(s)}D_A(s) \qquad \ldots(28)$$

$$\overline{P}_B^{C_1}(s)=\frac{\lambda_B\lambda_C(1-\lambda_D)}{A(s)B(s)}D_B(s) \qquad \ldots(29)$$

$$\overline{P}_E^{C_1}(s)=\frac{\lambda_E\lambda_C(1-\lambda_D)}{A(s)B(s)}D_E(s) \qquad \ldots(30)$$

$$\overline{P}_D^{E_1}(s)=\frac{\lambda_C\lambda_D(1-\lambda_D)}{A(s)B(s)}D_D(s) \qquad \ldots(31)$$

$$\overline{P}_C^{W}(s)=\frac{\lambda_C^2(1-\lambda_D)}{(s+\alpha)A(s)B(s)} \qquad \ldots(32)$$

$$\overline{P}_C^{R}(s)=\frac{\alpha\lambda_C^2(1-\lambda_D)}{(s+\alpha)A(s)B(s)}D_C(s) \qquad \ldots(33)$$

$$\overline{P}_{EV}(s)=\frac{\lambda_{EV}}{B(s)}\left[1+\frac{\lambda_C(1-\lambda_D)}{A(s)}\right] \quad D_{EV}(s) \qquad \ldots(34)$$

where, $D_i(j)=\dfrac{1-\overline{S}_i(j)}{j}$ *for all* i and j …(35)

$$A(s)=\lambda_C+\lambda_{EV}+s[1+\lambda_A D_A(s)+\lambda_B D_B(s)+\lambda_E D_E(s)+\lambda_D D_D(s)] \qquad \ldots(36)$$

and $B(s)=s[1+\lambda_A D_A(s)+\lambda_B D_B(s)+\lambda_E D_E(s)]+\lambda_{EV}+\lambda_C(1-\lambda_D)$

$$-\frac{\alpha\lambda_C^2(1-\lambda_D)\overline{S}_C(s)}{(s+\alpha)A(s)}-\lambda_{EV}\left[1+\frac{\lambda_C(1-\lambda_D)}{A(s)}\right]\overline{S}_{EV}(s) \qquad \ldots(37)$$

It is worth noticing that

Sum of equations (23) through (34) = $\dfrac{1}{s}$ …(38)

6. STEADY-STATE BEHAVIOUR OF THE SYSTEM

By using Abel's lemma, viz., $\underset{t\to\infty}{Lim}\,P(t)=\underset{s\to 0}{Lim}\,s\ \overline{P}(s)=P$ (say), provided the limit on L.H.S. exists, one can obtain the steady-state probabilities from equations (23) through (34):

7. PARTICULAR CASE

When all repairs follow exponential time distribution

In this case, we have obtained the following Laplace transforms of various flow state probabilities from equations (23) through (34) by putting $\overline{S}_i(s)=\dfrac{\mu_i}{s+\mu_i}$, for all i:

$$\overline{P}_0(s)=\frac{1}{C(s)} \quad \ldots(39)$$

$$\overline{P}_A(s)=\frac{\lambda_A}{C(s)}.\frac{1}{s+\mu_A} \quad \ldots(40)$$

$$\overline{P}_B(s)=\frac{\lambda_B}{C(s)}.\frac{1}{s+\mu_B} \quad \ldots(41)$$

$$\overline{P}_E(s)=\frac{\lambda_E}{C(s)}.\frac{1}{s+\mu_E} \quad \ldots(42)$$

$$\overline{P}_0^{C_1}(s)=\frac{\lambda_C(1-\lambda_D)}{E(s)C(s)} \quad \ldots(43)$$

$$\overline{P}_A^{C_1}(s)=\frac{\lambda_A\lambda_C(1-\lambda_D)}{E(s)C(s)}\cdot\frac{1}{s+\mu_A} \quad \ldots(44)$$

$$\overline{P}_B^{C_1}(s)=\frac{\lambda_B\lambda_C(1-\lambda_D)}{E(s)C(s)}\cdot\frac{1}{s+\mu_B} \quad \ldots(45)$$

$$\overline{P}_E^{C_1}(s)=\frac{\lambda_E\lambda_C(1-\lambda_D)}{E(s)C(s)}\cdot\frac{1}{s+\mu_E} \quad \ldots(46)$$

$$\overline{P}_D^{C_1}(s)=\frac{\lambda_C\lambda_D(1-\lambda_D)}{E(s)C(s)}\cdot\frac{1}{s+\mu_D} \quad \ldots(47)$$

$$\overline{P}_C^{W}(s)=\frac{\lambda_C^2(1-\lambda_D)}{(s+\alpha)E(s)C(s)} \quad \ldots(48)$$

$$\overline{P}_C^{R}(s)=\frac{\alpha\lambda_C^2(1-\lambda_D)}{(s+\alpha)E(s)C(s)}\cdot\frac{1}{s+\mu_C} \quad \ldots(49)$$

and $$\overline{P}_{EV}(s)=\frac{\lambda_{EV}}{C(s)}\left[1+\frac{\lambda_C(1-\lambda_D)}{E(s)}\right].\frac{1}{s+\mu_{EV}} \quad \ldots(50)$$

where, $$E(s)=\lambda_C+\lambda_{EV}+s\left[1+\frac{\lambda_A}{s+\mu_A}+\frac{\lambda_B}{s+\mu_B}+\frac{\lambda_E}{s+\mu_E}+\frac{\lambda_D}{s+\mu_D}\right] \quad \ldots(51)$$

and $$C(s)=s\left[1+\frac{\lambda_A}{s+\mu_A}+\frac{\lambda_B}{s+\mu_B}+\frac{\lambda_E}{s+\mu_E}\right]+\lambda_{EV}+\lambda_C(1-\lambda_D)$$
$$-\frac{\alpha\lambda_C^2(1-\lambda_D)}{(s+\alpha)E(s)}\cdot\frac{\mu_C}{s+\mu_C}-\lambda_{EV}\left[1+\frac{\lambda_C(1-\lambda_D)}{E(s)}\right]\frac{\mu_{EV}}{s+\mu_{EV}} \quad \ldots(52)$$

8. RELIABILITY AND M.T.T.F. OF THE SYSTEM

Laplace transform of system's reliability is given by:

$$\overline{R}(s) = \frac{1}{s + \lambda_A + \lambda_B + \lambda_E + \lambda_{EV} + \lambda_C(1 - \lambda_D)}$$

$$\therefore R(t) = L^{-1}\{\overline{R}(s)\}$$

$$= \exp.\{-(\lambda_A + \lambda_B + \lambda_E + \lambda_{EV} + \lambda_C(1 - \lambda_D))t\} \quad \ldots(53)$$

Also, M.T.T.F. $= \lim_{s \to 0} \overline{R}(s)$

$$= \frac{1}{\lambda_A + \lambda_B + \lambda_E + \lambda_{EV} + \lambda_C(1 - \lambda_D)} \quad \ldots(54)$$

9. AVAILABILITY EVALUATION

We have

$$\overline{P}_{up}(s) = \frac{1}{s + \lambda_A + \lambda_B + \lambda_E + \lambda_{EV} + \lambda_C(1 - \lambda_D)}\left[1 + \frac{\lambda_C(1 - \lambda_D)}{s + \lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E + \lambda_{EV}}\right]$$

On taking inverse Laplace transform, we obtain

$$P_{up}(t) = (1 + A)\exp.[-\{\lambda_A + \lambda_B + \lambda_E + \lambda_{EV} + \lambda_C(1 - \lambda_D)\}t]$$

$$- A\exp.[-\{\lambda_A + \lambda_B + \lambda_C + \lambda_D + \lambda_E + \lambda_{EV}\}t] \quad \ldots(55)$$

where, $A = \frac{\lambda_C(1 - \lambda_D)}{\lambda_D(1 + \lambda_C)}$ …(56)

It is important to note that $P_{up}(0) = 1$

Also, $P_{down}(t) = 1 - P_{up}(t)$ …(57)

10. NUMERICAL COMPUTATION

For a numerical computation, let us consider the values

$\lambda_A = 0.001,\ \lambda_B = 0.02,\ \lambda_C = 0.003,\ \lambda_D = 0.4,\ \lambda_E = 0.04,\ \lambda_{EV} = 0.005$ an t = 0,1,2,-----.

By using these values in equations (53), (54) and (55), one can compute the table- 1, 2, 3 and 4. The corresponding graphs have been shown in fig-2, 3, 4 and 5, respectively.

11. RESULTS AND DISCUSSION

In this paper, the authors have considered a solar PV system to evaluate its reliability measures. Supplementary variables technique has been used to formulate a mathematical model for the system. The so obtained difference-differential equations have been solved by using Laplace transform. Reliability, availability and M.T.T.F. of the system have computed. Steady-state behaviour and a particular case (when all repairs follow exponential time distribution) have also mentioned to make the model more compatible. A numerical example has also appended in last to highlight important results of the study. By using this numerical example tables- (1) through (4) have been computed and the corresponding graphs have been shown by the figs- (2) through (5), respectively.

12. REFERENCES

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t	R(t)
0	1
1	0.934447
2	0.873192
3	0.815952
4	0.762464
5	0.712482
6	0.665777
7	0.622134
8	0.581351
9	0.543242
10	0.507631

Table-1

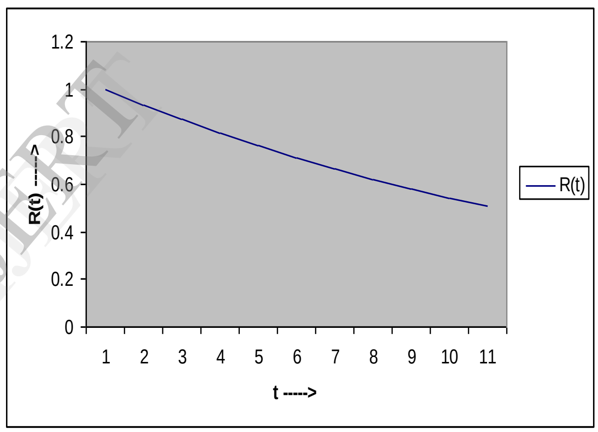

Fig-2

t	$P_{up}(t)$
0	1
1	0.935833
2	0.875353
3	0.818514
4	0.765197
5	0.715249
6	0.668495
7	0.624757
8	0.583854
9	0.545614
10	0.509868

Table-2

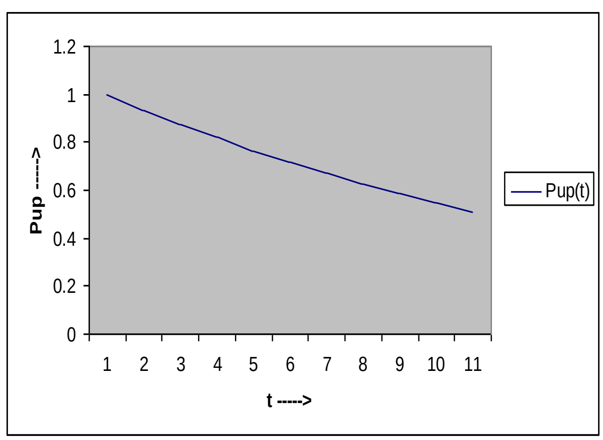

Fig-3

λ_D	M.T.T.F.
0	14.49275
0.1	14.55604
0.2	14.61988
0.3	14.68429
0.4	14.74926
0.5	14.81481
0.6	14.88095
0.7	14.94768
0.8	15.01502
0.9	15.082296
1.0	15.15152

Table-3

λ_{EV}	M.T.T.F.
0	14.49275
0.001	14.55604
0.002	14.61988
0.003	14.68429
0.004	14.74926
0.005	14.81481
0.006	14.88095
0.007	14.94768
0.008	15.01502
0.009	15.082296
0.010	15.15152

Table$_{-4}$

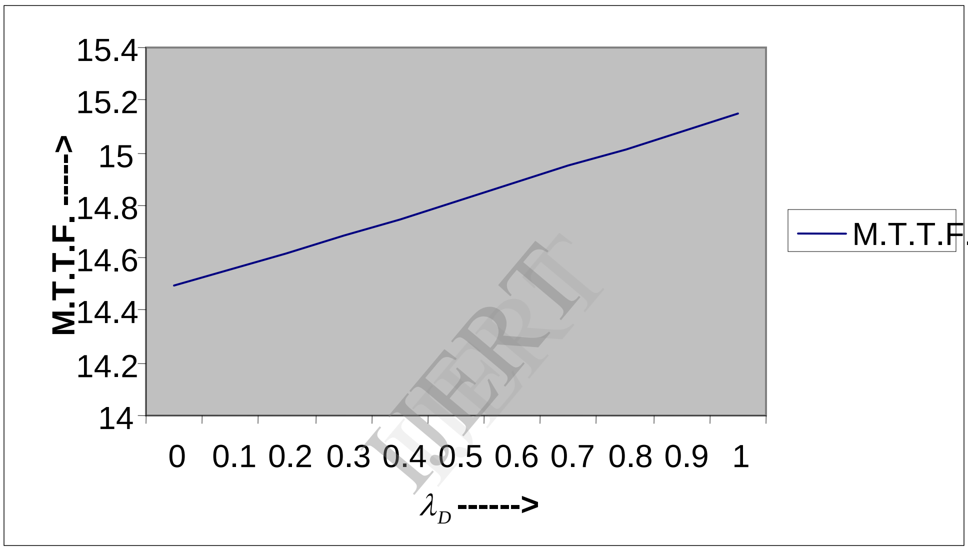

Fig-4

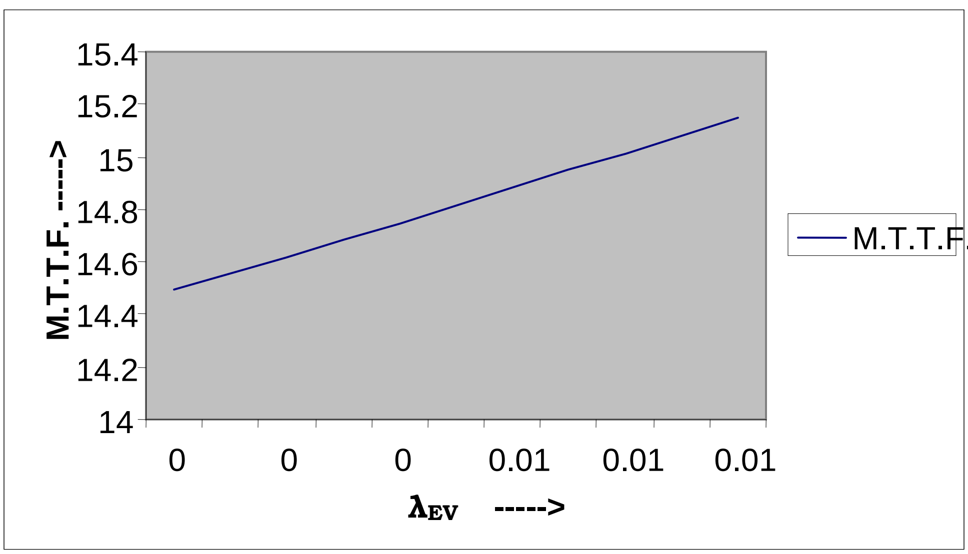

Fig-5