Research Article

Gain-function of two-unit non-identical warm standby nuclear power system with failure due to extremely high radiations and failure due to nuclear accidents caused by releasing of fission products into the environment

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Abstract

Introduction: The **environmental impact of nuclear power** results from the nuclear fuel cycle, operation, and the effects of nuclear accidents. The routine health risks and greenhouse gas emissions from nuclear fission power are small relative to those associated with coal, oil and gas. However, there is a "catastrophic risk" potential if containment fails, which in nuclear reactors can be brought about by over-heated fuels melting and releasing large quantities of fission products into the environment. The public is sensitive to these risks and there has been considerable pubic opposition to nuclear power. The 1979 Three Mile Island accident and 1986 Chernobyl disaster, along with high construction costs, ended the rapid growth of global nuclear power capacity. A further disastrous release of radioactive materials followed the 2011 Japanese tsunami which damaged the Fukushima I Nuclear Power Plant, resulting in hydrogen gas explosions and partial meltdowns classified as a Level 7 event. The large-scale release of radioactivity resulted in people being evacuated from a 20 km exclusion zone set up around the power plant, similar to the 30 km radius Chernobyl Exclusion Zone still in effect. In **Nuclear Reactor** the leakage in form of radiations becomes highly dangerous to the lives of living beings. The radiations from the nuclear reactor are always under serious consideration due to fatal and miserable results to human race. Every precautions and extra care is taken to avoid any miss-happening due to radiations. But still due carelessness or due to failure of some equipment in Nuclear Reactors there occur leakage of radiations causing a major casualty. In the present paper we have taken two-dissimilar warm standby nuclear power system with failure due to extremely high radiations which we abbreviated as **FEHR** and failure due to nuclear accidents caused by releasing of Fission products into the Environment which we abbreviated as **FNAF**. When there are radiations of extremely high magnitude the working of unit stops automatically to avoid excessive damage of the units and when the unit comes in no normal position the repair of the units' starts immediately. The failure time distribution is taken as exponential and repair time distribution as general. Using Markov regenerative point technique we have calculated different reliability characteristics such as MTSF, reliability of the system, availability analysis in steady state, busy period analysis of the system under repair, expected number of visits by the repairman in the long run and Gain-function. Special case by taking failure and repair as exponential have been derived and graphs are drawn.

Keyword: warm standby, extremely high radiations, nuclear accidents caused by releasing of Fission products into environment, MTSF, Availability, busy period, Gain - function.

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

Access this article online	
Quick Response Code:	Website: www.statperson.com
	DOI: 07 October 2014

How to site this article: Ashok Kumar Saini. Gain-function of two-unit non-identical warm standby nuclear power system with failure due to extremely high radiations and failure due to nuclear accidents caused by releasing of fission products into the environment. *International Journal of Statistika and Mathemtika* Aug-Oct 2014; 11(3): 207-213. http://www.statperson.com(accessed 07 October 2014)

INTRODUCTION

Nuclear power is the fourth-largest source of electricity in India after thermal, hydroelectric and renewable sources of electricity. As of 2013, India has 21 nuclear reactors in operation in 7 nuclear power plants, having an installed capacity of 5308 MW and producing a total of 30,292.91 GWh of electricity while seven other reactors are under construction and are expected to generate an additional 6,100 MW. In October 2010, India drew up "an ambitious plan to reach a nuclear power capacity of 63,000 MW in 2032",but, after the 2011 Fukushima nuclear disaster in Japan, "populations around proposed Indian NPP sites have launched protests, raising questions about atomic energy as a clean and safe alternative to fossil fuels". There have been mass protests against the French-backed 9900 MW Jaitapur Nuclear Power Project in Maharashtra and the Russian-backed 2000 MW Kudankulam Nuclear Power Plant in Tamil Nadu. The state government of West Bengal state has also refused permission to a proposed 6000 MW facility near the town of Haripur that intended to host six Russian reactors. A Public Interest Litigation (PIL) has also been filed against the government's civil nuclear programme at the Supreme Court. Despite this opposition, the capacity factor of Indian reactors was at 79% in the year 2011-12 compared to 71% in 2010-11. Nine out of twenty Indian reactors recorded an unprecedented 97% Capacity factor during 2011-12. With the imported uranium from France, the 220 MW Kakrapar 2 PHWR reactors recorded 99% capacity factor during 2011-12. The Availability factor for the year 2011-12 was at 89%. India has been making advances in the field of thorium-based fuels, working to design and develop a prototype for an atomic reactor using thorium and low-enriched uranium, a key part of India's three stage nuclear power programmes. In **Nuclear Reactor** the leakage in form of radiations becomes highly dangerous to the lives of living beings. The radiations from the nuclear reactor are always under serious consideration due to fatal and miserable results to human race. In the present paper we have taken two-dissimilar warm standby system with failure due to extremely high radiations- **FHER** and failure due to nuclear accidents caused due to releasing of fission products into the environment -**FNAF**

Assumptions

1. The failure time distribution is exponential whereas the repair time distribution is arbitrary of two non-identical units.
2. The repair starts immediately upon failure of units and the repair discipline is FCFS.
3. The repairs are perfect and start immediately as soon as the extremely high radiations of the system become normal. The radiations of both the units do not go extremely high.
4. The failure of a unit is detected immediately and perfectly.
5. The switches are perfect and instantaneous.
6. All random variables are mutually independent.

SYMBOLS FOR STATES OF THE SYSTEM

Superscripts: O, WS, SO, FEHR, FNAF

Operative, Warm Standby, Stops the operation, Failure due to extremely high radiations, failure due to nuclear accidents caused from large release of fission products into the environment respectively

Subscripts: nehr, ehr,naf, ur, wr, uR

No extremely high radiations. Extremely high radiations, nuclear accidents fission, under repair, waiting for repair, under repair continued respectively

Up states: 0, 1, 2, 9;

Down states: 3,4,5,6,7,8,10,11

Regeneration Point: 0, 1, 2, 4, 7, 10

States of the System

0(O_{nehr}, WS_{nehr}) One unit is operative and the other unit is warm standby and there is no extremely high radiations in both the units.

1(SO_{nehr}, O_{nehr})

The operation of the first unit stops automatically due to extremely high radiations and warm standby units starts operating and there is no extremely high radiations.

2($FEHR_{ehr,ur}$, O_{nehr})

The first unit fails and undergoes repair after failure due to extremely high radiations are over and the second unit continues to be operative with no extremely high radiations.

3($FEHR_{ehr,uR}$, SO_{ehr})

The repair of the first unit is continued from state 2 and in the other unit extremely high radiations occur and stops automatically due to extremely high radiations.

4($FEHR_{ehr,ur}$, SO_{uehr})
The one unit fails and undergoes repair after the extremely high radiations are over and the other unit also stops automatically due to extremely high radiations.
5($FEHR_{ehr,uR}$, $FEHR_{ehr,\ wr}$)
The repair of the first unit is continued from state 4 and the other unit is failed due to extremely high radiations in it and is waiting for repair.
6(O_{nehr}, $FEHR_{ehr,ur}$)
The first unit is operative with no extremely high radiations and the second unit failed due to extremely high radiations is under repair.
7(SO_{nehr}, $FNAF_{naf,ur}$)
The operation of the first unit stops automatically due to extremely high radiations and the second unit fails due nuclear accidents caused due release of fission products and undergoes repair.
8($FEHR_{ehr,wr}$, $FNAF_{naf,uR}$)
The repair of failed switch is continued from state 7 and the first unit is failed after extremely high radiations and waiting for repair.
9(O_{nehr}, SO_{uehr})
The first unit is operative and the warm standby dissimilar unit is under extremely high radiations
10(SO_{nehr}, $FNAF_{naf,ur}$)
The operation of the first unit stops automatically due to extremely high radiations and the second unit fails due to nuclear accidents due to release of fission products and undergoes repair after the extremely high radiations is over.
11($FEHR_{ehr,wr}$, $FNAF_{naf,uR}$)
The repair of the second unit is continued from state 10 and the first unit is failed due to extremely high radiations is waiting for repair.

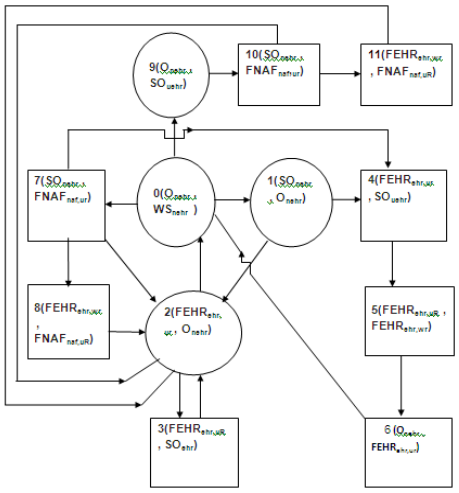

Figure 1: The State Transition Diagram
Up state **Down state**

TRANSITION PROBABILITIES

Simple probabilistic considerations yield the following expressions:

$p_{01} = \frac{\lambda 1}{\lambda 1+\lambda 2+\lambda 3}$, $P_{07} = \frac{\lambda 2}{\lambda 1+\lambda 2+\lambda 3}$

$p_{09} = \frac{\lambda 2}{\lambda 1+\lambda 2+\lambda 3}$, $p_{12} = \frac{\lambda 1}{\lambda 1+\lambda 3}$, $p_{14} = \frac{\lambda 3}{\lambda 1+\lambda 3}$

$P_{20} = G_1^*(\lambda_1)$, $P_{22}^{(3)} = G_1^*(\lambda_1) = p_{23}$, $P_{72} = G_2^*(\lambda_4)$,

$P_{72}^{(8)} = G_2^*(\lambda_4) = P_{78}$

We can easily verify that

$p_{01} + p_{07} + p_{09} = 1$, $p_{12} + p_{14} = 1$, $p_{20} + p_{23} (= p_{22}^{(3)}) = 1$, $p_{46}^{(6)} = 1$ $p_{60} = 1$,

$p_{72} + P_{72}^{(5)} + p_{74} = 1$, $p_{9,10} = 1$, $p_{10,2} + p_{10,2}^{(11)} = 1$ (1)

We can easily verify that

$p_{01} + p_{07} + p_{09} = 1$, $p_{12} + p_{14} = 1$, $p_{20} + p_{23} (= p_{22}^{(3)}) = 1$, $p_{46}^{(6)} = 1$ $p_{60} = 1$,
$p_{72} + P_{72}^{(5)} + p_{74} = 1$, $p_{9,10} = 1$, $p_{10,2} + p_{10,2}^{(11)} = 1$ (1)

And mean sojourn time are

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

Mean Time To System Failure

We can regard the failed state as absorbing

$\theta_0(t) = Q_{01}(t)[s]\theta_1(t) + Q_{09}(t)[s]\theta_9(t) + Q_{07}(t)$

$\theta_1(t) = Q_{12}(t)[s]\theta_2(t) + Q_{14}(t)$, $\theta_2(t) = Q_{20}(t)[s]\theta_0(t) + Q_{22}^{(3)}(t)$

$\theta_4(t) = Q_{9,10}(t)$ (3-5)

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

$Q_0^*(s) = N_1(s) / D_1(s)$ (6)

Where

$N_1(s) = Q_{01}^*(s) \{ Q_{12}^*(s) Q_{22}^{(3)*}(s) + Q_{14}^*(s) \} + Q_{09}^*(s) Q_{9,10}^*(s) + Q_{07}^*(s)$

$D_1(s) = 1 - Q_{01}^*(s) \quad Q_{12}^*(s) Q_{20}^*(s)$

Making use of relations (1) and (2) it can be shown that $\theta_0(0) = 1$, which implies that $\theta_0(t)$ is a proper distribution.

MTSF = $E[T] = d/ds\ \theta_0^*(0) \Big|_{s=0} = (D_1'(0) - N_1'(0)) / D_1(0)$

$= (\mu_0 + p_{01} \mu_1 + p_{01} p_{12} \mu_2 + p_{09} \mu_9) / (1 - p_{01} p_{12} p_{20})$

Where

$\mu_0 = \mu_{01} + \mu_{07} + \mu_{09}$, $\mu_1 = \mu_{12} + \mu_{14}$, $\mu_2 = \mu_{20} + \mu_{22}^{(3)}$, $\mu_9 = \mu_{9,10}$

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 $M_0(t)$, $M_1(t)$, $M_2(t)$, $M_4(t)$ can be found easily.

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

$A_0(t) = M_0(t) + q_{01}(t)[c]A_1(t) + q_{07}(t)[c]A_7(t) + q_{09}(t)[c]A_9(t)$

$A_1(t) = M_1(t) + q_{12}(t)[c]A_2(t) + q_{14}(t)[c]A_4(t)$, $A_2(t) = M_2(t) + q_{20}(t)[c]A_0(t) + q_{22}^{(3)}(t)[c]A_2(t)$

$A_4(t) = q_{46}^{(3)}(t)[c]A_6(t)$, $A_6(t) = q_{60}(t)[c]A_0(t)$

$A_7(t) = (q_{72}(t) + q_{72}^{(8)}(t))\ [c]A_2(t) + q_{74}(t)[c]A_4(t)$

$A_9(t) = M_9(t) + q_{9,10}(t)[c]A_{10}(t)$, $A_{10}(t) = q_{10,2}(t)[c]A_2(t) + q_{10,2}^{(11)}(t)[c]A_2(t)$ (7-14)

Taking Laplace Transform of eq. (7-14) and solving for $\hat{A}_0(s)$

$\hat{A}_0(s) = N_2(s) / D_2(s)$ (15)

Where

$N_2(s) = (1 - \hat{q}_{22}^{(3)}(s)) \{ \hat{M}_0(s) + \hat{q}_{01}(s) \hat{M}_1(s) + \hat{q}_{09}(s) \hat{M}_9(s) \} + \hat{M}_2(s) \{ \hat{q}_{01}(s) \hat{q}_{42}(s) + \hat{q}_{07}(s) (\hat{q}_{72}(s) + \hat{q}_{73}^{(8)}(s)) + \hat{q}_{09}(s) \hat{q}_{9,10}(s) (\hat{q}_{10,2}(s) + \hat{q}_{10,2}^{(11)}(s)) \}$

$D_2(s) = (1 - \hat{q}_{22}^{(3)}(s)) \{ 1 - \hat{q}_{46}^{(5)}(s) \hat{q}_{60}(s) (\hat{q}_{01}(s) \hat{q}_{44}(s) + \hat{q}_{07}(s) \hat{q}_{74}(s)) - \hat{q}_{20}(s) \{ \hat{q}_{01}(s) \hat{q}_{12}(s) + \hat{q}_{07}(s) (\hat{q}_{72}(s)) + \hat{q}_{72}^{(8)}(s) + \hat{q}_{09}(s) \hat{q}_{9,10}(s) (\hat{q}_{10,2}(s) + \hat{q}_{10,2}^{(11)}(s)) \}$

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

$A_0 = \lim_{s\to 0} \frac{N_2(s) + s N_2'(s)}{D_2'(s)} = \frac{N_2(0)}{D_2'(0)}$ (16)

Where

$N_2(0) = p_{20}(\hat{M}_0(0) + p_{01}\hat{M}_1(0) + p_{09} \hat{M}_9(0)) + \hat{M}_2(0) (p_{01}p_{12} + p_{07} (p_{72} + p_{72}^{(8)} + p_{09}))$

$D_2'(0) = p_{20} \{ \mu_0 + p_{01} \mu_1 + (p_{01} p_{14} + p_{07} p_{74}) \mu_4 + p_{07} \mu_7 + p_{07} \mu_7 + p_{09}(\mu_9 + \mu_{10}) + \mu_2 \{ 1 - ((p_{01}p_{14} + p_{07} p_{74})\}$

$\mu_4 = \mu_{46}^{(5)}, \mu_7 = \mu_{72} + \mu_{72}^{(8)} + \mu_{74}, \mu_{10} = \mu_{10,2} + \mu_{10,2}^{(11)}$

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

$\lambda_u(t) = \int_0^{\infty} A_0(z)dz$ So that $\widehat{\lambda_u}(s) = \frac{\hat{A}_0(s)}{s} = \frac{N_2(S)}{SD_2(S)}$ (17)

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

$\lambda_d(t) = t - \lambda_u(t)$ So that $\widehat{\lambda_d}(s) = \frac{1}{s^2} - \widehat{\lambda_u}(s)$ (18)

The expected busy period of the server for repairing the failed unit under extremely high radiations in (0, t]

$R_0(t) = S_0(t) + q_{01}(t)[c]R_1(t) + q_{07}(t)[c]R_7(t) + q_{09}(t)[c]R_9(t)$

$R_1(t) = S_1(t) + q_{12}(t)[c]R_2(t) + q_{14}(t)[c]R_4(t)$,

$R_2(t) = q_{20}(t)[c]R_0(t) + q_{22}^{(3)}(t)[c]R_2(t)$

$R_4(t) = q_{46}^{(3)}(t)[c]R_6(t)$, $R_6(t) = q_{60}(t)[c]R_0(t)$

$R_7(t) = (q_{72}(t) + q_{72}^{(8)}(t))\,[c]R_2(t) + q_{74}(t)[c]R_4(t)$

$R_9(t) = S_9(t) + q_{9,10}(t)[c]R_{10}(t)$, $R_{10}(t) = q_{10,2}(t) + q_{10,2}^{(11)}(t)[c]R_2(t)$ (19-26)

Taking Laplace Transform of eq. (19-26) and solving for $\widehat{R_0}(s)$

$\widehat{R_0}(s) = N_3(s) / D_2(s)$ (27)

Where

$N_2(s) = (1 - \hat{q}_{22}^{(3)}(s))\,\{\hat{S}_0(s) + \hat{q}_{01}(s)\hat{S}_1(s) + \hat{q}_{09}(s)\hat{S}_9(s)\}$ and $D_2(s)$ is already defined.

In the long run, $R_0 = \frac{N_3(0)}{D_2'(0)}$ (28)

where $N_3(0) = p_{20}(\hat{S}_0(0) + p_{01}\hat{S}_1(0) + p_{09}\hat{S}_9(0))$ and $D_2'(0)$ is already defined.

The expected period of the system under extremely high radiations in (0, t] is

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

The expected Busy period of the server for repair of dissimilar units by the repairman in (0, t]

$B_0(t) = q_{01}(t)[c]B_1(t) + q_{07}(t)[c]B_7(t) + q_{09}(t)[c]B_9(t)$

$B_1(t) = q_{12}(t)[c]B_2(t) + q_{14}(t)[c]B_4(t)$, $B_2(t) = q_{20}(t)[c]\,B_0(t) + q_{22}^{(3)}(t)[c]B_2(t)$

$B_4(t) = T_4(t) + q_{46}^{(3)}(t)[c]B_6(t)$, $B_6(t) = T_6(t) + q_{60}(t)[c]B_0(t)$

$B_7(t) = (q_{72}(t) + q_{72}^{(8)}(t))\,[c]B_2(t) + q_{74}(t)[c]B_4(t)$

$B_9(t) = q_{9,10}(t)[c]B_{10}(t)$, $B_{10}(t) = T_{10}(t) + (q_{10,2}(t) + q_{10,2}^{(11)}(t)[c]B_2(t)$ (29- 36)

Taking Laplace Transform of eq. (29-36) and solving for $\widehat{B_0}(s)$

$\widehat{B_0}(s) = N_4(s) / D_2(s)$ (37)

Where

$N_4(s) = (1 - \hat{q}_{22}^{(3)}(s))\,\{\hat{q}_{01}(s)\hat{q}_{14}(s)(\hat{T}_4(s) + \hat{q}_{46}^{(5)}(s)\hat{T}_6(s)) + \hat{q}_{07}^{(3)}(s)\hat{q}_{74}(s)(\hat{T}_4(s) + \hat{q}_{46}^{(5)}(s)\hat{T}_6(s)) + \hat{q}_{09}(s)\hat{q}_{09,10}(s)\hat{T}_{10}(s))$

And $D_2(s)$ is already defined.

In steady state, $B_0 = \frac{N_4(0)}{D_2'(0)}$ (38)

where $N_4(0) = p_{20}\{(p_{01}p_{14} + p_{07}p_{74})(\hat{T}_4(0) + \hat{T}_6(0)) + p_{09}\hat{T}_{10}(0)\}$ and $D_2'(0)$ is already defined.

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 $\widehat{\lambda_{ru}}(s) = \frac{\hat{B}_0(s)}{s}$ (39)

The expected Busy period of the server for repair of unit for failure due nuclear accidents caused due to release of fission products in (o, t]

$P_0(t) = q_{01}(t)[c]P_1(t) + q_{07}(t)[c]P_7(t) + q_{09}(t)[c]P_9(t)$

$P_1(t) = q_{12}(t)[c]P_2(t) + q_{14}(t)[c]P_4(t)$, $P_2(t) = q_{20}(t)[c]P_0(t) + q_{22}^{(3)}(t)[c]P_2(t)$

$P_4(t) = q_{46}^{(3)}(t)[c]P_6(t)$, $P_6(t) = q_{60}(t)[c]P_0(t)$

$P_7(t) = L_7(t) + (q_{72}(t) + q_{72}^{(8)}(t))\,[c]P_2(t) + q_{74}(t)[c]P_4(t)$

$P_9(t) = q_{9,10}(t)[c]P_{10}(t)$, $P_{10}(t) = (q_{10,2}(t) + q_{10,2}^{(11)}(t))[c]P_2(t)$ (40-47)

Taking Laplace Transform of eq. (40-47) and solving for

$\widehat{P_0}(s) = N_5(s) / D_2(s)$ (48)

where $N_2(s) = \hat{q}_{07}(s)\,\hat{L}_7(s)\,(1 - \hat{q}_{22}^{(3)}(s))$ and $D_2(s)$ is defined earlier.

In the long run, $P_0 = \frac{N_5(0)}{D_2'(0)}$ (49)

where $N_5(0)= p_{20}\, p_{07}\, \hat{L}_4(0)$ and $D_2'(0)$ is already defined.

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

$\lambda_{rs}(t) = \int_0^{\infty} P_0(z)dz$ So that $\widehat{\lambda_{rs}}(s) = \frac{\hat{P}_0(s)}{s}$ (50)

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

$H_0(t) = Q_{01}(t)[c]H_1(t) + Q_{07}(t)[c]H_7(t) + Q_{09}(t)[c]H_9(t)$

$H_1(t) = Q_{12}(t)[c][1+H_2(t)] + Q_{14}(t)[c][1+H_4(t)]$, $H_2(t) = Q_{20}(t)[c]H_0(t) + Q_{22}^{(3)}(t)[c]H_2(t)$

$H_4(t) = Q_{46}^{(3)}(t)[c]H_6(t)$, $H_6(t) = Q_{60}(t)[c]H_0(t)$

$H_7(t) = (Q_{72}(t)+ Q_{72}^{(8)}(t))\,[c]H_2(t) + Q_{74}(t)[c]H_4(t)$

$H_9(t) = Q_{9,10}(t)[c][1+H_{10}(t)]$, $H_{10}(t) = (Q_{10,2}(t)[c] + Q_{10,2}^{(11)}(t))[c]H_2(t)$ (51-58)

Taking Laplace Transform of eq. (51-58) and solving for $H_0^*(s)$

$H_0^*(s) = N_6(s) / D_3(s)$ (59)

Where

$N_6(s) = (1 - Q_{22}^{(3)*}(s))\,\{ Q^*_{01}(s)(Q^*_{12}(s)+ Q^*_{14}(s)) + Q^*_{09}(s)\, Q^*_{9,10}(s)\}$

$D_3(s) = (1 - Q_{22}^{(3)*}(s))\,\{1 - (Q^*_{01}(s)\, Q^*_{14}(s) + Q^*_{07}(s)\, Q^*_{74}(s))\, Q_{46}^{(5)*}(s)\, Q^*_{60}(s)\}$
$- Q^*_{20}(s)\{ Q^*_{01}(s)\, Q^*_{12}(s)+ Q^*_{07}(s)(Q^*_{72}(s)) + Q^*_{72}{}^{(8)}(s) +$
$Q^*_{09}(s)\, Q^*_{9,10}(s)\,(Q^*_{10,2}(s) + Q_{10,2}^{(11)*}(s))\}$

In the long run, $H_0 = \frac{N_6(0)}{D_3'(0)}$ (60)

where $N_6(0)= p_{20}\,(p_{01} + p_{09})$ and $D'_3(0)$ is already defined.

The expected number of visits by the repairman for repairing the unit for failure due nuclear accidents caused due to release of fission products in the environment in (0, t]

$V_0(t) = Q_{01}(t)[c]V_1(t) + Q_{07}(t)[c]V_7(t) + Q_{09}(t)[c]V_9(t)$

$V_1(t) = Q_{12}(t)[c]V_2(t) + Q_{14}(t)[c]V_4(t)$, $V_2(t) = Q_{20}(t)[c]V_0(t) + Q_{22}^{(3)}(t)[c]V_2(t)$

$V_4(t) = Q_{46}^{(3)}(t)[c]V_6(t)$, $V_6(t) = Q_{60}(t)[c]V_0(t)$

$V_7(t) = (Q_{72}(t)[1+V_2(t)]+ Q_{72}^{(8)}(t))\,[c]V_2(t) + Q_{74}(t)[c]V_4(t)$

$V_9(t) = Q_{9,10}(t)[c]V_{10}(t)$, $V_{10}(t) = (Q_{10,2}(t) + Q_{10,2}^{(11)}(t))[c]V_2(t)$ (61-68)

Taking Laplace-Stieltjes transform of eq. (61-68) and solving for $V_0^*(s)$

$V_0^*(s) = N_7(s) / D_4(s)$ (69)

where $N_7(s) = Q^*_{07}(s)\, Q^*_{72}(s)\,(1 - Q_{22}^{(3)*}(s))$ and $D_4(s)$ is the same as $D_3(s)$

In the long run, $V_0 = \frac{N_7(0)}{D_4'(0)}$ (70)

where $N_7(0)= p_{20}\, p_{07}\, p_{72}$ and $D'_3(0)$ is already defined.

COST BENEFIT ANALYSIS

The cost-benefit function of the system considering mean up-time, expected busy period of the system under extremely high radiations when the units stops automatically, expected busy period of the server for repair of unit for **failure due nuclear accidents caused by release of fission products,** expected number of visits by the repairman for unit failure, expected number of visits by the repairman for **failure due nuclear accidents caused by release of fission products**. The expected total cost-benefit incurred in (0, t] is

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

- expected total repair cost for **unit failure due nuclear accidents caused by release of fission products** in (0,t]
- expected total repair cost for repairing the units in (0,t]
- expected busy period of the system under extremely high radiations when the units automatically stop in (0,t]
- expected number of visits by the repairman for repairing the **unit failure due nuclear accidents caused by release of fission products** in (0,t]
- expected number of visits by the repairman for repairing of the units in (0,t]

The expected total cost per unit time in steady state is

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

$= K_1A_0 - K_2P_0 - K_3B_0 - K_4R_0 - K_5V_0 - K_6H_0$

Where

K_1: revenue per unit up-time,

K_2: cost per unit time for which the system is uner repair **failure due nuclear accidents caused by release of fission products**
K_3: cost per unit time for which the system is under unit repair
K_4: when units automatically stop cost per unit time for which the system is under extremely high radiations
K_5: cost per visit by the repairman for which **unit under repair for failure due to nuclear accidents caused by release of fission products**
K_6: 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 nuclear accidents caused by fission, failure rate due to extremely high radiations increases, the MTSF and steady state availability decreases and the cost function decreased as the failure increases.

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