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Analysis of a Redundant System with Imperfect Switch

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The behaviour and profit analysis of a two unit redundant system in cold/warm/hot stand-by modes with imperfect switch over device is done, introducing the concept of capacity factor/duty-cycle and the fuzziness measure of the state(s). The mean time to system failure, availability and other key parameters of the system are evaluated using the regenerative-point graphical technique, discussed in Section 2.6.

The researchers including, Goel & Singh [38], Singh, J. [95], Chander S. & Mukender Singh [14], Goyal, Rashmi & Ashok Kumar [40] and Gupta, P.P. & Sharma [43], Taneja [108] and many others have analyzed the stochastic systems considering only the operation time and without taking into account the capacity factor of the system/sub-system(s). Taneja [108] discusses a system with one main unit and two programmable logic controllers (PLC's) with one of the PLC's is in hot stand-by mode. The failed state 1 is considered while writing the state equations used for the calculation of the mean time to system failure under steady state conditions and the busy period for the replacements of type II is not evaluated which is significant and thus the profit analysis done by the author is incomplete.

There may be situations where the main unit works in reduced state(s) or its working continues in a reduced state even after the redundant units are in the down state while undergoing the repairs and replacements etc. For example: on the breakdown of the PLC's, the coal feeder in a thermal plant can continue its working with reduced capacity because of the accumulated stock of the crushed coal, This is dealt with by considering the fuzziness measure of the states, making the system analysis more realistic. Instead of the hot stand-by case, the more general case of redundancy to the extent that it can be in cold/warm/ hot stand by modes is considered.

f: Behavior And Profit Analysis Of A Redundant System With Imperfect Switch', Published in Journal Of Mathematics And Systems Sciences (JMASS), India; June, 2007; Vol.3, No. 1; pp. 16-35.

There may be failures caused due to the failures of the switch. This physical situation may be observed in PLC's used in many plants including thermal power plants, refineries, and fertilizer- plants etc. Further, it is possible that the main unit may not be in the working mode although it is available for the operation. For example, the motor of the refrigerator runs for a fraction of the total time of operation of the refrigerator. Therefore, the actual operation time of the motor is just a fraction of the calendar time of operation of the refrigerator. If A, be the failure rate of the main unit and c be the capacity factor/duty cycle of the main unit (fraction of time for which the main unit is in working condition during the calendar time of operation), then the contribution to the total failure rate of the main unit is ***c.X.***

The objective of this chapter is to obtain the important and key parameters under steady state conditions useful for the behaviour and profit analysis of the system, using the formulae (2.5.1) to (2.5.4) of the regenerative-point graphical technique, introduced in Chapter II.. The concepts of capacity factor and fuzziness measure of the states of the system are introduced. The analysis of the system is carried out by assuming that the failure times and replacement/repair times of the redundant units are exponentially distributed, whereas the repair-time of the main unit and inspection-time of the redundant units follow the general distributions. Mean time to system failure (MTSF), availability and other useful key parameters are evaluated. The tables and the graphs are drawn to study the effect of the various system parameters on MTSF, availability of the system and the profitability of the plant. The analytical analysis is done and conclusions are made by taking an example. Special cases are considered for the operating time, calendar time, and perfect switch and for cold stand-by, warm stand-by and hot stand-by modes.

THE SYSTEM

The system consists of two redundant units and the main unit with imperfect switch over device. The redundant units may be in cold/warm/hot stand-by modes and the main unit may work with reduced capacity. It consists of the following sub-systems: **Sub-system** A: It consists of two redundant units Al and A2 (each composed of several components in series), one is on-line unit while the other is in cold/warm/hot stand-by mode.

Sub-system B: It (main unit) consists of several repairable components in series. The failure of any one of its components, causes the failure of the system.

Switch over device E: The switch may not be 100 % perfect. Whenever the on-line unit fails it is switched out and the stand-by unit is switched in successfully with probability 'a'. The block diagram of the system is shown in Fig. 3.1.

Block Diagram of the System Fig. **3.1**

A unit may stop working due to some repairable fault or some source fault in an unrepairable component of a unit or the unit is burnt or due to power recycling but is found in good state after inspection.

a) Type-1 Failure: the redundant unit on failure, is found (after due inspection) to be repairable or that it needs some part to be replaced, called replacement of type I (Repl).

b) Type-II Failure: the redundant unit on failure is found (after due inspection) to be unrepairable owing to total burnt of the unit and needs full replacement, called replacement of type II (ReplI).

ASSUMPTIONS AND NOTATIONS

The following assumptions and notations are used in the analysis of the system:

1) The system starts from 0- state (good state) at time t = 0.

2) Nothing can fail further when the system is in a failed state. The switching over time is negligible. A repaired unit is as good as a new one.

3) There are no demand failures of the main unit. The failure rate of the main unit during the down mode is negligible. If the main unit fails, then system is in the failed state and the redundant units are stopped. The main unit is immediately put under repair.

4) In ease the switch fails to detect and disconnect the failed redundant unit or both the redundant units are under repair or Repl/ReplI, then the system is in the reduced state/down state.

5) On the failure of a redundant unit, an inspection is carried out to detect the type of failure. It is assumed that the inspection for the type of failure finishes before any other failure of the main unit or of the stand-by unit.

6) The failure of a redundant unit may be of casual nature, which needs no repairs or replacements and the system starts functioning as such after a while.

7) It is assumed that repair/Repl/ReplI of a redundant unit finishes before the repair of the main unit is completed.

pr k : probability.

P : state 'k' is a non-regenerative state.

: steady state transition probability from a regenerative state / to a regenerative state *j* without visiting any other state, *p^ j - q* j* (o).

: steady state transition probability from a regenerative state *i* to a regenerative state *j* while visiting non-regenerative state *k* once.

Ri(t) : the reliability that the system is in the regenerative state / at time *t,* given that the system entered regenerative state / at *t* = 0.

a,(<) : availability of the system is in regenerative state / at time *t,* given that the system entered regenerative state / at *t* = 0.

Bil) : probability that the repairman is busy doing a particular job at epoch *t,* given that the system entered regenerative state *iatt* = 0.

Bf{f)/ ***Bf(t)*** : P r°b aDm ty that the repairman is busy doing repairs of the main unit/ redundant units at epoch r, given that the system entered regenerative state / at ***t*** = 0.

B1^ if) /B^11if) : P r°bability that the server is busy in Repl/ReplI of a redundant unit at epoch r, given that the system entered regenerative state / at ***t*** **=** 0.

jj(t): probability that the repairman is busy doing inspection of a failed redundant unit at epoch r, given that the system entered regenerative state / at ***t*** = 0.

(r) : waiting-time probability that the repairman is busy doing a particular job in the regenerative state / at epoch ***t,*** without transiting to any other regenerative state or returning to the state / through one or more non-regenerative states, given the system entered regenerative state / at ***t*** **=** 0.

Viif) **'•** the expected number of visits by the server for a given job in (0, r], given that the system entered the regenerative state / at ***t*** **=** 0.

yM ^ : the expected number of visits by the server to repair the main unit in the interval (0, r], given the system entered the regenerative state / at ***t*** **=** 0.

y^s.(t) **'■** the expected number of visits by the server to repair the switch in the interval (0, r], given the system entered regenerative state / at ***t*** **=** 0.

yR(t) **'•** the expected number of the visits by the server for doing inspection/repairs/Repl/ReplI of the redundant unit(s) in the time interval (0, r], given that the system entered the regenerative state / at time ***t*** **=** 0.

gi.(t)/ R^i*) **'** me exPected number of Repl/Repll in (0, r], given that the system entered regenerative state / at ***t*** =0.

ReplI/ReplI : replacement of type 1/ II for a redundant unit.

M_0 / Ma : main unit is operative/main unit is in down state.

Co/ C_s : redundant unit is in operative/ hot stand-by mode.

Fur / Fur : main unit under repair/ repair continuing from the previous state.

Ca / **C_ui / C_wj** : redundant unit is down/under I nspection/ waiting for inspection.

Cf/Cr/CR : redundant unit is failed/ is under repair/repair continuing from the previous state.

C_{re}pi / C_{Rep}i : Rep I is taking place/ Rep I continuing from previous state.

Crepii /C_{Rep}ii : Rep II is taking place/ Rep II continuing from previous state

: capacity factor/duty cycle of the main unit

: failure rate of the main unit with capacity factor c; *X]= c.X* where *X* is the constant failure rate of the main unit.

: probability of successful working of the switch. For perfect detection of failure and successful switching a = 1.

: constant failure rate of a redundant unit during operation/stand-by mode.

: probability that a failed redundant unit has failure of type-I/type-II/ probability that the failed redundant unit is found o.k. after inspection; Pi + P2 + P3 =1-

: probability that a failed redundant unit needs repair/Repl; ai+ a_2=l : constant rate of repair/ Repl / Repll of a redundant unit. : constant failure/repair rate of the switch. For perfect switch 8 = 0. : probability density function (p.d.f.)/cumulative distribution function (c.d.f.) of the inspection time of a failed redundant unit.

H(t) = l-H(f).

: probability density function (p.d.f.) and cumulative distribution function (c.d.f.) of the repair-time of the main unit. ***G (t)*** = 1- G (f).

: the triplet exhibits the status of the system. X denotes the status of the main unit, Y denotes the status of the PLC (on-line unit) and Z denotes the status of the PLC in the hot stand-by mode. : a = a (ai +012); b = (I - a) (ai +a_2) + 8

STATE TRANSITION DIAGRAM OF THE SYSTEM AND THE RESULTS

Following the above assumptions and notations, the transition diagram showing various states of transition is given in Fig. 3.2. The epochs at which the system enters the states 0 to 12 are the regenerative points and the corresponding states are the regenerative states. The state '13' is a non-regenerative state.

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