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Reliability Prediction for Input-Output Cards of Distributed Control Systems in Power Plants

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Abstract: Distributed control systems in power plants are the latest trends to optimize and control performance. Reliability prediction of input-output components of distributed control systems have a key role to play in the power plant scenario. Triple modular redundancy is a means of increasing reliability of systems. Triple modular redundancy of three modules each containing m cards is studied in this paper. Also, in this paper the reliability of analog input card, digital output card and analog output card are predicted with triple modular redundancy and 128 cards/dpu and standby redundancy (1 out of 2). The results of triple modular redundancy as against standby redundancy are compared for different mission times.

Keywords: *Reliability prediction, triple modular redundancy, standby redundancy*

1. Introduction

Reliability, in engineering applications, is defined as:

- The probability that an item can perform its intended functions under given conditions for a given time interval (t_1, t_2). This is normally denoted either by the letter R or by R(t), with t denoting the time interval (t_1, t_2).
- Instantaneous failure rate is given by:

$$\lambda(t) = f(t) / [1 - F(t)] \tag{1}$$

  where f(t) is the probability density function and F(t) is the cumulative distribution function of the time to failure of the component [1].

2. Purpose of Reliability Prediction

The primary purposes of reliability prediction are to:

- Evaluate whether or not a particular design concept is likely to meet a specified reliability requirement under defined conditions
- Compare alternative design solutions
- Provide inputs to related project activities, such as:
  - Design evaluation
  - Trade-off studies
  - Life cycle costs
  - Spares provisioning
  - Logistic and maintenance support studies
- Assist in the identification and elimination of any potential reliability problems by imposing a systematic discipline that ensures all reliability aspects of a design are examined
- Measure progress towards achieving the specified reliability requirements

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The prediction process is a continuing activity throughout a project, with the prediction being regularly updated as more design, test and evaluation data become available. The accuracy of any prediction depends largely upon the availability of detailed design and operating data. However, this is seldom available during the early stages of a project.

The requirement for prediction must be used to force detailed information to be made available as early as possible, particularly in critical areas, so that a more thorough and realistic pre-design assessment can be produced. Clearly, therefore, prediction must be part of the design process and not simply a parallel activity.

3. Reliability Expression

Reliability of a module is given by

$$R_0 = e^{-\lambda t} \tag{2}$$

where, λ is the failure rate and t is the mission time. Mission time represents the maximum period of time for which a subsystem (or system) can be used. This formula works under the assumption that failure time of a component/module follows an exponential distribution assuming that the instantaneous failure rate is constant. Let us proceed on to define the reliability of Triple Modular Redundant (TMR) systems and perceive its effect on system reliability. TMR is a special case of NMR fault-tolerant redundancy architecture, in which three modules perform a same task/process and the result is polled by a voting system to produce a single output. If any one of the three modules fails, the other two modules can correct and mask the fault. If the voter fails then the complete system will fail.

Reliability of triple modular redundancy as originally proposed by Von Neumann is given by the formula [2]:

$$R_T = R_0^3 + 3R_0^2(1-R_0) \tag{3}$$

This formula is derived by assuming the reliabilities of all three non-redundant modules are equal to R_0. This is the sum of the probabilities of the system states corresponding to:

a. all three modules function, and
b. one of the three modules fail, other two function

$$R_T = 3R_0^2 - 2R_0^3 \tag{4}$$

The above formula can be modified if there are a number of cards in each of the three modules. In each case the reliability R of each of the m cards is given by $R = (R_0)^{1/m}$. The triple modular redundancy for each three-card set is given by:

$$R_T = 3(R_0)^{2/m} - 2(R_0)^{3/m} \tag{5}$$

If the entire system is replaced by m units and TMR is used for each set of the 3 modules, the system behaves like a series system containing m TMR subsystems and triple modular redundancy for the entire system is given by [3]:

$$R_T^m = [3(R_0)^{2/m} - 2(R_0)^{3/m}]^m \tag{6}$$

It may be noted that formulas (3) and (4) are used when TMR configuration is implemented at the module level, whereas formula (6) is used when TMR configuration is implemented for each set of the cards.

The standby redundancy for a generic set of N units in a system where D units are needed for operation and λ the failure rate of individual unit is given by:

$$R_{sr} = e^{-D\lambda t} \sum_{k=0}^{N-D} (D\lambda t)^k / k! \tag{7}$$

4. I/O Modules of Distributed Control System

The Distributed Control System (DCS) designed and developed in-house for support to power plant systems has a range of I/O cards driving it. We are computing the reliability of these I/O cards. The cards taken for study are analog input card, digital output card and analog output card. A study is undertaken here to ensure that minimum reliability values are maintained. The reliability of the DCS I/O modules in TMR configuration is also computed. The case is extended to I/O modules in TMR configuration with 128 cards per DPU. Reliability of active redundancy or standby redundancy is also computed for the purpose of comparison and better decision making.

5. Reliability Prediction for I/O of DCS

The reliability prediction report of the analog input card – II used in the distributed control system has been generated by importing the Bill of Materials (BOM). A number of minor parts like resistors and capacitors have not been recognized by our software. But these can be extrapolated using single values of failure rates for resistors and capacitors that can be located in the parts library.

The calculated failure rate for the analog input card – II excluding the resistors and capacitors is 5.906046. Failure rate is in terms of failures per million hours. There are 83 capacitors and 137 resistors each with a failure rate of 0.000163 and 0.003860 respectively. Hence, total failure rate would be 0.013529 and 0.52882 for capacitors and resistors respectively. The overall failure rate for the BOM is 6.448395, ~6.5. Similar calculations for the digital output card and analog output card are shown in Table – I. The mean time between failures (MTBF) is the reciprocal of λ. It is nothing but the mean time taken between two successive failures of the same component within a specified time period or mission time. It is in hours.

The MTBF is typically part of a model that assumes the failed system is immediately repaired (mean time to repair, or MTTR), as a part of a renewal process. This is in contrast to the mean time to failure (MTTF), which measures average time to failures with the modeling assumption that the failed system is not repaired (infinite repair time).

Table 1: Indicating overall λ and MTBF for AI, DO and AO

Card	**Calc. λ**	**No. of Cap. λ**	**No. of Res. λ**	**λ**	**MTBF (1/λ)**
AI	5.91	83, 0.0135	137, 0.5288	6.5	153846
DO	2.33	59, 0.0096	115, 0.4439	3.0	333333
AO	9.04	65, 0.0106	95, 0.3667	9.5	105263

Table 2 indicates the overall failure rate, mission time, reliability, TMR and standby redundancy (SR) for the DCS I/O cards. The mission time is taken as 1 yr/ 2 yrs for 24/7, 365 days operation of DCS.

Table 2: Comparing TMR with Standby Redundancy for 1 yr/ 2yrs Mission Times

Crd	**λ**	**MT yrs**	**R**	**TMR**	**TMR 128**	**SR**
AI	6.5	1	0.94	0.99	0.999	0.998
AI	6.5	2	0.89	0.97	0.999	0.994
DO	3.0	1	0.97	0.998	0.999	0.999
DO	3.0	2	0.95	0.99	0.999	0.999
AO	9.5	1	0.92	0.98	0.999	0.997
AO	9.5	2	0.85	0.94	0.999	0.988

One year is equivalent to 8760 hours and two years is equivalent to 17520 hours. The reliability of each module is computed from formula (2). The TMR for the individual component is computed from formula (3). The TMR with 128 cards in each DPU is computed from formula (6). The standby redundancy is computed from formula (7).

For rugged systems wherein mission time is assumed to be equal to mean time to failure (MTTF) *i.e.*, 17-38 years, TMR works incredibly well and gives high values of reliability especially when the number of I/O cards employed are of ~128 per DPU. In such cases there is no repair done. The component is assumed to last for the entire mission time. This is a hypothetical case study carried out. The reliability obtained for TMR is ~0.977386471 computed from formula (1) and (6) for a period of 17 years. But under normal conditions, for shorter realistic mission times standby redundancy (1 out of 2) computed from formula (7) also exhibits higher values of reliability (0.997-0.999) on par with TMR as shown in Table-2.

6. Conclusions

We were able to generate a fairly good idea as to reliability of DCS I/O cards. Further studies as to implementation of TMR in the I/O modules were undertaken. The study was extended to TMR with 128 cards per DPU. These results were compared with the computed results of reliability of active redundancy or standby redundancy to enable appropriate decision making at the development stage of the product.

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