Estimation of Processor Module Life in NPP's Environment

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1. Introduction

In this paper, we will estimate the probability of failure (life) for INVENSYS TRICON Main Processor used in the research reactor protection system. Life may be calculated by the Arrhenius equation, and may be calculated by applying the failure rate. In this paper, we calculate each of the independent failure probability and probability of common cause failure of the processor module(CPU Card).

2. Estimation of life by Arrhenius model

Arrhenius model represents the life-stress relation when the applied stress is temperature, so that it is widely used in accelerated life testing using temperature as a stress. The equation is that item's life is exponentially decreasing with the increase in temperature due to chemical reaction of materials (gas, liquid and solid).

Arrhenius model is as follow.

$$\frac{1}{t} = A\exp\left(-\frac{E_a}{k_B T}\right),$$

where

- t : life
- A : unknown nonthermal constant
- E_a : activation energy (eV)
- k_B : Boltzmann's Constant (8.617 x 10-5 eV/°K)
- T : absolute temperature

The lives of at normal temperature T_2 and accelerated temperature T_1 are related by follow expression.

$$\frac{t_2}{t_1} = \exp^{-\left(\frac{E_a}{k_B}\right)\left(\frac{1}{T_1}-\frac{1}{T_2}\right)},$$

where

- t_1 : accelerated aging life at temperature T_1
- t_2 : normal service life at temperature T_2
- E_a : activation energy (eV)
- k_B : Boltzmann's Constant(8.617×10^{-5} eV/°K)
- T_1 : accelerated aging temperature(°K)
- T_2 : normal service temperature(°K)

3. Estimation of failure probability for processor module

A TRICON system utilizes three Main Processor Modules to control three separate legs of the system. Each Main Processor Module operates independently with no shared clocks, power regulators, or circuitry.

In Model 3008, each module owns and controls one of the three signals processing legs in the system, and each contains two 32-bit processors.

One of the 32-bit processors is a dedicated, leg-specific I/O communication (IOC) microprocessor that processes all I/O with the system I/O modules, and a dedicated, leg-specific processor manages interfaces with all Communication Modules in the system. [2]

The 32-bit primary processor manages execution of the control program and all system diagnostics at the Main Processor Module level. Between both 32-bit processors is a dedicated dual port RAM allowing for direct memory access data exchanges.

The system has assumed 1/2 of safe and dangerous failure rate, and the rate to detect the failure by Periodic inspection was assumed to 99%. Repair time has assumed 24 hours and inspection period has assumed 45 day.

Independent failure probability for processor module is as follow.

$$P = (\lambda_{DU} + \lambda_{DD})t_{CE} = (0.008025+0.5386)t_{CE}$$

Where,

$$t_{CE} = \frac{\lambda_{DU}}{\lambda_D}\left(\frac{T_1}{2} + MTTR\right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

$$\lambda_{DU} = 0.008025,\ \lambda_D = 0.5466,\ T_1 = 45\times 24, MTTR = 24, \lambda_{DD} = 0.5386$$

Therefore

$$t_{CE} = \frac{0.008025}{0.5466}\left(\frac{45\times 24}{2} + 24\right) + \frac{0.5386}{0.5466}\times 24 = 31.9292E-06$$

Consequently

$$P = (\lambda_{DU} + \lambda_{DD})t_{CE} = 17.4533E-06$$

4. Calculation of Common Cause Failure(CCF) for processor module

For CCF calculation, the value of beta-U and beta-D should be calculated in accordance with requirements of IEC-61508.

The table below to calculate beta_U and beta_D score sheet for calculating and assigning a value to each item, and the results of the beta-D beta-U, 0.02 (2%) and 0.01 (1%) were evaluated respectively.

This is similar to CCF beta factor 0.02 (2%) provided by the Invensys.

Because one module of Invensys consists of three lag, failure rate calculation provided by Invensys was reflected ccf3leg 0.5.

Scoring Item	**Logic subsystem**		**Sensors and final elements**	
	X	Y	X	Y
Separation/segregation	7	3	6	4
Diversity/redundancy	3	1.5	8.5	1
Complexity/design/..	1	2.5	1.5	1.5
Assessment/analysis..	0	0	0	0
Procedures/human interface	3.5	2	2.5	1.5
Competence/training/..	0	0	0	0
Environmental control	5.5	4.5	5.5	4.5
Environmental testing	10	10	10	10
Total	30	23.5	34	22.5
Diagnostic coverage (Z)	1.5		1.5	
Score (S)	**53.5**		**56.5**	
Score (SD)	**98.5**		**107.5**	
Beta-U	**2%**		**5%**	
Beta-D	**1%**		**2%**	

CCF calculation formula of the module is beta_D * lambda_D + beta_U * lambda_U. If consider the testing and repair time, following formula as the probability of failure.

$$P_{CCF} = (\lambda_{CCFDU} + \lambda_{CCFDD})t_{CE} \quad ,$$

$$t_{CE} = \frac{\lambda_{CCFDU}}{\lambda_{CCFD}}\left(\frac{T_1}{2} + MTTR\right) + \frac{\lambda_{CCFDD}}{\lambda_{CCFD}} MTTR$$

Where,

λ_{CCFDU} is undetected dangerous CCF failure rate (per hour) of a channel in a subsystem (this is the sum of all the undetected dangerous failure rates within the channel of the subsystem)

λ_{CCFDD} is detected dangerous CCF failure rate (per hour) of a channel in a subsystem (this is the sum of all the detected dangerous failure rates within the channel of the subsystem)

t_{CE} is channel equivalent mean down time (hour) for 1oo1, 1oo2, 2oo2 and 2oo3 architectures (this is the combined down time for all the components in the channel of the subsystem)

λ_{CCFD} is CCF dangerous failure rate (per hour) of a channel in a subsystem, equal to 0,5 l (assumes 50 % dangerous failures and 50 % safe failures)

T_1 is primary(Basic) Event Data.

$MTTR$ is mean time to restoration(hour)

Calculation of Common Cause Failure(CCF) for processor module is as follow.

$$\lambda_{CCFDU} = 0.002693, \lambda_{CCFDD} = 0.000080$$

(From IEC 61508-6, TMR Module Failure Rates)

Where,

$$\lambda_{CCFDU} = CCF3Legs \times Beta - U \times \lambda_{DU}$$

$$\lambda_{CCFDD} = CCF3Legs \times Beta - d \times \lambda_{DD}$$

Therefore

$$P = (\lambda_{CCFDU} + \lambda_{CCFDD})t_{CE} = (0.002693+0.000080)t_{CE}$$

Where,

$$t_{CE} = \frac{\lambda_{CCFDU}}{\lambda_{CCFD}}\left(\frac{T_1}{2} + MTTR\right) + \frac{\lambda_{CCFDD}}{\lambda_{CCFD}} MTTR$$

$$\lambda_{CCFDU} = 0.000080, \lambda_{CCFD} = 0.002773, T_1 = 45\times 24, MTTR = 24, \lambda_{CCFDD} = 0.002693$$

Therefore

$$t_{CE} = \frac{0.000080}{0.002773}\left(\frac{45\times 24}{2} + 24\right) + \frac{0.002693}{0.02773}\times 24 = 39.6261E-06$$

Consequently

$$P = (\lambda_{CCFDU} + \lambda_{CCFDD})t_{CE} = 0.1099E\text{-}06$$

5. Conclusion

In this paper, we described the life estimation methodology (Arrhenius, IEC), and was estimate the lifetime of the INVENSYS TRICON processor module by IEC-61508 methodology. Life calculation result, it was the life of the processor module 1/0.1099E-06.

REFERENCES

[1] Invensis, "Tricon TMR Controller Module Failure Rates", Triconex Part No. : 9100051, Rev.1.0, 2010.

[2] IEC 61508-6, 2000 "Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems – Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3".