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Development of a software to predict the remaining useful life of electronic components of I&C system under dynamic temperature and electrical stress conditions

Inseok Jang [a*], Chang Hwoi Kim [a]
[a] *Advanced Instrumentation & Control Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea*
[*] *Corresponding author: isjang@kaeri.re.kr*

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1. Introduction

Precise prediction of the remaining useful life (RUL) of electronic components in the instrumentation and control (I&C) systems under time-varying temperature and electrical stress conditions is very difficult since most of current approaches to estimating the RUL of electronic components assume that the factors affecting the RUL of electronic components are static constants which is a critical limitation of precise RUL prediction of electronic components in real world.

To overcome this limitation, the authors proposed a method to predict the RUL, considering dynamically changed environments, of the electronic components in the POSAFE-Q programmable logic controller (PLC) and OPERA distributed control system (DCS) platform In addition, we verified the feasibility of this method by performing the several case studies to predict the RUL of electronic components [1,2].

During the prementioned case studies from previous research, we recognized the necessity of software development to predict the RUL of electronic components of I&C system under dynamic temperature and electrical stress conditions because there are thousands of electronic components in I&C systems and various combinations of temperature and electrical stress conditions to estimate the RUL which means manual calculations become difficult.

In this light, we first briefly explain the proposed the electronic component RUL prediction method based on the results of previous studies. After that, the proposed electronic component RUL prediction method is expanded to apply it to control module (CM) including hundreds of electronic components. Finally, the software for predicting the RUL of electronic component and CM under dynamic temperature and electrical stress conditions is explained in this study.

2. RUL prediction method of electronic component and control module

In this section, the RUL prediction method of electronic component and control module is briefly explained with electronic component failure rate database based on the previous studies [1,2].

2.1 Electronic component failure rate database

The electronic component failure rate database include the failure rates of various electronic components in POSFAE-Q PLC and OPERA DCS according to the combinations of temperature and electrical stresses. Table 1 and 2 show that the part of electronic component failure rate database of NCPU-2Q of POSAFE-Q PLC (here, 'fpmh' as a unit stands for failure per million hours).

Table 1: Failure rates of NCPU-2Q-04 (Memory) according to stress conditions (unit: fpmh)

NCPU-2Q-04 (Memory)		**Electrical Stress (Ratio)**				
		0.1	**0.3**	**0.5**	**0.9**	**1.0**
Temp Stress (°C)	**30**	1.017	1.017	1.017	1.017	1.017
	40	1.617	1.617	1.617	1.617	1.617
	50	2.516	2.516	2.516	2.516	2.516
	60	3.833	3.833	3.833	3.833	3.833
	70	5.727	5.727	5.727	5.727	5.727
	80	8.401	8.401	8.401	8.401	8.401
	90	12.11	12.11	12.11	12.11	12.11
	100	17.19	17.19	17.19	17.19	17.19

Table 2: Failure rates of NCPU-2Q-79 (Capacitor) according to stress conditions (unit: fpmh)

NCPU-2Q-79 (Capacitor)		**Electrical Stress (Ratio of operating to rated voltage)**				
		0.1	**0.3**	**0.5**	**0.9**	**1.0**
Temp Stress (°C)	**30**	.004643	.005199	.007296	.02022	.02602
	40	.007125	.007979	.0112	.03103	.03993
	50	.01065	.01192	.01673	.04637	.05967
	60	.01553	.0174	.02441	.06765	.08705
	70	.02217	.02482	.03483	.09654	.1242
	80	.031	.03472	.04872	.135	.1737
	90	.04257	.04767	.06689	.1854	.2385
	100	.05746	.06434	.09029	.2502	.322

It is noted that the failure rates of NCPU-2Q-04 do not change when electrical stress increases since the failure rate of this electronic component is not affected by electrical stress.

Finally, we collected the failure rate data tables like Table 1 and 2 for 2,000 electronic components approximately called the electronic component failure rate database. These database used as input data to predict the RUL of electronic component and control module under dynamic temperature and electrical stress conditions.

2.2 RUL prediction of electronic component/control module under dynamic stress conditions

The RUL prediction method of electronic component and control module under dynamic temperature and electrical stress conditions is proposed by using the substantial amount of electronic component failure rate database.

Let us assume that the failure rate of an electronic component varies with the operation time under changing stress conditions as shown in the upper side of Fig.1.

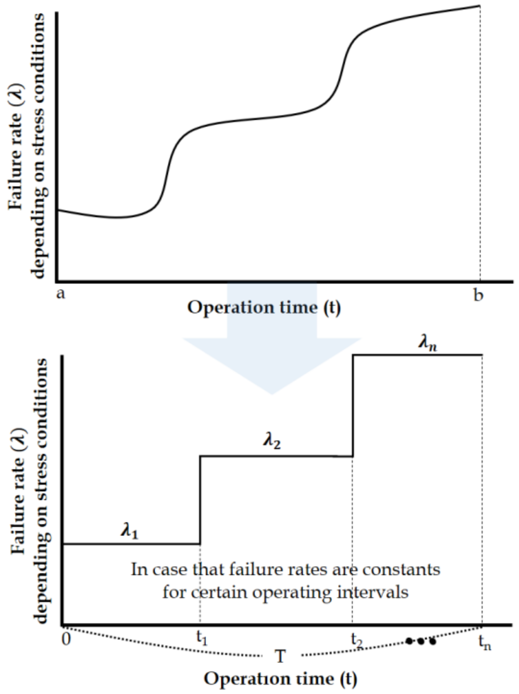


Fig. 1. Failure rates as stress conditions change over time; adopted from Ref. [2].

If the failure rate that continuously changes by stress condition with operation time (upper side of Fig. 1) can be subdivided and expressed as a constant failure rate for a certain operation interval under a specific stress condition (lower side of Fig. 1), the average of a component failure rate accumulated over a certain interval can be expressed as Equation (1).

$$\lambda_{average} = \frac{1}{T}\sum_{n=i} \lambda_i t_i \tag{1}$$

$where,\ T = Total\ operation\ time\ (hr)$
$t_i = Operation\ time\ with\ \lambda_i\ (hr)$
$\lambda_i = i_{th}\ \lambda\ under\ specific\ stress\ condition$

Finally, the MTTF (mean time to failure), which has an expectation of an exponential distribution with $\lambda_{average}$, can be calculated in Equation (2), and then the RUL of electronic components under dynamic temperature and electrical stress conditions can be calculated by subtracting the total operation time from the MTTF of the electronic components.

$$MTTF = \frac{1}{\lambda_{average}}, \qquad RUL = MTTF - T \tag{2}$$

If we expand the concept of RUL prediction method for electronic component shown in Equation (1) and (2) to CM, we can simply consider Equation (3) and (4) with the conservative assumption that the electronic components in CM are connected in series which allows that the failure rate of a CM can be simply predicted by a summation of the failure rates of all electronic components making up the CM.

$$\lambda_{avg\_CM} = \lambda_{avg\_component(1)} + \lambda_{avg\_component(2)} + \cdots + \lambda_{avg_{component(n)}} \tag{3}$$

$$MTTF_{CM} = \frac{1}{\lambda_{avg\_CM}}, \quad RUL_{CM} = MTTF_{CM} - T \tag{4}$$

3. Software for RUL prediction of electronic component and control module

Based on the electronic component failure rate database in Section 2.1 and RUL prediction method proposed in Section 2.2, a software for RUL prediction of electronic component and control module under dynamic temperature and electrical stress conditions was developed. The main functions of this software are largely divided into three categories such as (1) management of electronic component failure rate database, (2) RUL prediction of electronic component, and (3) RUL prediction of CM.

3.1 Management of electronic component failure rate database

The failure rate of electronic components in a specific stress condition is stored in a form of a *csv* file. The electronic component failure rate database accept this *csv* file as input and allows users to search the electronic component according to various conditions as shown in Fig 2.

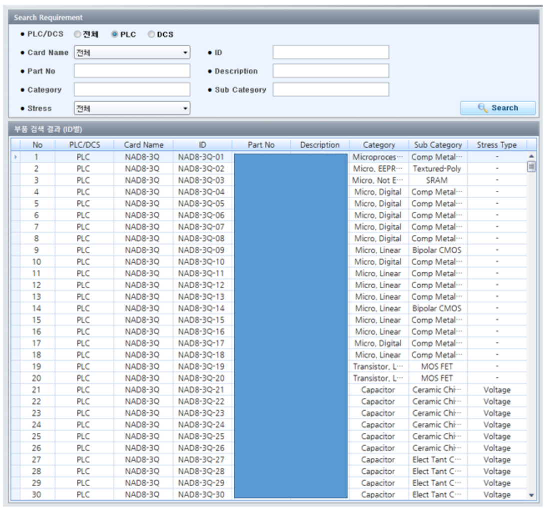


Fig. 2. Electronic component failure rate database

In addition, the failure rate of electronic components calculated according to temperature and electrical stress are organized in a table of failure rate according to stress condition as shown in Fig. 3. Currently, there are more than 1000 *csv* files stored in the database, which stores the failure rate date of 10,000 cases of stress-dependent failure rates of components included in POSAFE-Q PLC and OPERA DCS.

Failure Rate Table

보드 예측

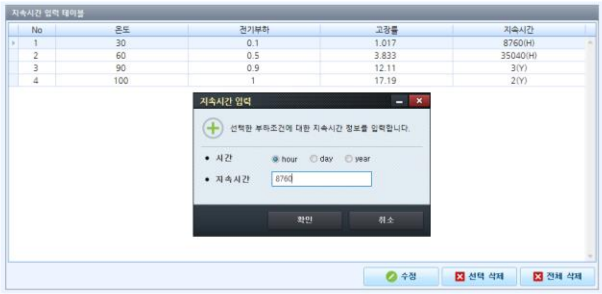
구분	전기부하									
온도	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
30	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017
40	1.617	1.617	1.617	1.617	1.617	1.617	1.617	1.617	1.617	1.617
50	2.516	2.516	2.516	2.516	2.516	2.516	2.516	2.516	2.516	2.516
60	3.833	3.833	3.833	3.833	3.833	3.833	3.833	3.833	3.833	3.833
70	5.727	5.727	5.727	5.727	5.727	5.727	5.727	5.727	5.727	5.727
80	8.401	8.401	8.401	8.401	8.401	8.401	8.401	8.401	8.401	8.401
90	12.11	12.11	12.11	12.11	12.11	12.11	12.11	12.11	12.11	12.11
100	17.19	17.19	17.19	17.19	17.19	17.19	17.19	17.19	17.19	17.19

Fig. 3. Electronic component failure rate table according to stress conditions

3.2 RUL prediction of electronic component and control module under dynamic temperature and electrical stress conditions

The functions of RUL prediction of electronic component and CM in the software is performed based on Equation (1) to (4) with electronic component failure rate of user-entered stress conditions in the database.

First of all, the user selects the electronic component whose RUL is to be calculated from the electronic component failure rate database in Fig. 2. Then, the user selects the failure rate corresponding to the temperature and electrical stress to be calculated from the table as shown in Fig.3, and enters the operation time under corresponding stress condition as shown in Fig 4. (In order to predict the RUL of CM instead of RUL of electronic component, *board prediction* button should be selected in Fig 3). There is no limit to the number of inputs for the stress conditions and corresponding operation times to which the electronic components are exposed.



지속시간 입력 테이블

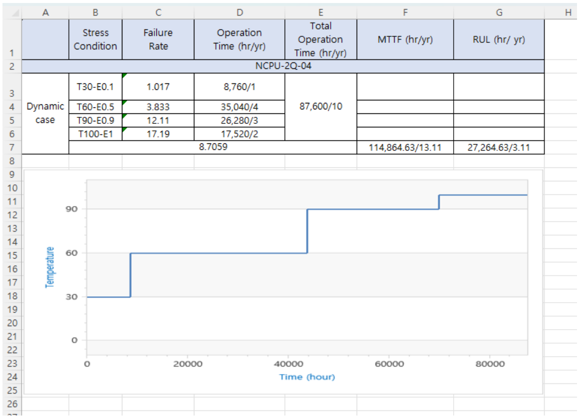
No	온도	전기부하	고장률	지속시간
1	30	0.1	1.017	8760(H)
2	60	0.5	3.833	35040(H)
3	90	0.9	12.11	3(Y)
4	100	1	17.19	2(Y)

Fig. 4. Stress conditions and operation times to be calculated

When all the stress conditions and corresponding operation times to which the electronic component has been exposed are entered, it can be seen that a profile shows the operation time entered so far (x-axis) and temperature/electrical stress (y-axis) as shown in Fig.5

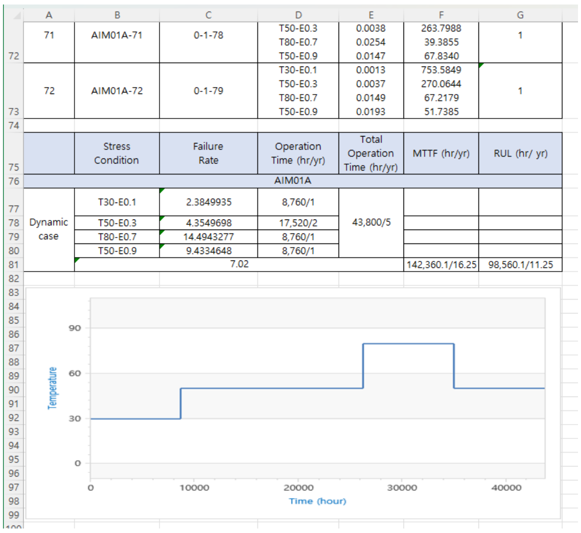
Fig. 5. Profile according to stress conditions

Finally, we can export RUL prediction results of electronic component and CM under dynamic temperature and electrical stress conditions as shown in Fig. 6 and Fig. 7, respectively



	Stress Condition	Failure Rate	Operation Time (hr/yr)	Total Operation Time (hr/yr)	MTTF (hr/yr)	RUL (hr/ yr)
NCPU-2Q-04						
Dynamic case	T30-E0.1	1.017	8,760/1	87,600/10		
	T60-E0.5	3.833	35,040/4			
	T90-E0.9	12.11	26,280/3			
	T100-E1	17.19	17,520/2			
	8.7059				114,864.63/13.11	27,264.63/3.11

Fig. 6. Example of RUL prediction of electronic component



71	AIM01A-71	0-1-78	T50-E0.3 T80-E0.7 T50-E0.9	0.0038 0.0254 0.0147	263.7988 39.3855 67.8340	1
72	AIM01A-72	0-1-79	T30-E0.1 T50-E0.3 T80-E0.7 T50-E0.9	0.0013 0.0037 0.0149 0.0193	753.5849 270.0644 67.2179 51.7385	1

	Stress Condition	Failure Rate	Operation Time (hr/yr)	Total Operation Time (hr/yr)	MTTF (hr/yr)	RUL (hr/ yr)
AIM01A						
Dynamic case	T30-E0.1	2.3849935	8,760/1	43,800/5		
	T50-E0.3	4.3549698	17,520/2			
	T80-E0.7	14.4943277	8,760/1			
	T50-E0.9	9.4334648	8,760/1			
	7.02				142,360.1/16.25	98,560.1/11.25

Fig. 7. Example of RUL prediction of CM

For example, it is confirmed that the RUL prediction results of analog input module (AIM) which is the one of CM of OPERA DCS under four kinds of temperature-electrical stress condition with 5 year total operation time is about 11.25 years as shown in Fig. 7.

4. Conclusions

In order to overcome the limitation of current RUL prediction for I&C systems, we proposed a method to predict the RUL considering dynamically changed environments and verified the feasibility of this method by performing the several case studies to predict the RUL of electronic components. At the same time, we recognized the need to develop a software to automatically perform RUL prediction for electronic components and extend the scope of the RUL prediction to CM. As a result, the developed software not only effectively manages a large database of electronic components failure rates, but also accurately predicts the RUL of electronic components and CMs in real time under various stress conditions. This not only helps to calculate the replacement cycle of the I&C system based on the current manual calculation, but it is also expected to be able to calculate the replacement cycle of the I&C system considering the changing environment conditions.

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