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V-I Curve Analysis for Status Prediction of Nuclear Power Plant Safety-Grade PLC

Ka-Ram Park [a*], Su-Hyun Kim [a], Chi-Uk An [a], Kwan-Woo Yoo [a], Gi-Ho Cho [a], Dong-Yeon Lee [a]
[a] *[a]SOOSAN ENS Co., Research Institute, 2F, Soosan Building, 13, Bamgogae-ro 5-gil, Gangnam-gu, Seoul, 06367*
[*] *Corresponding author: psh6514@soosan.co.kr*

1. Introduction

In recent years, digital control systems have replaced analog circuits in nuclear power plants [1]. However, sudden failures of digital control systems can result in the shutdown of nuclear power plants, causing significant social and economic damage [2]. Regular preventative maintenance is performed at set intervals to reduce the risk of a power plant being shut down. However, since this maintenance is performed regardless of whether or not the actual part is defective, there is a limit to preventing sudden system failure and unnecessary replacement of normal parts. To solve this problem, this study attempts to predict the state of the PLC (Programmable Logic Controller) by utilizing the self-diagnosis register provided by the PLC and the analysis of the V-I curve of the PLC components [3] [4]. Furthermore, the goal of this study is to establish a system for predicting the status of safety-class PLC applied to the safety system of nuclear power plants.

2. Methods and Results

2.1 Overview of V-I curve analysis

V-I curve analysis is a method of predicting the condition of a component by analyzing its voltage-current characteristics. This method compares the voltage-current characteristics of the component in normal operating conditions with those in fault conditions to determine the component's condition. In this study, we aim to utilize V-I curve analysis of PLC components as an indicator for distinguishing between normal and faulty states.

2.2 Failure Types of Components in the PLC

Electronic components may fail due to potential factors inherent in the components that interact with stress, or when stress has a sole impact on failure. Generally, failures in electronic components can be classified into four categories: short, open, parameter shift, and electric instability, which can be identified by measuring changes in the V-I characteristic curve of the components. In this study, we aim to confirm failures by measuring the V-I curve of the components.

2.3 Failure Types of Components in the PLC

The safety grade PLC diagnose their own status and inform the user of any abnormalities via registers. The following are some of the self-diagnostic registers used by PLC [5].

Table I: Description of Error Diagnosis Register

Register	Error name	Description of Errors
MX1.1792	Diagnostic Error	This is a general error register that is diagnosed if any error occurs in the configured system.
MX1.1794	Memory Error	This error occurs when normal values are not recorded in the memory area to be diagnosed.
MX1.1805	Reference Clock Error	This error is diagnosed when an error occurs in the reference clock of the processor module.
MX1.1806	Data integrity Error	This is an error diagnosed when the data of the installed I/O module is judged to be abnormal by the bus module.
-	Fault	In case the module did not boot normally, it can be checked through the LED on the front panel.

Among these, we aim to measure the V-I characteristic of the failed component when a ‘Fault’ occurs, including ‘Memory error’, ‘Reference clock error’, and ‘Data integrity error’, which are related to hardware failures. Furthermore, we intend to compare the measured results with those of normal components to identify any differences.

2.4 V-I Characteristic Curve Analysis

We aimed to confirm the difference in V-I characteristic curves between normal and defective components by configuring a test environment as shown in the figure.

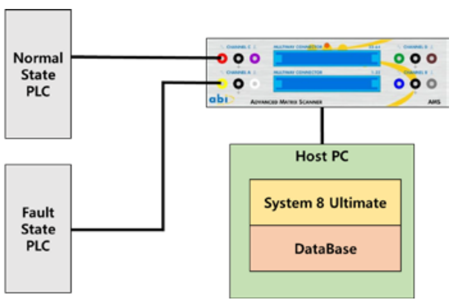

Fig. 1. Test configuration diagram.

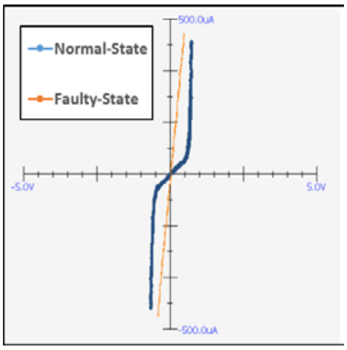

Fig. 2. Comparison result graph when Memory Error occurs.

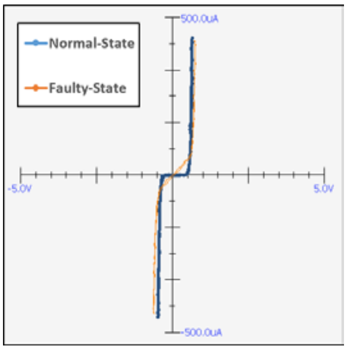

Fig. 3. Comparison result graph when Reference Clock Error occurs.

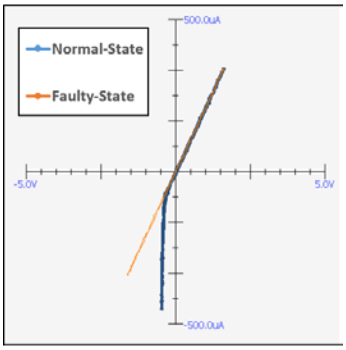

Fig. 4. Comparison result graph when Data Integrity Error occurs.

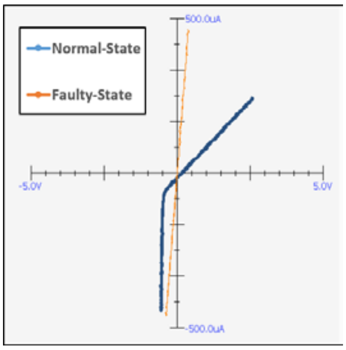

Fig. 5. Comparison result graph when Fault occurs.

A clear difference in the V-I curve was confirmed between the defective product and the normal product, and through this, it was possible to confirm the hardware defect of the PLC for which the error was diagnosed. And through the analysis of the characteristics of the V-I curve, it is possible to present a healthy grade that can judge the status of PLC. PLC's Healthy Grade can be divided into 'Healthy', 'Warning', and 'Faulty', and the corresponding criteria are as follows.

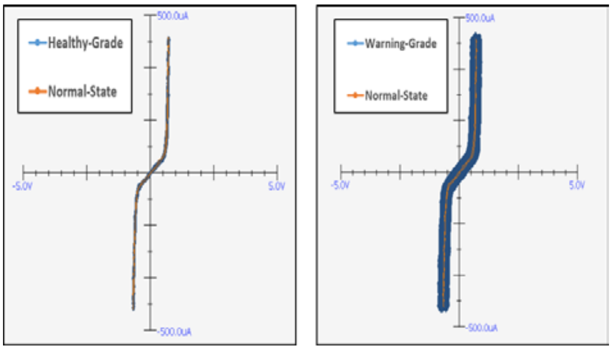

Fig. 6. Diagnosis result graph when memory error occurs.

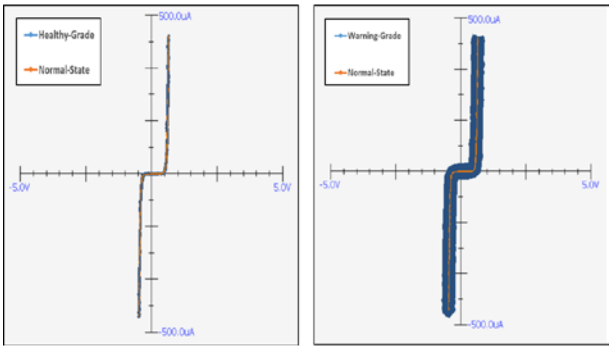

Fig. 7. Diagnosis result graph when Reference Clock Error occurs.

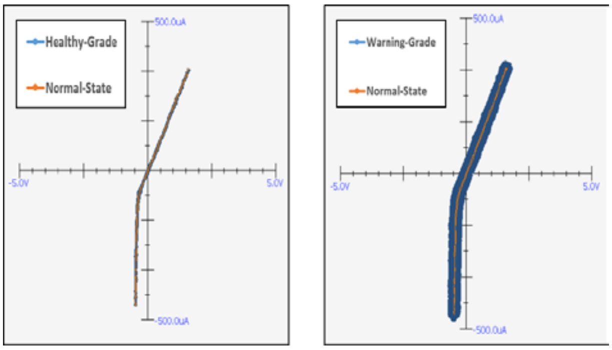

Fig. 8. Diagnosis result graph when Data Integrity Error occurs.

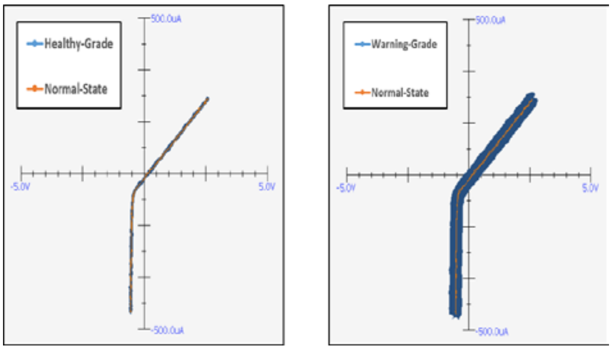

Fig. 9. Diagnosis result graph when Fault occurs.

If the V-I curve belongs to 'Healthy-grade', it can be confirmed that it is in a normal state. If the V-I curve is in ‘Warning-grade’, it means that the function is still operating normally but may fail soon. Therefore, if it belongs to the corresponding grade, prompt maintenance is required. If the V-I curve belongs to ‘Faulty-grade’, it is confirmed that an error has occurred. The state of the PLC was determined using the self-diagnosis register and the V-I curve. In addition, Healthy-Grade, which can predict the status of PLC by using the measured V-I curve, was presented. If the V-I curve belongs to 'Healthy-grade', it can be confirmed that it is in a normal state. If the V-I curve is in ‘Warning-grade’, it means that the function is still operating normally but may fail soon. Therefore, if it belongs to the corresponding grade, prompt maintenance is required. If the V-I curve belongs to ‘Faulty-grade’, it is confirmed that an error has occurred.

The state of the PLC was determined using the self-diagnosis register and the V-I curve. In addition, Healthy-Grade, which can predict the status of PLC by using the measured V-I curve, was presented.

3. Conclusions

In this study, we proposed a state prediction system for safety grade PLC using self-diagnosis registers and V-I curve analysis techniques. We were able to distinguish between normal and faulty products by analyzing the V-I characteristics of the components installed in the PLC. Furthermore, by measuring the extent to which the V-I curve deviates from the normal state, we could determine the state of the safety-rated control device and predict faults. In the future, we plan to aim to digitize the V-I characteristics of all components and train an ANN model with the data to further improve the fault prediction system for safety grade PLC. By using the trained AI model, we intend to establish a more advanced system for predicting faults in safety-grade control devices, with the ultimate goal of enhancing the safety of nuclear power plant safety systems.

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