Journal of Energy and Power Engineering 16 (2022) 147-155
doi: 10.17265/1934-8975/2022.04.001

Fault Detection and Protection System of Electric Railway Substation

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Abstract: The industrial power systems are moving to digital networks, and unmanned systems are increasing recently with the technological development of information and communication technology. In particular, reliability of system operation is very important for stable power supply. Most industrial power distribution facilities use a 154 kV or 22.9 kV extra HV (high voltage) power system, and a special monitoring system is required because a large loss occurs when an error occurs in the power facility in the field. Although digital protection relay (IED; intelligent electronic device) and FR (fault recorder) are applied to the field to protect the power system, various improvement activities are still ongoing. In this paper, a 22.9 kV high-voltage panel and its test bed, which are widely used in railway stations, tunnels, substations and large plants, were tested as test subjects. The developed fault detection system automatically starts the AL (auto-lock) circuit or outputs an alarm signal to user by monitoring in real time problems such as CT (current transformer)-open and poor-contact that the existing digital protection relay cannot cover. In addition, it is intended to increase the safety and reliability of the power system by blocking various accidents in the system in advance and accurately analyzing the causes of faults with the developed fault detection system.

Key words: CT open, poor contact, fault detection, protection relay, substation, HV panel.

1. Introduction

Railroad power supply systems are classified into various types such as incoming pannel, transformer pannel, feeder pannel, and HV (high voltage) pannel depending on the application. In this paper, a 22.9 kV HV pannel, which is widely used in railway stations and tunnels as well as substations and large plants was tested. In order to secure the stability of the power system, the input of the digital protection relay should always be provided stably without external influence. However, various accidents occur in the actual field due to unstable factors. In particular, various problems such as poor-contact, overheating, and power unbalance occur in the process of supplying to protective equipment by converting power to optimum levels for CT (current transformer) and PT (potential transformer) to monitor the system. The developed system monitors the voltage, current, and phase values of the system in real time and outputs signals such as AL (auto-lock protection) circuit activation or alarm depending on the situation to solve these problems. The developed fault detection system works quickly to notify the user of the situation and minimizes damage when a fault occurs.

There are several types of faults in the power circuit, but open and bad contact of CT and voltage imbalance of PT were selected as subjects of study. In addition, the interference with the existing power equipment by setting the CT for measuring the current of the system in a clamp type was eliminated when installing and maintaining the fault detector. And the LED (light-emitting diode) display for each function on the front of fault detector was designed to check the operation status. As a result of this study, it is possible to monitor the power system by measuring the current, voltage, and phase of each circuit, and to prevent

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danger through prompt action and prevent similar accidents from reoccurring in the future.

2. Design of Fault Detector System

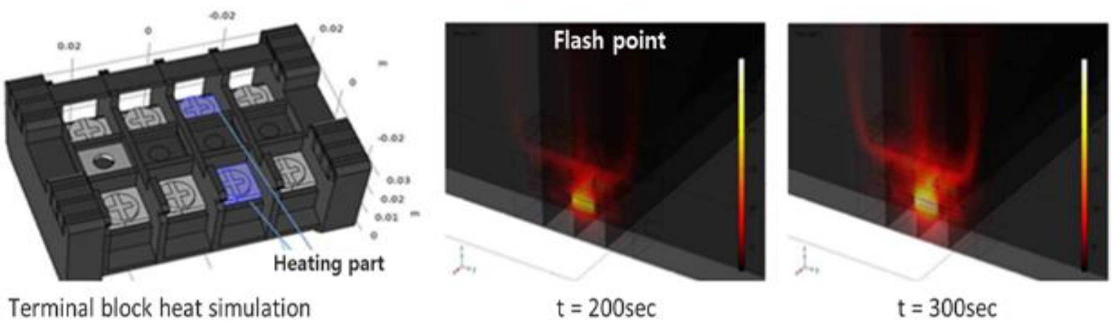
2.1 Analysis of Poor-Contact Fault

The heat generation of TB (terminal block) which is frequently used in the power system, was simulated and the results were compared and analyzed with the values measured at the substation site in order to analyze the severe heat generation due to poor-contact. Thermal simulation of TB was performed using ANSYS Fluent. In order to derive the convective heat transfer coefficient of the terminal block, the condition of contact resistance of 5 Ω and current of 1.1 A was applied. Fig. 1 shows the thermal simulation and actual measurement results of TB. In the simulation, the flash point was after 200 s. The actual measured value showed the temperature rise characteristic in proportion to the magnitude of resistance and current, and showed similar results to the simulation.

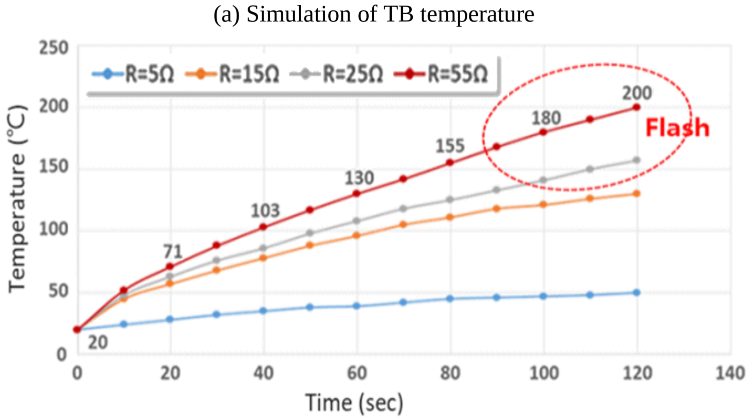
Fig. 2 is a vibration and chattering generation circuit for poor-contact testing. Joule heat caused by poor-contact is accumulated for a long time in a high-temperature, closed space, so it acts as a limiting factor in the test. So, a vibration and chattering generation circuit was applied, allowing the user to adjust the rate of poor-contact generation [1-4].

2.2 Analysis of CT-Open Fault

Fig. 3 shows saturation voltage increase due to open secondary side of CT. As shown in Fig. 3a, the magnitude of the magnetic flux on the primary side and the secondary side is the same and the phase difference is 180°, so they cancel out each other, and the voltage on the secondary side of the CT is almost zero However, the secondary side impedance becomes infinite, the secondary side current becomes almost zero and the voltage increases rapidly when the secondary side of the CT is open as shown in Fig. 3b. At this time, even if the secondary side of the CT is open, the exciting current caused by the primary current that still flows causes problems such as HV and overheating.



(a) Simulation of TB temperature



(b) Measurement of TB temperature

Fig. 1 Test of Joule heat increase.

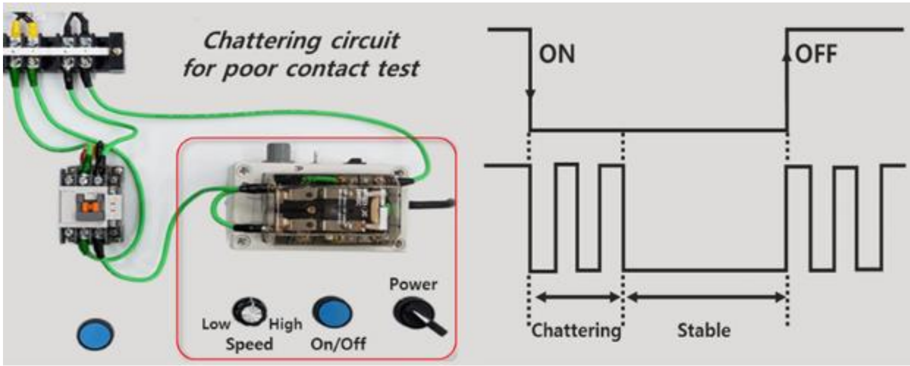
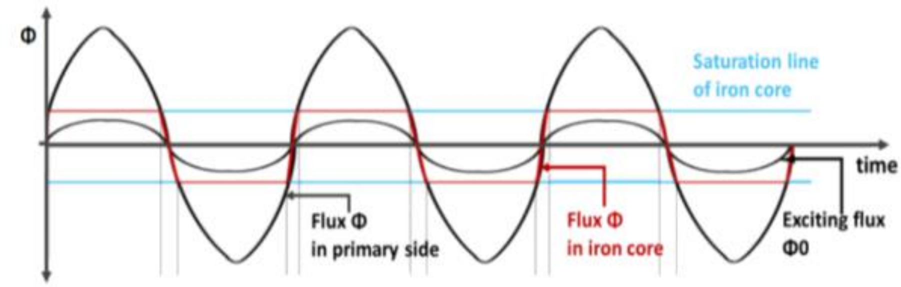
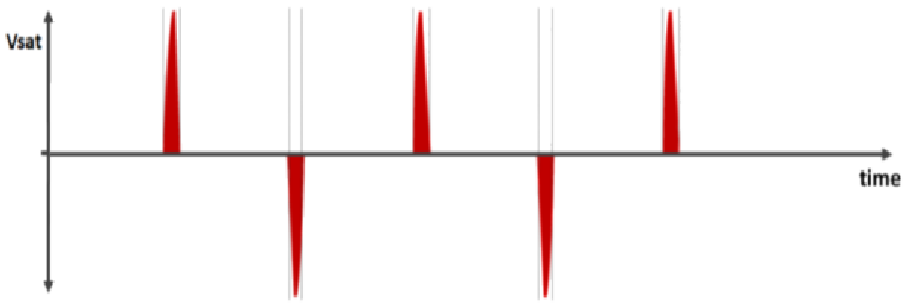


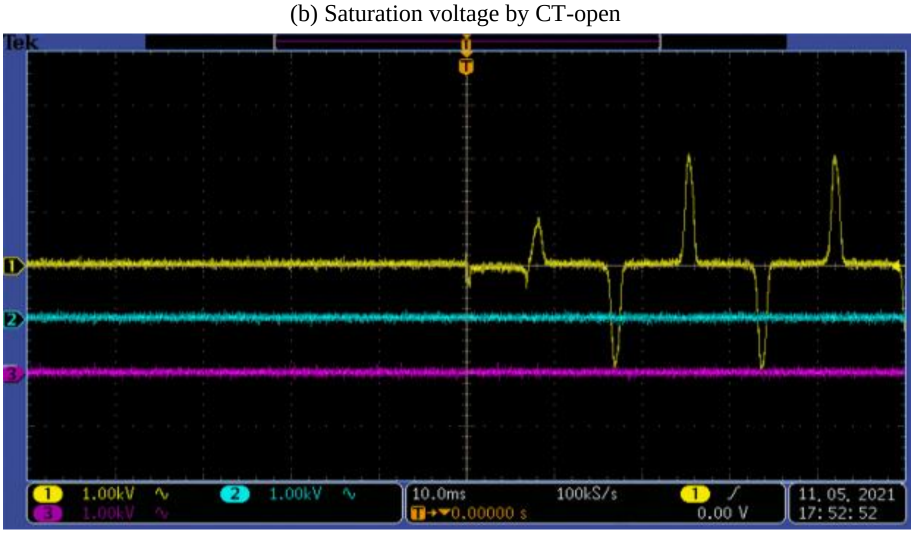
Fig. 2 Test of poor-contact.



(a) Flux change by CT-open



(b) Saturation voltage by CT-open



(c) CT-open oscilloscope waveform

Fig. 3 Voltage increase by CT-open.

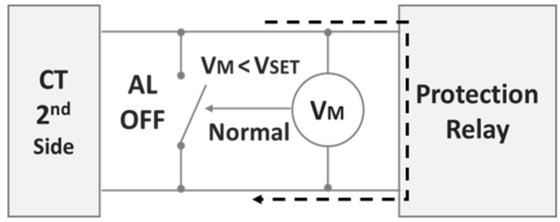
Fig. 3c shows the increase in open-circuit voltage on the secondary side of the CT monitored by an oscilloscope when the CT primary side current was 100 A. The voltage showed a voltage rise of 800~2,200 V when the secondary side was opened [5].

3. Design and Evaluation of Detector System

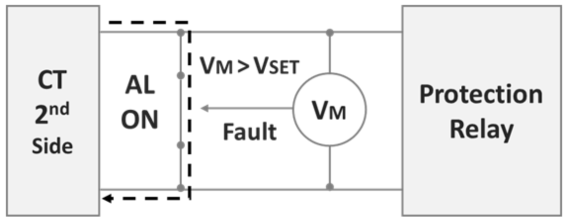
3.1 Design of System

The fault detection system of this study is to monitor faults such as CT-open or contact fault, which are difficult to monitor by digital protection relays. If the contact faults of CT or PT are also accumulated, they can cause serious accidents. However, the most serious thing is CT-open. In this case, it is impossible to provide current and voltage information to the protective relay, which is essential for system monitoring, and it is a direct cause of a major accident because the protective relay cannot perform its function.

Fig. 4 is the concept of AL circuit operation when the CT is open. Fig. 4a shows the state of providing grid current information to the protection relay by the flow of current during normal operation, and Fig. 4b is a state in which the AL circuit operates when CT is open. The AL circuit operation to prevent accidents cuts off the current flow to the protective relay, and this situation is resolved by the manager's quick action, so that the protective relay can again monitor the normal system. The system notifies the user of system failure information due to poor-contact, open CT, and unbalance in real time, and the user can force to reset the AL circuit after confirming and troubleshooting. Fault events are saved in COMTRADE file format on the server PC for analysis and used for cause analysis.



(a) Normal state (AL circuit OFF)



(b) CT-open state (AL circuit ON)

Fig. 4 Protection circuit of CT-open state.

Fig. 5 is a block diagram of a failure detection system. After inputting the analog current and voltage through the CT and PT of the 22.9 kV power system, it is input to the MCU (TMS320F28335) through AD conversion. The MCU performs internal logic operations and outputs digital outputs corresponding to errors and alarms. When the CT-open signal is detected, the AL circuit starts immediately, and when a bad contact signal is detected, the alarm signal is output. All waveforms and event information of the event are stored in the fault detector in real time, and the occurrence of the event is notified to the user through the network. Users can check the remotely stored data and analyze the waveform and cause of the event in the HMI (human machine interface) program for analysis installed on the PC.

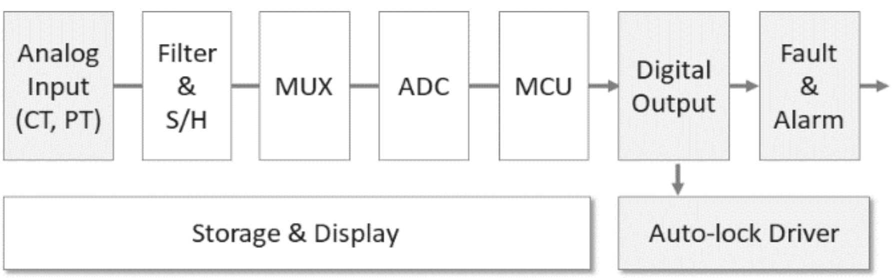


Fig. 5 Detection system configuration.

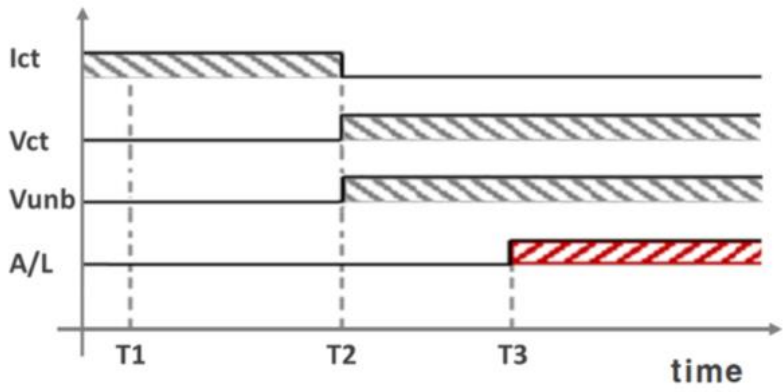


Fig. 6 Timing chart of fault detection system.

Table 1 Parameters of fault detector system.

Detection	Measurement parameters	Remarks
CT-open	• voltage and current • current unbalance	• V_{ct}, I_{ct} • I_{ub}
Poor-contact	• voltage and current • current unbalance • zero-sequence current $3I_o = I_a + I_b + I_c$ • current phase	• V_{ct}, I_{ct} • I_{ub} • $3I_o$ • θ_I
PT unbalance	• zero sequence voltage $3V_o = V_a + V_b + V_c$	• $3V_o$

Fig. 6 is the operation logic diagram to start the AL circuit by monitoring the current and voltage of the CT secondary side when the CT is open. Time setting is important because AL circuit must maintain mutual cooperation with protection relay in this case.

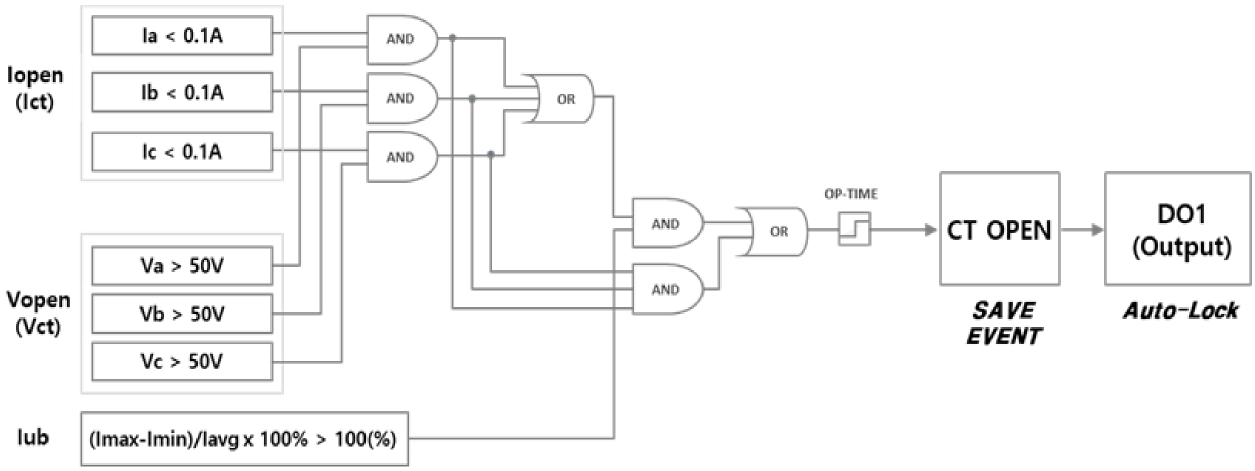
Table 1 is the main parameters of fault detector system. Factors mainly applied to the logic operation of a fault detector are open and poor-contact of CT and voltage unbalance of PT. V_{ct} is the CT secondary voltage, and I_{ct} is the CT secondary current. I_{ub} is the current unbalance factor, $3I_o$ is the zero-sequence current, and $3V_o$ is the zero-sequence voltage.

Fig. 7 is a logic circuit for CT-open and poor-contact detection. Fig. 7a is a logic circuit for CT-open detection, and Fig. 7b is a logic circuit for CT poor-contact detection. In the CT-open detection, the AL circuit (auto-lock protection circuit) is started by outputting a digital output of CT-open by measuring the current, voltage and current unbalance of the secondary side of the CT. In the CT poor-contact, the zero sequence current and zero sequence voltage of the secondary side of the CT are measured, and the digital output of poor-contact is issued to notify the user as an alarm.

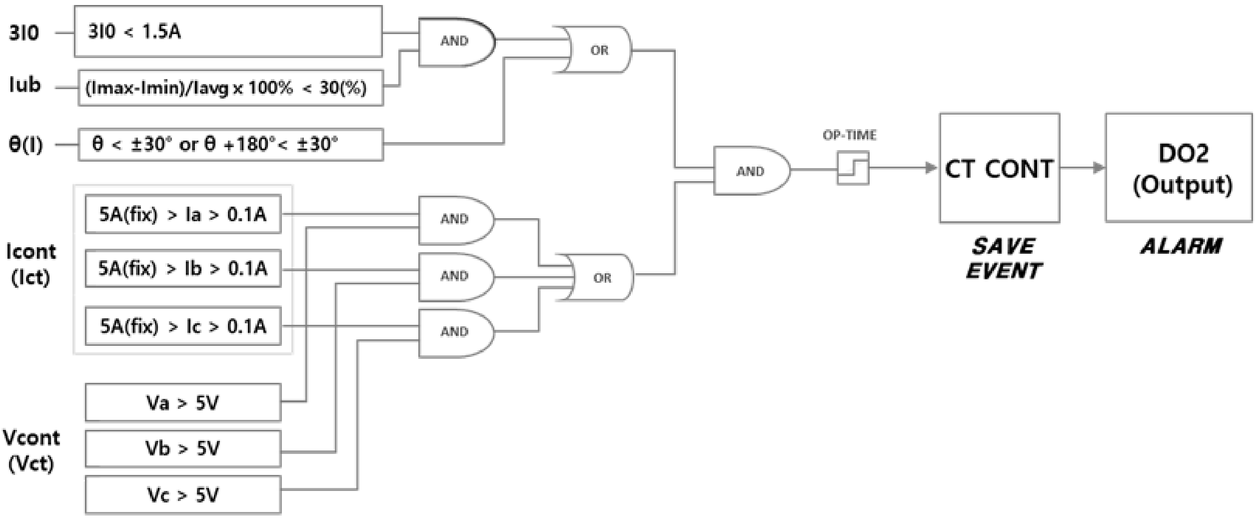
Fig. 8 is application test diagram of fault detector in 22.9 kV substation. Clamp-type CTa (600/5) installed in the substation site and CTb (800/1), which can be tuned to a level suitable for the detector, were applied. The digital protection relay setting condition of 22.9 kV substation was considered. The wave data and status of multiple detectors installed in the substation can be saved. All saved waveform data are saved in COMTRADE format, and these data can be compared and analyzed in other power circuit simulators.

3.2 Evaluation of System

Fig. 9 is a fault detector test-bed. Fig. 9a is the fault detector test-bed circuit, and Fig. 9b is the developed test-bed and HMI program. After the test-bed test was completed, a system test was conducted in 22.9 kV substation site [6, 7].



(a) Logic circuit for CT-open detection



(b) Logic circuit for CT poor-contact detection

Fig. 7 Logic circuit for CT-open and poor-contact detection.

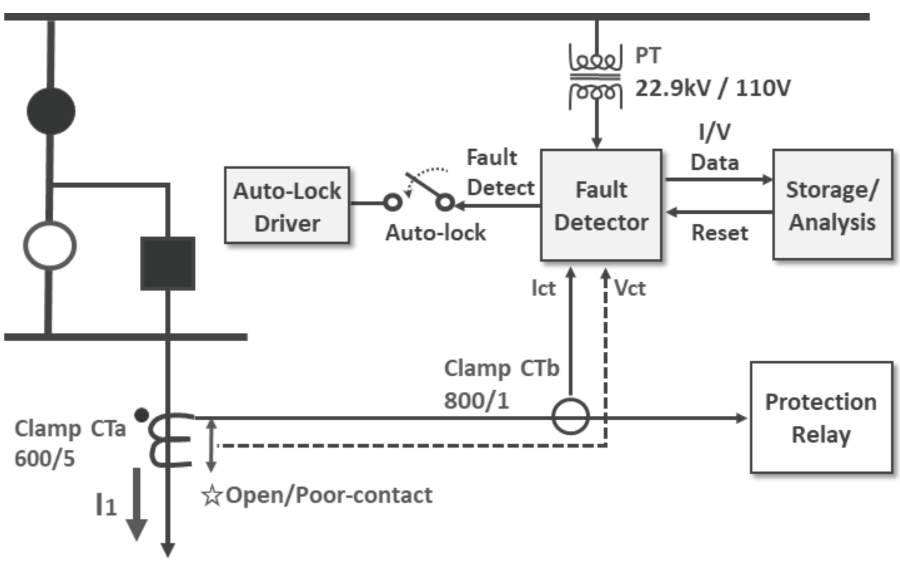
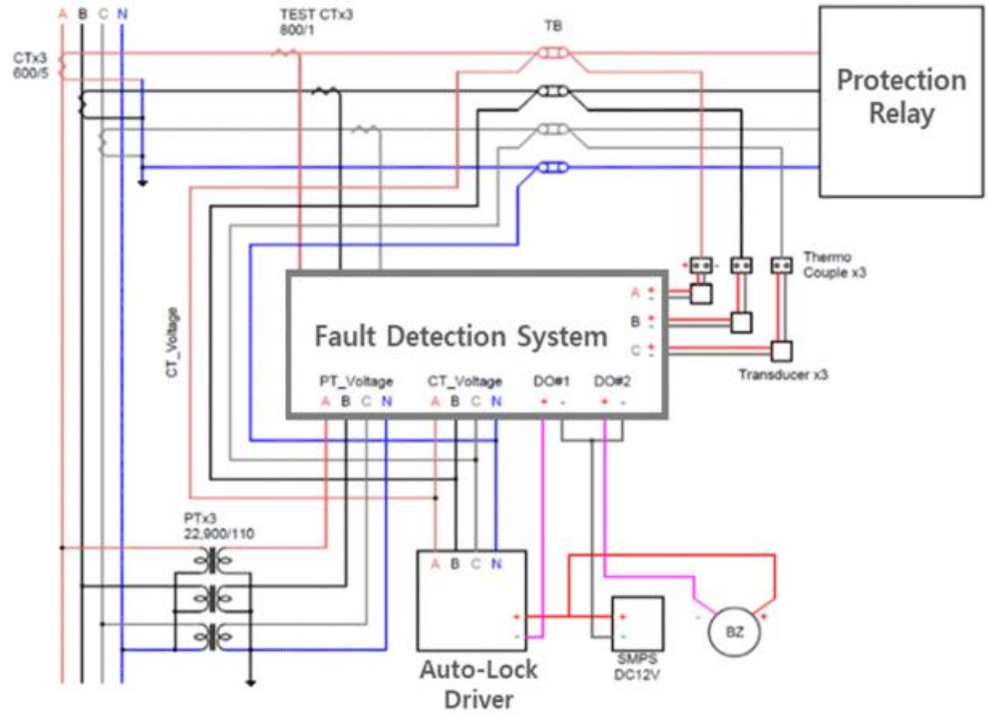


Fig. 8 Fault detector application test diagram in 22.9 kV substation.



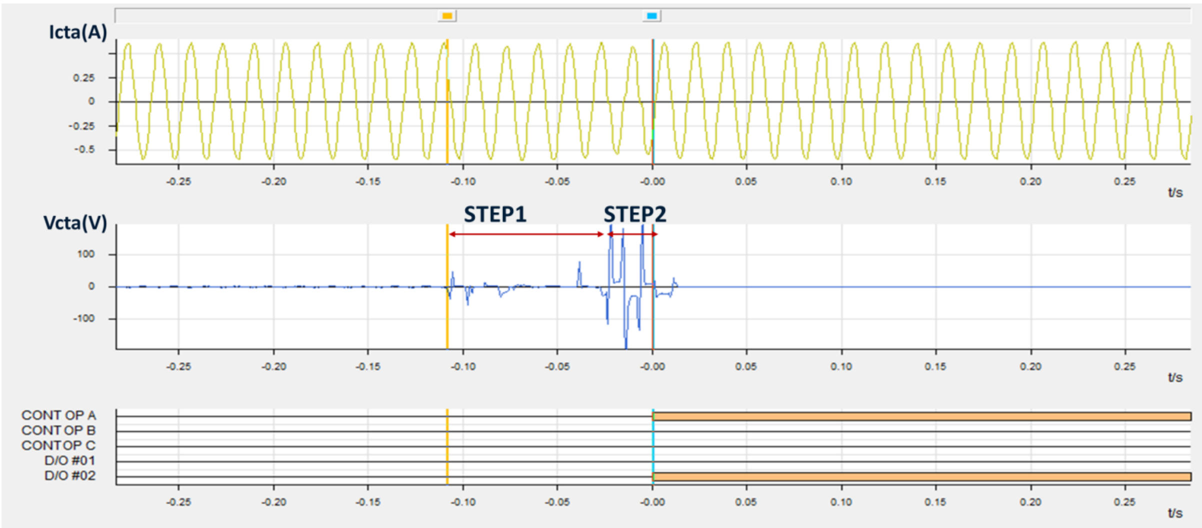
(a) Fault detector test-bed circuit

(b) Test-bed and HMI program

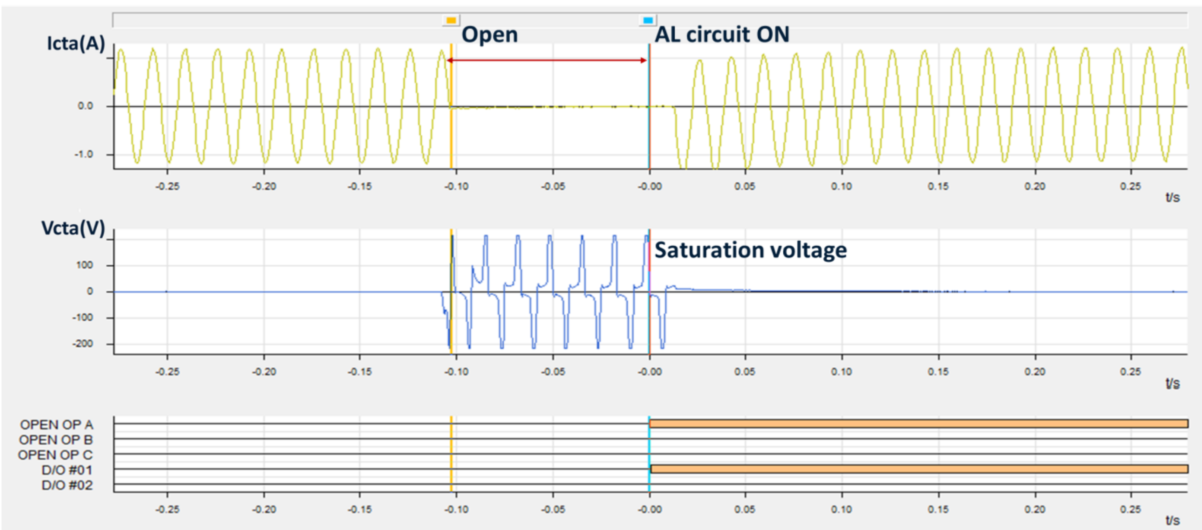
Fig. 9 Fault detector test-bed.

Fig. 10 is the result of fault detector application test in 22.9 kV substation site. Fig. 10a is CT poor-contact test at 50 A, and Fig. 10b is CT-open test wave at 100 A. A vibration and chattering generation circuit was used to reproduce the poor-contact in the CT secondary side TB. The chattering of the poor-contact test was conducted in two stages. That is, in STEP1, it started with small chattering, and in STEP2, strong chattering was applied. In STEP1, the fault detector that detected the poor-contact outputs an alarm, and in STEP2, it was confirmed that the instantaneous voltage on the CT secondary side decreases due to the operation of the AL circuit when the voltage rise increases beyond the threshold.

Fig. 10b is the result of reproducing CT-open by opening the test circuit breaker of the CT secondary side line. At the moment of opening the breaker, the CT current decreased and the distorted voltage increased



(a) Poor-contact test waveform at 50 A



(b) CT-open test waveform at 100 A

Fig. 10 Fault detector application test.

rapidly. After the fault detector detected this condition, it was confirmed that the CT voltage decreased by activating the AL circuit immediately.

4. Conclusion

In this paper, a fault detection system was developed to secure the power system stability of railway stations, tunnels, substations and large plants. And it was tested on a 22.9 kV HV pannel, and various faults that frequently occur in substations were analyzed to prevent accidents in the power system, and measures were presented for countermeasures. The method was developed by setting the correlation between voltage, current and phase due to CT-open and poor-contact in the extra-HV transformer system and the method for system protection with MCU-based logic. The fault detector system of this study was designed according to the operation principle of the industrial digital protection system. The degree of heat generation due to poor-contact was analyzed to determine the fault occurrence status of the substation site. After thermal simulation of TB using ANSYS Fluent, it was compared and analyzed with the measured values. The faults of poor-contact and CT-open were reproduced, and each voltage and current waveform was analyzed. In particular, a vibration and chattering generation circuit was used to reproduce the poor-contact state. As a result of the application test of the developed product for substation site suitability evaluation, it was confirmed that the CT AL circuit of the fault detector automatically and immediately operates in case of CT disconnection or poor contact, thereby preventing power system accidents in advance.

Acknowledgments

This study was conducted by the Ministry of Land, Infrastructure and Transport's Research Project on Railway Technology-Projects (21RTRP-B146037-04).

References

[1] Kim, H. K., Choi, C. S., Kim, D. O., and Chung, H. S. 2003. "A Study on Thermal Characteristics of Power Cord Sets for Low Voltage according to Poor Contacts." In *Proceedings of the Korean Institute of Electrical Engineers Summer Conference*, pp. 1466-8.

[2] Kim, H. K., Moon, H. W., Lee, K. Y., Kim, D. W., and Choi, H. S. 2009. "Analysis of Thermal Characteristics by Poor Contacts at the Connection Parts of DC Power Appliances." In *Proceedings of the Korean Institute of Electrical Engineers Summer Conference*, pp. 2158-9.

[3] Lee, H. S. 2012. "Detection and Thermal Characteristics of Abnormal Signal by Poor Contact." In *Collection*, pp. 15-9.

[4] Han, M. S. 2015. "A Study on the Danger of the Electrical Fire due to the Weakness of the Contact of Wiring Utensil." M.Sc. thesis, Seoul National University of Technology.

[5] Kang, Y. C., Lee, B. G., Lee, H. W., Kim, J. D., Park, J. S., Lee., M. S., Park, J. Y., and Lee, B. E. 2006. "Algorithm for Detecting the Failure of a Current Transformer Using the Zero-Sequence Current." In *Proceedings of the Korean Institute of Electrical Engineers Summer Conference*, pp. 163-4.

[6] Geum, D. S. 2015. "A Study on the Electrical Fire Hazard by Poor Contact and Tracking of the Terminal Block." In *Collection*, pp. 28-32.

[7] Kim, H. G. 2000. "Comparison of Characteristics between Cu_2O Growing by Poor Connection and Heating up Wire." M.Sc. thesis, Chosun University.