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Design and implementation of a real-time training environment for protective relay

Yoon-Sung Cho [a], Chul-Kyun Lee [a], Gilsoo Jang [b,*], Tae-Kyun Kim [c]

[a] Electrotechnology R&D Center, LS Industrial Systems, Cheongju 361-720, Republic of Korea
[b] School of Electrical Engineering, Korea University, Seoul 136-701, Republic of Korea
[c] Korea Electric Power Research Institute, Taejon 305-380, Republic of Korea

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ABSTRACT

This paper presents our work involving the development of a real-time operator training system using a protective relay implemented by the user defined component (UDC) model of a Real-Time Digital Simulator (RTDS). Operator training, within a real-time environment for the principles and behavior of protective relaying with respect to power system stability and protection, can provide a very strong benefit in facilitating operators' understanding of the basic concepts of a protective relay as well as handing undesirable operations. The operator training system includes (a) RTDS hardware, (b) a mimic board that has detailed state information of a simple two-area system with an electronically display, (c) a control panel so that the user can apply a disturbance to the system (i.e., fault, load shedding, etc.), and (d) a generator protective relay model. The relay model using a UDC, which is designed to facilitate the investigation and evaluation of the protective relay, is based on integrating six functions into a single model. The testing of the relay model described in this paper is summarized into three steps: static, dynamic and advanced testing methods. The simulation results of these tests show that the developed relay model using the UDC operates correctly for the various events. We also discuss the utilization of an operator training system via simple application examples.

1. Introduction

Synchronous generators are an essential part of a power system. The effect of generator action owing to mal-operation of a generator protective relay may have critically important significance in terms of the stability of the power system. The design for the protective relay of a synchronous generator should take into account the types of faults and potentially abnormal operating conditions. However, the extensive testing of a generator protection system is difficult because of the many complex interactions between the generator and the power system as well as between the generator and the relevant control systems [1,2].

As the technology advances, the necessity for extensive testing of a generator protection system using a real-time simulator has being significantly increased [3,4]. The in-depth testing of the digital relay algorithm using a real-time simulator can improve the reliability of the relay. This is because a real-time simulator like a RTDS can dynamically test the relay. Although a number of relay models have been implemented and tested by PSCAD/EMTDS, ATP, EMTP, and MATLAB SIMULINK, these simulators cannot be tested dynamically [5–9]. EMTP-type simulators may not allow comprehensive dynamic testing due to their playback approach.

With the introduction of real-time testing for relay performance evaluation, developing an operator training system for a protective relay in a real-time environment is a challenge [10–12]. In this respect, Meliopoulos and Cokkinides have presented an excellent approach for a virtual environment for protective relaying evaluation, testing, and education [10]. Although this tool is effective from the viewpoint of its application for visualization and animation of protective relaying, the gap between the real power system and virtual power system obviously exists. Oza and Brahma introduce a protective relay performance testing environment based on the hardware and experiments in the laboratory [11]. Lee et al. describe a physical laboratory for protective relay education that focuses on demonstrating more realistic characteristics and operations of a protective relay and teaching them using simulated network component modules [12]. From this perspective, this paper presents a real-time operating training system for power system operation and protection using RTDS and mimic board, and describes the development of the generator protective relay integrated into six functions using RTDS UDC. This system has the advantages that young engineers and students can understand the concepts, theory, and technology associated with power system operation, protection and stability. They get experience and enjoyment in learning about power system field. In addition, an operator can handle unforeseen situations because of having had many varied training

* Corresponding author. Tel.: +82 2 3290 3246; fax: +82 2 3290 3692.
E-mail address: gjang@korea.ac.kr (G. Jang).

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experiences in various operating situations. The operator training system described in this paper is based on RTDS, a mimic board, a control panel, a monitor and communication software. A real-time simulator based on the RTDS of the Korea Electric Power Corporation (KEPCO) was developed in 2001. It provides the most competitive environment worldwide. It is possible to integrate an operator training system and the testing of a protective relay.

In this paper, a discussion of the development of the six models involving distance, volts per Hz, reverse power, over voltage, out-of-step, and abnormal frequency relays are also described. We have verified and tested the developed relay model with both static and dynamic tests. In addition, we present the sample result of the comparative study between the G60 generator management relay and the developed relay model.

This paper is organized as follows. Section 2 introduces algorithms used in the developed generator relay model. Section 3 presents an overall structure of the developed relay model using a UDC. Static and dynamic testing for the various events was conducted to demonstrate the validity of the developed relay model. The results are presented in Section 4. A real-time operator training system using a generator protective relay is described in Section 5. Some comments about future work and conclusions are discussed in Sections 6 and 7.

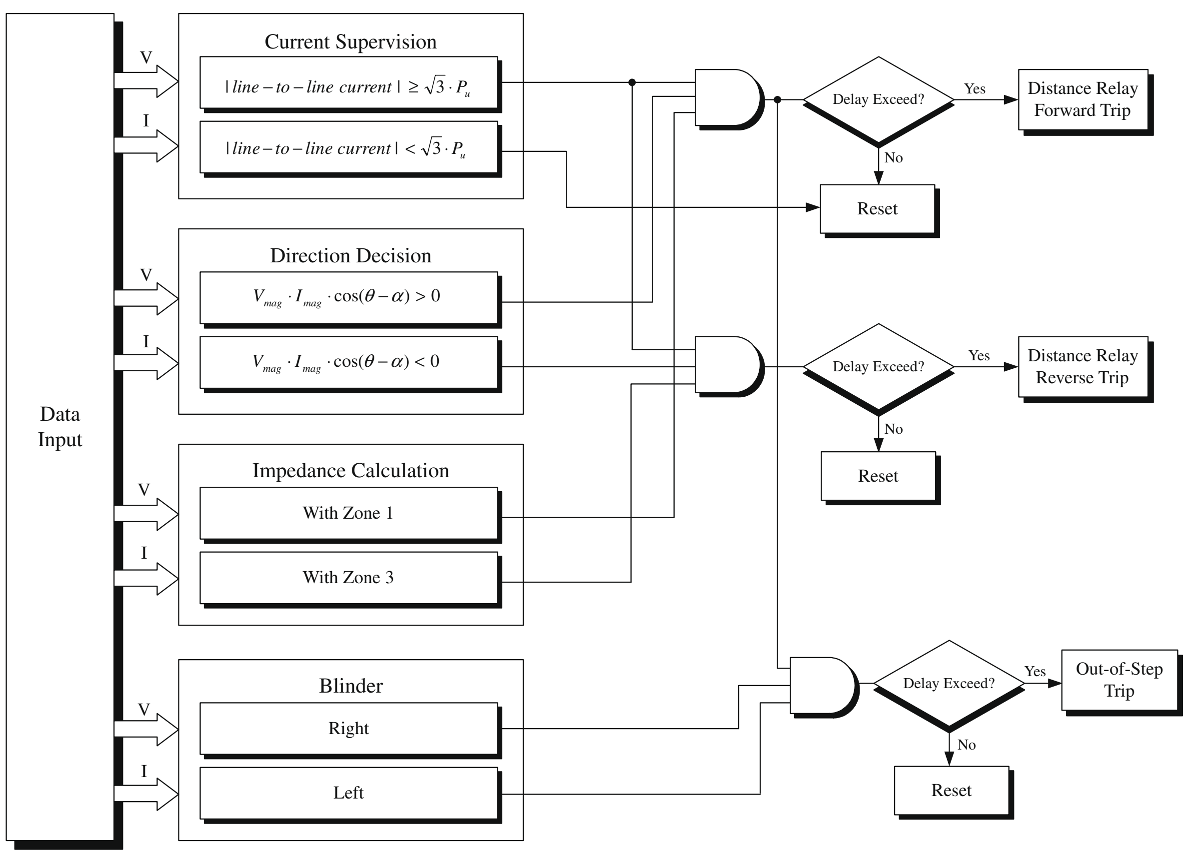

Fig. 1. Flowchart of phase distance relay and out-of-step relay.

Table 1
The proposed equation with respect to the distance element.

Module	Loop		
	AB	BC	CA
Impedance calculation			
	$\frac{\frac{1}{\sqrt{3}}(V_{AB}-V_{BC})}{-\sqrt{3}I_B}$	$\frac{\frac{1}{\sqrt{3}}(V_{BC}-V_{CA})}{-\sqrt{3}I_C}$	$\frac{\frac{1}{\sqrt{3}}(V_{CA}-V_{AB})}{-\sqrt{3}I_A}$
Directional decision	$\|(V_B-V_C)-(V_C-V_A)\|\cdot\|I_A-I_B\|\cdot\cos\theta$	$\|(V_C-V_A)-(V_A-V_B)\|\cdot I_B-I_C\|\cdot\cos\theta$	$\|(V_A-V_B)-(V_B-V_C)\|\cdot I_C-I_A\|\cdot\cos\theta$
Current supervision			
	$\|I_A-I_B\|>\sqrt{3}P_u$	$\|I_B-I_C\|>\sqrt{3}P_u$	$\|I_C-I_A\|>\sqrt{3}P_u$

P_u is the value of the threshold pickup setting.