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Design of an interactive application for educational support and performance analysis of overcurrent relay

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ABSTRACT

The analysis of overcurrent relay operation is complex when compared with other protection principles, because the time when protection should operate is unknown, as this time depends on the evolution of the fault current. The main purpose of this article is to present an analysis of the operation of overcurrent relays under different operating conditions, using computational resources. By simplifying the analysis of real or simulated events, the proposed computational tool facilitates the evaluation of the design and implementation of relays in power systems. The software also allows for the editing of the conventional and unconventional time curves. Some examples are presented to illustrate possible applications of this tool.

1. Introduction

The performance of protective relays is evaluated by determining their ability to detect faults within a zone of protection (selectivity and sensitivity), at the correct time. The level of complexity of a postmortem analysis depends on the variables used by the relay to perform the function of protection. On the principles of protection as the differential and pilot, the protection zone is constant and insensitive to the operating state of the grid; being an absolute selectivity protection does not provide backup functions, simplifying the analysis of its operation that focuses on the certainty of the decision of operation. In these protection principles, the uncertainty in the relay's operating time is restricted to a small range and in many cases is not the focus of analysis. Another type of protection, the distance relay has a limited dynamic zone of protection due to its polarization. The real and imaginary parts of fault impedance represent a source of error that result in uncertainty in the location of the fault. The determination of the apparent impedance and its relationship with the electrical distance to the point of failure is a central theme in an analysis. In the large majority of studies on differential relays, pilot, or distance, the dynamic modeling of the relay is not required, and only the dynamic conditions of the network are needed.

For the specific case of an overcurrent relay, the current signal is the only measurement variable, and it is sensitive to the load effect, as well as the location and dynamics of the fault. Thus, determining the location of the fault is difficult because its protection zone is dynamic and sensitive to the operating conditions of the electrical system. The post-mortem analysis of the operation of an overcurrent relay is complicated because it has a greater dynamic reach than other protection principles, and because the time at which the protection should operate is unknown, as this depends on the dynamics of the fault current. It is common practice to perform a reconstruction of the operation of the relay by injecting event records in the laboratory to validate the operating time of protection. Other alternative methods are to reproduce the dynamics of operation by developing hardware prototypes, or with the use of relay modeling software.

The relay prototype development route is a difficult one that involves a considerable investment of time, mainly due to the signal conditioning challenges and the issue of hardware stability. Refs. [1,2] describe the designs of an analog electronic overcurrent relay and a microprocessor overcurrent relay; the relays proposed there are intended for laboratory applications. While prototyping might be a valuable experience, it is not recommended for validation of relay operation given the development time and the dependence on physical simulators for playing events. Also the use of communication channels and hardware implementation are studied [3].

To evaluate and model relay operation using software, simulators in both academic and commercial platforms have been developed that allow an evaluation of relay response in various test scenarios. The feasibility of relay performance analysis through digital simulation has been demonstrated in [4], and the

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requirements for this are specified in [5]. The academic simulation platforms must model the system components and perform calculations to obtain values for variables such as flows and faults [6,7]. The analysis of overcurrent relay coordination and test modules for distance relays developed in PSCAD and Matlab are presented in [8–12], respectively.

However, with the academic software it is difficult to achieve the level of modeling reached in recognized commercial packages such as EMTP. Moreover, the analysis of relay protection performance should be done for a variety of operational conditions, which can hardly be covered by a single simulation platform.

The analysis of relay operation is facilitated by the development of software tools consisting essentially of the dynamic model of the relay and its associated protection functions, which allow the inclusion of signals from real events or records of simulations of electrical systems. Another benefit resulting from the development of relay modeling applications is found in education and training activities. The authors in [13] points out the importance of engineering design courses for power systems, and refers to an urgent need to identify and develop the materials needed for the education and training of future engineers of protection.

Frequently, graphical resources are used to aid in education and in the study of electrical power systems [14–16]. The performance evaluation of protection in particular is well served by visually comparing the operating conditions of an electrical system with the characteristics of relays.

In this paper we propose a computational application that emulates the operation of the dynamic state of protective relays. The application is designed to address theoretical as well as practical needs, by facilitating operational analysis by relay-protection engineers, and also by supporting the training of high-level human resources by serving as a teaching resource, so as to facilitate the transmission of knowledge in the area of electrical protection. This computational tool does not evaluate the directional relay function, since this does not influence the dynamics of the relay, and it is only a permissive condition of operation. It will be assumed that this function operates satisfactorily. Moreover, our proposed application is not comparable with the test equipment used for calibration and analysis of relay functions, rather it only provides a simple alternative for evaluating the operation of the relay.

2. Design of the protection functions

The proposed application has been made to contain a graphical user interface, and its functional structure consists basically of three modules: signal generation, phasor estimation, and protection functions. The relay evaluation algorithm takes as input either internally generated signals, or it reads data from external files in ASCII format. Such files may have been generated either in simulation programs (EMTP, PSCAD, Matlab, etc.) or they might contain data consisting of real fault records (Fig. 1). The superposition principle is used for insertion of the fault signal and additional sources of different frequency components.

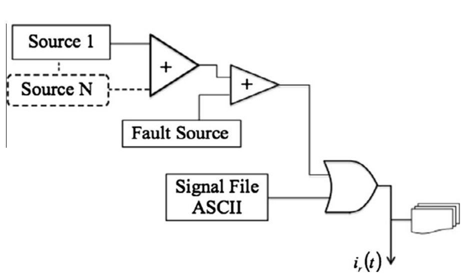

Fig. 1. Signal generation module.

The electrical input signal to a relay from a current transformer is composed of signals that are representative of electrical phenomena. They should not be used to determine the relay operating criterion, because they exhibit a random character that precludes the correct determination of the location of a fault. Digital processing must remove unwanted signal quantities and retain the quantities of interest [17]. The overcurrent relay operation should be established only using the fundamental component of the signal, because it is that component which is proportionally affected by the location of the fault.

To obtain the phasor, it was necessary to incorporate two filter stages (Fig. 2), one analog and one digital filter to remove unwanted frequency components. Generally the analog filter used is a Butterworth filter; this filter is preferred as it has a flat response in the passband and mono-tonic decreasing in the stop band [18]. After the analog filter stage, an analog to digital converter (ADC) is used; while high sampling rates can achieve a substantial signal resolution, they do increase the processor load. Aliasing removal is obtained using a filter which is tuning between the analog (anti-aliasing) and digital filtering, allowing for overlapping frequency filtering. It is also possible to eliminate the analog filter by oversampling the signal [19].

Digital filtering is performed with finite impulse response (FIR) filters, since they involve no recursion. In addition, infinite impulse response (IIR) filters generally produce phase distortion, contrary to the FIR type that has a linear phase response. This condition allows the frequency response to have zeros at the natural harmonic frequencies, enabling a rejection of these components in the signal. A Cosine filter is preferred, because it has a better rejection of the direct current component. The proposed application offers versatility in the variation of tuning parameters in the signal conditioning. It has controls to modify the parameters of the analog filter, for example it is possible to analyze the effects of aliasing and assess the effect of oversampling of the signal. However, since the size of the data window has a minimal impact on the time of operation of an overcurrent relay, this parameter is pre-set to a single cycle.

Dynamic algorithms of overcurrent relays take as input signal the phasor estimate of a current. Even when a digital filter has the ability to reject harmonic components, inter-harmonic and sub-harmonic signals are merely modulated and are not rejected totally, representing a source of error in the phasor estimate. This too can be evaluated in the proposed application.

The protection functions consist of the dynamic model of an overcurrent relay, the instantaneous relay, the cold load function, and a module for editing a time curve (Fig. 3). The subroutine of

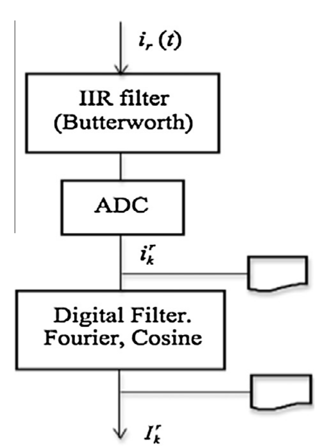

Fig. 2. Phasor module.