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DSP Based Numerical Relay For Overcurrent Protection

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Abstract

Primary purpose of Power System is to ensure continuous delivery of power supply despite of various faults like Overcurrent, Earth faults, and Phase faults etc. Thus different protection devices are used for Power System Protection out of which numerical relays embedded with digital signal processor (DSP) are able to improve the protection operations significantly. These relays are capable of performing complex processing faster and with higher accuracy as DSP is optimized for real-time signal processing. Various DSP techniques such as Fast Fourier Transform (FFT), Discrete Fourier Transform (DFT) and Wavelet Transform along with Artificial Neural Networks (ANNs) can be used to detect spurious signals and faults. Implementation of an overcurrent relay with Inverse Definite Minimum Time (IDMT) characteristics is focused in this paper. The proposed relay model can be implemented in MATLAB/Simulink or using C-language code as discussed here.

Keywords: Numerical Relay, DSP, IDMT, Overcurrent Protection

1. Introduction

The main purpose of Power System is to generate, transmit and distribute electric energy to customers without interruptions in the most economical and safe manner. Power System suffers through many faults such as Phase and Earth Faults [1]. Most of these faults result into sudden and significant increase in current. Thus, overcurrent protection is essential in order to minimize the disturbances caused by any failure in the system and to ensure continuous power delivery. Therefore, it is a common practice to interconnect major elements of Power System such as generators, power transformers, transmission lines, etc. by using protection devices such as fuses, switchgears and circuit breakers along with various types of relays [2].

The overcurrent relay, used for short circuit protection monitors current and operates when current magnitude exceeds a preset value. Standard overcurrent relays of Inverse Definite Minimum Time (IDMT) include characteristics such as Standard Inverse (SI), Very Inverse (VI), Extremely Inverse (EI) and Definite Time (DT).

A very important aspect of the relay operation is that it should be able to detect all fault conditions but should not trip due to spurious signals generated during power system transients. DSP based Numerical Relay discussed in this paper can discriminate better between above conditions due to their enhanced fault current waveform processing capabilities as compared to electromechanical relays or solid state relays.

2. Numerical Relay–A Detailed Approach

Numerical relays can avoid false tripping due to their enhanced fault current waveform capacity. The relay uses DSP cards, which contain dedicated microprocessors especially designed to perform digital signal processing. It uses the concept of Open System Relaying where different relay functions can be obtained from the same hardware just by modifying microprocessor programming. It also saves capital cost and maintenance cost over the other types of relays. Numerical relays are classified broadly into four different types as Overcurrent relays, Distance relays, Directional relays and Differential relays depending upon their applications [3].

The generalized numerical relay consists of a minimum set of hardware modules and functions of modern digital and numerical relays. The schematic of a generalized numerical relay structure is shown in Figure 1 [4], [5].

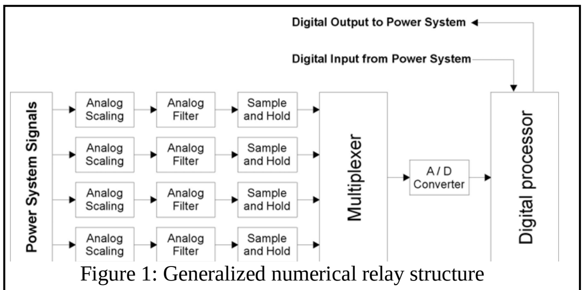

Figure 1: Generalized numerical relay structure

1. *Isolation and analog signal scaling:* Current and voltage waveforms from instrument transformers are acquired and scaled down to convenient voltage levels for use in the numerical relays.

2. *Analog anti-aliasing filtering:* Low-pass filters are used to avoid aliasing effect.

3. *Analog-to-digital conversion:* The waveforms of inputs must be sampled at discrete times because digital processors can process numerical or logical data only. Therefore, each analog signal is passed through a sample-and-hold module and conveyed, one at a time, to an Analog-to-Digital Converter (ADC) by a multiplexer.

4. *Phasor estimation algorithm:* Software algorithm implemented in a microprocessor estimates the amplitude and phase of the waveforms provided to the relay.

5. *Relay algorithm and trip logic:* The equations specific to the protection algorithm and the associated trip logic are implemented in the software of the processor used in the relay. It calculates the phasors representing the inputs, acquires the status of the switches, performs protective relay calculations and finally provides outputs for controlling the circuit breakers. The processor may also support communications, self-testing, target display, time clocks, and other tasks.

Numerical relays have different features like self check feature, multiple protection characteristics, adaptive protection characteristics, instrumentation, remote communication, motor protection, data storage etc [1]. It has various advantages over the other relays such as reduced size, reduced number of protection elements, reduced cost, increased speed etc.

But by combining many features into one piece of hardware, numerical relay centres on the issues of reliability and availability. A failure of a numerical relay may cause many more functions to be lost compared to applications where different functions are implemented by separate hardware items. Also, it requires continuous power supply. Figure 2 shows cost comparison of numerical relay with electromechanical and static relay [1].

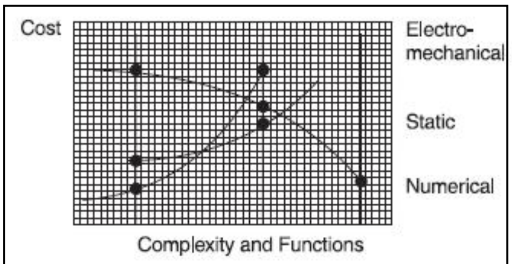

Figure 2: Cost Comparison of Numerical relay with electromechanical and static relay

3. Overcurrent Relay Characteristics and Implementation

An overcurrent relay ANSI device number is 50 for an instantaneous overcurrent (IOC), 51 for a time over current (TOC). In a typical application the overcurrent relay is connected to a current transformer and calibrated to operate at or above a specific current level.

The principle of working is based on relay operating time and the preset current value. When a fault occurs, the computed RMS value of current exceeds the setpoint value and then the relay computes the tripping (operation) time using tripping time-versus-current characteristics.

The operating time of a relay for a particular setting and magnitude actuating quantity can be known from the relay characteristics. Overcurrent relays are also provided with elements having independent or definite time characteristics. These characteristics provide a ready means of coordinating several relays in series in situations in which the system fault current varies very widely due to changes in source impedance, as there is no change in time with the variation of fault current.

The IEC 60255 standard defines four standard current time characteristics as standard inverse (SI), very inverse (VI) and extremely inverse (EI). Each characteristic can be calculated from:

$$t = \frac{K}{-1 + \left(\frac{\mathrm{I}}{\mathrm{Is}}\right)^{\propto}} \times \mathrm{TMS}$$

where,

t = tripping time in (S)
I = fault (actual) secondary CT current (A)
I_s = relay current setting (multiplier)
TMS = time multiplier setting (multiplier)

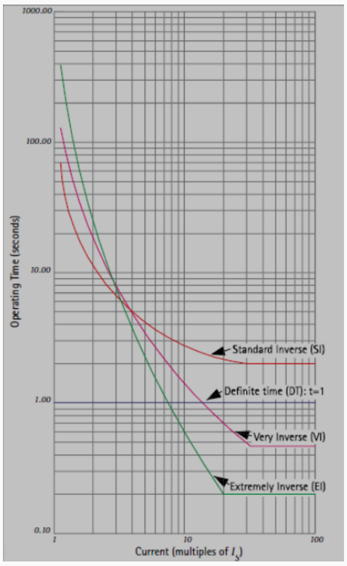

Figure 3: IEC characteristics

The typical characteristics are shown in Figure 3. An inverse curve is the one in which the operating time becomes less as the magnitude of the actuating quantity is increased. However, for higher magnitudes of actuating quantity, the time is constant. Definite time curve is the one in which operating time is little affected by magnitude of actuating current. However, even definite time relay has a slightly inverse characteristic. The characteristic with definite minimum time and of inverse type is also called IDMT characteristics [6].

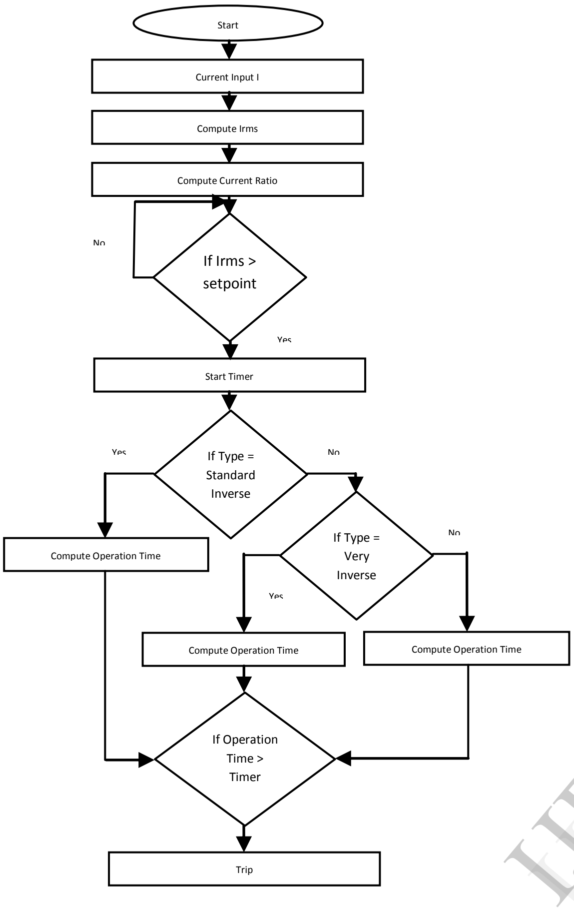

Figure 4: System Flow Chart

Implementation of IDMT characteristics can be carried out by computing the Root Mean Square i.e. RMS value of the input current. The RMS value is then compared with setpoint value and then based on the timer value, characteristic is identified and relay trip logic is activated. Relay characteristic is identified based on comparison of operation time and timer value. The whole process can be represented in the form of a flowchart as given in Figure 4 [7], [8].

4. DSP Approach to Implementation

Digital signal processing is the mathematical manipulation of an information signal to modify or improve it in some way. It is characterized by the representation of discrete time or discrete frequency or other discrete domain signals by a sequence of numbers or symbols and processing of these signals.

Digital signals are studied usually in time domain (one-dimensional signals), spatial domain (multidimensional signals) and frequency domain. The domain is chosen to process a signal by trying different possibilities. A sequence of samples from a measuring device produces a time or spatial domain representation, whereas a discrete Fourier transform produces the frequency domain information, i.e. the frequency spectrum.

DSP techniques include techniques such as Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Short Time Fourier Transform (STFT), Wavelet Transform and Discrete Wavelet Transform (DWT) along with Artificial Neural Network (ANN).

DSP (Digital Signal Processor) is a specific microprocessor that is designed for typical mathematical operations to manipulate measured digital data. DSP is capable of processing data speedily and generate output data in real-time. The additional hardware units embedded in the processor will speed up the computational of mathematical operations.

5. Proposed System Implementation

Two methods can be used for proposed implementation on DSP. For the first method, the overcurrent relay simulation model from MATLAB/Simulink is directly downloaded into the DSP while, for the second method, C-Language codes are written for the relay in the DSP. These codes are then complied, linked, downloaded and executed on DSP. The results from the execution are viewed from Code Composer Studio (CCS). CCS provides a single user interface where the contents of the memory saved in the DSP can be viewed.

The MATLAB/Simulink model of numerical relay for overcurrent protection is shown in Figure 5 [8], [9]. The overcurrent relay of IDMT type can be used for the same. In the simulation model shown here, the input currents of sine waveform with frequency of 50Hz can be generated. The inputs are then quantized in order to process them digitally. The input currents will be sampled at higher sampling frequency. The sampling frequency must be at least twice of the fundamental frequency. This is to ensure that the Nyquist criterion is fulfilled so that the aliasing of the input signals is avoided.

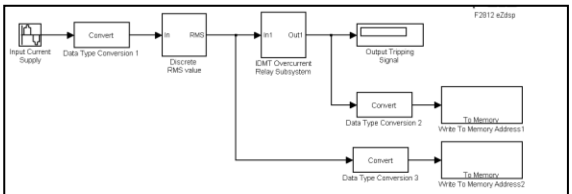

Figure 5: MATLAB/Simulink Model of Overcurrent Relay

These samples will then be used to compute the root mean square (RMS) value of the input current. The RMS computation is necessary in order to extract the fundamental component of the input current samples. These calculated RMS currents are then supplied to the overcurrent relay. The RMS values are then compared with the setpoint value to obtain the current ratio [7], [8].

The protection algorithm embedded in the relay starts the process to determine the operation time of the relay [9]. The algorithm is based on IEC standard which includes different types of inverse characteristics of the IDMT relay. The algorithm requires current setpoint value, TMS and type of inverse characteristics to determine the operation time. An output tripping signal is generated if the RMS input current exceeds the setpoint value or in other word when the current ratio is more than 1. The overcurrent relay will trip after the intended operation time which is calculated from the protection algorithm [9].

The proposed system block diagram is shown in Figure 6 [7], [8]. The relay modelled in MATLAB/Simulink can be directly downloaded into target support package. Any DSP technique or RMS value computation technique can be applied to well discriminate between the power transients and overcurrent surges. C-language code written can also be implemented directly on the DSP chip.

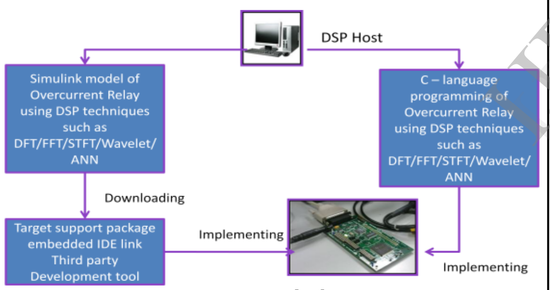

Figure 6: System Block Diagram

6. Conclusion

The paper presents the possible methods of implementing numerical relay for overcurrent protection. IDMT relay characteristics are selected for the implementation. RMS value computation technique which can be used to implement IDMT characteristics is also detailed. MATLAB/Simulink based method and C language method for the implementation of Proposed Relay Model are also discussed along with the DSP techniques which can be applied in IDMT characteristic implementation in order to improve performance of system during false tripping.

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