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Low cost microcontroller based fault detector, classifier, zone identifier and locator for transmission lines using wavelet transform and artificial neural network: A hardware co-simulation approach

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A B S T R A C T

A low cost, fast and reliable microcontroller based protection scheme using wavelet transform and artificial neural network has been proposed and its effectiveness evaluated in real time. The proposed scheme, based on the hardware co-simulation approach performs all the functions of transmission line protection i.e. fault detection/classification, fault zone/section identification and location estimation. The fault detection/classification and zone identification algorithms use fundamental frequency current component to estimate a fault index. The fault location estimation module uses wavelet transform coefficients in hybridization with a parallel artificial neural network structure. For hardware implementation, a 8-bit ATmega microcontroller is used and interfaced with the simulated power system model using Integrated Development Environment (IDE). The scheme is tested on a power system model of 400 kV, 50 Hz three phase double circuit line with source at both the ends. Laboratory tests have been performed in real time for 20,000 fault cases including evolving faults with varying fault resistance, fault inception angle, fault distance, direction of power flow angle and its magnitude. The tests confirm the suitability and reliability of proposed scheme even with Current Transformer (CT) saturation. The implementation of the proposed approach on a low cost microcontroller with the lesser execution time, makes the prototype ideal for implementation on a digital platform (digital relay), thus leading to financial viability and sustainability of the protection scheme.

Introduction

Transmission lines are exposed to extreme atmospheric conditions, due to which occurrence of fault in transmission lines are much more as compared to other power system equipments. Fault leads to the interruption of power flow and distresses the performance of power system. Hence it is imperative to limit the impact of faults to the minimum extent. This can be achieved by a highly reliable, fast and accurate fault detection/classification, fault section identification and location estimation scheme. Proper fault classification allows implementing single pole tripping and reclosing, while fault section identification (differentiating between internal and external fault) leads to removal of only the faulted line and accurate fault location helps in faster restoration of the supply, post fault.

Over the past few years, extensive research has been carried out on transmission line protection. Traditionally, distance protection has been used for transmission line. However, the performance of distance relay based protection schemes gets degraded because of mutual coupling effect, ground fault resistance, prefault system conditions, shunt capacitance, etc. [1–4]. In this regard, several techniques have been proposed to enhance the performance of the protection scheme of double circuit transmission lines. Techniques based on traveling waves to increase the speed of the protective relaying have been reported in [5,6]. Traveling wave method require high sampling rate and suffer from the limitation of distinguishing between waves reflected from the fault and from the remote end of the line. Also they have the innate shortcoming of not detecting the faults at zero crossing of the voltage waveform. Another method based on phasor measurement unit has been proposed in [7], which uses eigen value/eigen vector theory and thus requires complex mathematical calculations.

Recent times have witnessed the development of several protection schemes based on artificial intelligence viz. ANN (artificial neural network), fuzzy logic and their hybridization. The works

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reported in this context are based on ANN [8–11], fuzzy logic [12–15], ANFIS [16], and ANN with wavelet technique [17]. These techniques are mainly developed with the sole aim of classifying the fault, and hence do not provide any information regarding fault location. Some notable works for fault location estimation includes ANN [18], neural network with wavelet transform [19], wavelet and neuro-fuzzy [20]. However, these techniques have not concentrated on detection and classification of faults. Several protection schemes using ANN [21–23] and in combination with wavelet transform [24,25] have been proposed for detection, classification and location of fault. However, the effectiveness of these schemes has been inspected over a limited number of test cases only.

Advances in the field of digital processor have led to a paradigm shift on the implementation of algorithms for engineering systems. With regard to the implementation of protection scheme on digital platform for real time application, the related research work has been mainly focused on the implementation of over current relays using microprocessor [26], field programmable gate array (FPGA) [27–29] and DSP [30,31]. However, these protection schemes though quite effective require complex mathematical algorithms to approximate the relay characteristics and thus require large memory space. Moreover, these techniques were developed for fault detection task only.

A common limitation with all the techniques discussed above is that they are non directional i.e. they are unable to distinguish between internal and external faults or its zone. Techniques reported for fault direction discrimination are based on phase change in negative-sequence current [32], ANN [33], modular neural network [34], ANN with wavelet transform [35], positive-sequence components with fuzzy decision approach [36] and microcontroller based numerical relay [37,38]. However, all these techniques do not classify or locate the faults.

To the best of the knowledge of the authors, no work has been reported on the development of artificial neural network and wavelet transform based protection scheme with real time implementation on a cost effective digital platform that can perform all the functions of protective relaying i.e. fault detection/classification, faulty zone identification and fault location.

In this regard, the development of a low-cost commercially available 8-bit microcontroller based protection scheme in conjunction with hybridization of ANN with wavelet technique has been sought, which would be computationally efficient in performing all the above mentioned functions of protective relaying. The developed algorithm uses only the absolute value of fundamental component of current signals for fault detection, classification and faulty zone/section identification, while for location estimation, standard deviation of approximate wavelet coefficients of voltage and current signal at relaying point are utilized. The contribution of the present work is threefold, firstly a complete protection scheme has been proposed which simultaneously performs all the functions of a protective relaying i.e. fault detection, classification, zone identification and location estimation. Secondly, the proposed scheme has been implemented on a low cost microcontroller to assure its applicability for real time implementation. Finally, the need of a communication link for data acquisition is avoided for fault detection, classification and location estimation, which increases the reliability of the protection approach.

This article is organized as follows. Section 'Overview of the scheme' describes a brief overview of the proposed protection scheme and its hardware implementation. Section 'Power system model' describes the power system model under study. The protection algorithm is described in Section 'Proposed protection scheme'. Section 'Hardware implementation' describes the hardware implementation of the algorithm on a low cost microcontroller. Section 'Results' presents the experimental results and verifies the effectiveness of the proposed scheme and finally conclusions are drawn in Section 'Conclusion'.

Overview of the scheme

The overall framework of the proposed protection scheme implemented in digital domain on a low cost microcontroller is outlined in Fig. 1. The figure details the separation between the simulation environment and the hardware platform. The hardware co-simulation approach allows developing and testing of the proposed scheme in real time, by integrating Simulink running on host PC and a physical microcontroller board. This is achieved by directly incorporating a logic/algorithm running in a microcontroller with the simulation environment in Simulink. The modeling and simulation of power system model with the specified parameters, data pre-processing, sampling, A/D conversion and feature extraction are performed using Matlab and Simulink on host PC. The relay logic is coded in the Matlab script using Arduino open source language and communicated over USB to the board. The hardware realization of the proposed logic and the validation of performance of the prototype are carried out using ATmega microcontroller with the necessary interface in the board.

Power system model

The single line diagram of the power system under study is shown in Fig. 2. The power system is composed of a 400 kV, 50 Hz three phase double circuit transmission line of 200 km length, connected to sources at each end.

The transmission line model is simulated using Simulink and simpowersystem toolboxes of MATLAB. As shown in Fig. 2, the relay is installed at bus-1 at the sending end to provide primary protection upto 100 km of the line length from the sending end source (E_S) and backup protection to the line between bus-2 and receiving-end source (E_R). The line section between the relaying point and bus-2 is considered as protection zone-1/section-1 and the line section between bus-2 and the receiving-end source comprise the protection zone-2/section-2. Faults occurring in zone-1 are termed as inside or internal faults, while faults taking place on zone-2 are referred as forward or external faults.

Proposed protection scheme

The overall protection scheme proposed herewith involves three stages, namely (i) Data pre-processing (filtering) and extraction of features having greater distinctness for different faults, (ii) Development of proposed algorithm for fault detection/classification, zone identification and location, and (iii) The design and hardware implementation on a digital platform.

Data pre-processing (filtering) and feature extraction

Instantaneous voltage and current samples at relaying point are obtained by simulating the power system model (Fig. 2). The per unit values of voltage and current signals in different phases of both the circuits are given as:

$$V_{P,m} = \left\{V_{P(k)}, V_{P(k+1)}, \ldots V_{P(k-n+1)}\right\} \quad (1)$$

$$I_{P,m} = \left\{I_{P(k)}, I_{P(k+1)}, \ldots I_{P(k-n+1)}\right\} \quad (2)$$

where P represents the phase, n represents the number of samples, k is the sampling instant and m is the circuit i.e. 1 or 2.

Following the inception of faults in the line, the instantaneous voltage and current samples contain a wide range of frequency