A double ended AC series arc fault location algorithm for a low-voltage indoor power line using impedance parameters and a neural network

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Abstract

This paper presents a novel method for the distance estimation of a series arc fault in a low-voltage indoor power line. This method is based on the SIMULINK modeling of an electrical line by using its RLCG parameters. Rather than using an arc fault model, arc faults are inserted at different points across the line, using measured data. The algorithm estimates the arc fault distances by employing both the voltages and currents at two ends of the line, calculating their DFFT (Discrete Fast Fourier Transform) and then inserting these magnitudes, into Kirchhoff equations which take into account impedance parameters of the simplied approach line model. The arc fault is generated at an unknown distance. As the impedance parameters depend on the fault location, sets of supposed fault distances (varying by one-meter steps) are inserted in these equations. Thus, the extraction of currents peak values at the fundamental frequency (50Hz) generates a signature vector. A neural network is trained using signature vectors as inputs (for faults generated at dierent distances). Finally, the algorithm thus developed is validated. The results obtained in this work show that fault location can be successfully estimated.

Keywords: series arc fault, indoor power line, neural network, fault-location estimation, Discrete Fast Fourier Transform, impedance parameters.

1. Introduction

Series arc faults appear frequently and unpredictably [1] in low voltage distribution systems when degraded and aged wires are in contact with each other. Many methods have been developed to detect this type of faults and commercial protection systems such as AFCI (Arc fault circuit interrupter) have been used successfully in electrical networks to prevent damage and catastrophic incidents like fires [2–4].

However, these devices do not allow series arc faults to be located on the line in operating mode. The main commercial equipments using reflectometry, often involves disconnecting the power supply in order to inject signals on the line [5]. In this context, locating faults on a line can greatly facilitate the repair time of these lines.

Many researchers have been worked on algorithms to locate faults in high power transmission systems. These are mainly based on the impedance method [6–10], traveling wave methods [11–14], methods based on the electro-magnetic time reversal [15, 16] and methods based on artificial intelligence [17–19] which use directly fundamental components of current and voltages to estimate fault location. Also hybrid methods based on the Wavelet Packets and artificial neural networks (ANN) [20–22] are widely used in the location of linear phase to phase or phase to ground faults. All these artificial intelligence methods essentially locate parallel faults. An exception is the work presented in [23], where the authors implemented an ANN algorithm to estimate the series fault distance produced by an open conductor. The computational complexity of ANNs associated with Wavelet decomposition is very high in particular due to high frequency rates. Furthermore, these methods are mainly applied in very long transmission lines (up to 700Km).

Researchers developed algorithms to locate intermittent electric faults mainly on electrical aircraft wires, based on reflectometry methods (TDR, STDR, SSTDR) [24–26]. However, the impedance matching required between the power line and the load in order to avoid undesirable reflections represent the main weakness of these methods.

Little work has been devoted to locate parallel faults on low voltage lines of short length (up to 100m) using the impedance method [27, 28]. In this similar context, experimental tests of a time reversal method using a reduced-scale coaxial cable system are presented in [15]. The problematic of a series arc fault location is addressed in [29] where is presented the implementation of an algorithm for locating a series arc fault in an experimental DC platform consisting of physical modules that emulate a transmission line of 1200 m length. Inspirited by this work, the authors of this paper developed an algorithm to locate AC series arc faults based on an approach model of a home electrical line [30].

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Nevertheless, the accuracy of the method tested experimentally for different fault distances is strongly influenced by an adequate frequency band selection which only allows locating fault distances in the midstream of the line.

In the present work, we have focused on developing an algorithm capable of estimating the distance of a series arc fault in a short AC low-voltage indoor power line (49 m). The method proposed uses impedance parameters of the line and a neural network. The inputs of the neural network are composed of coefficients obtained from Kirchhoff equations which use recorded signals at two ends of the line under a series arc fault event.

2. System description

2.1. Indoor power line model

An indoor power line of 49 m in length is modeled in Simulink (Fig. 1). The line is powered with a 220 V - 50Hz source and the load is composed of a 47-ohm resistor. The power line model consists of 49 segments of cable [S(1m), S(2m)....,S(49m)], each segment representing the model of a chunk of cable. This type of configuration allows series arc faults to be inserted each 1 m across the line. Further, voltages and currents are registered at two ends of the line.

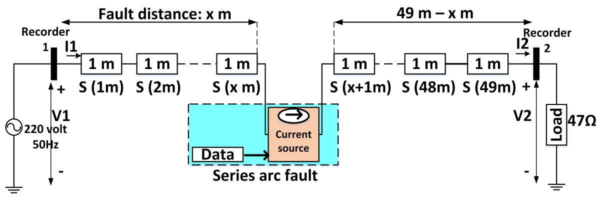

Figure 1: Indoor power line representation.

The model of a chunk of cable is obtained by using the *pi* configuration (asymmetric model) of electrical parameters in accordance with Fig. 2.

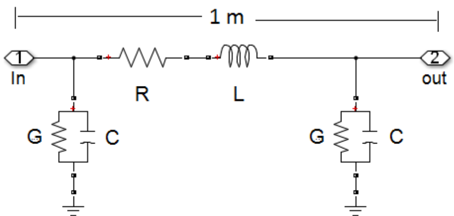

Figure 2: Model of a chunk of cable (Pi-model: 1m).

The immersed parameters are the resistance R, inductance L, conductance G and capacitance C. Based on a real test, we estimated RLCG parameters of a real cable per unit meter using the LCR HP 4263A meter.

2.2. Electric arc fault

An electric arc fault is generated when a gaseous plasma cloud is present between solid conductors [31]. This kind of fault is influenced by the evaporation process, the combustion of the electrode material and the magnetic field generated by the arc current itself [32].

As series arc faults are harder to identify, we focus our interest on distance estimation in order to locate this type of fault in a power line. The opening contacts tests were carried out using copper electrodes 6 millimeters in diameter.

The data appertaining to the measured currents were registered using an experimental test bench presented in Fig. 3 composed by two 49 m parallel cables, a 47-ohm power load resistor and a source of 220V - 50Hz. The process of experimental series arc faults tests was done inserting two copper electrodes in the power line.

Recordings were made by an oscilloscope (Lecroy HDO 6104, 1GHz bandwidth) using a sample rate of 1MHz. The current was measured using a Lecroy AP015 probe (75 MHz bandwidth) at one end of the experimental line close to the source. In each experimental test which imply the current line measurement, the data was recorded for 0.5 sec.

The current registered when a series arc fault is produced in the experimental test bench is intrinsically related to real parameters of the line and therefore can be perfectly inserted in the indoor power line model presented in Fig. 1.

3. Development of an algorithm for series arc fault location using impedance parameters and a neural network

Fig 4 presents a scheme of the proposed algorithm to estimate the distance of an arcing fault.

The fault location method is based on the generation of different signatures obtained from a series arc fault inserted at particular points across the line. The process to generate signatures uses the Kirchhoff equations from an approach

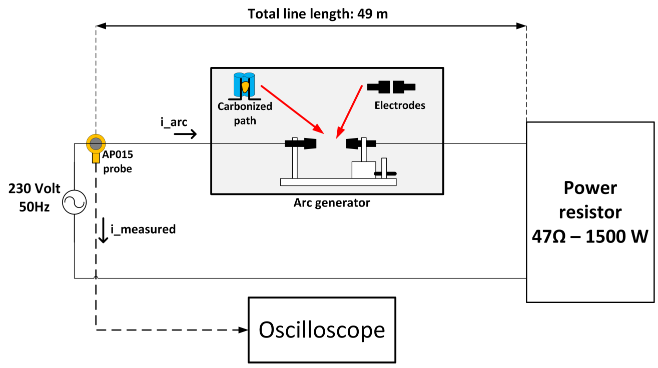

Figure 3: Experimental test bench.

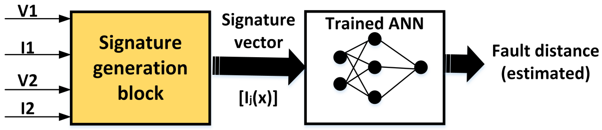

Figure 4: Proposed algorithm for fault distance estimation.

model with $Z_p = G//C$. This begins with the registration of currents and voltages at two ends of the indoor power line (Fig. 1) which are substituted in Kirchhoff equations 1, 2, 3 and 4:

$$V_1'(f) = V_1(f) - (R * x + j * w * L * x) * I_1(f) \tag{1}$$

$$I_1'(f) = I_1(f) - V_1'(f) * (j * w * Z_p * x) \tag{2}$$

$$V_2'(f) = V_2(f) + (R * y + j * w * L * y) * I_2(f) \tag{3}$$

$$I_2'(f) = I_2(f) + V_2'(f) * j * w * Z_p * y \tag{4}$$

Different steps used by the signature generation block presented in Fig. 5 are followed in order to obtain a signature vector [I(x)] associated with a fault distance.

signature vectors are used then to train a neural network. A trained neural network will be validated performing different fault distances estimation for not trained points.

In the learning process, the neural network uses the signature vectors as inputs and the real fault distances linked to each signature as outputs.

4. Results and performance

The validation step considers trained and non-trained points. Neural networks are evaluated by estimating distances of series arc faults whose dynamic characteristics were not included in the learning process. The evaluation of the performance is carried out by employing signature vectors obtained from different experimental tests.

Fig. 6 presents the results of fault distances estimations of a neural network trained with signature vectors using a series arc fault dynamic from an opening contacts test (data12), which is considered as the reference.

The estimated errors do not behave linearly with respect to the real fault distances. For real fault distances below 30 m, the errors estimated by the neural network are in the interval from 0 to 10% (data6 to data11). The same interval of errors is obtained for data13 but for all fault distances across the power line. Thus, the performance of the algorithm is affected by the dynamic of a series arc fault.

5. Conclusion and future works

This paper has presented a method for series arc fault distance estimation in a power line of short length (49 m). The algorithm works reliably, giving accurate estimations of fault distances for series arc faults located at positions where the neural network was not trained.

Additionally, the algorithm was tested using various data collected from experimental series arc faults tests (not considered in the learning process) which maintain a similar kind of dynamic characteristic. In this context, the algorithm is capable of approaching real fault distances. The presence of errors in the distance estimation is mainly related to the dynamic variations of different series arc faults (random and stochastic impedance behavior).

The proposed method for series arc fault detection keeps a simple and soft computing structure which could be implemented in an FPGA platform.

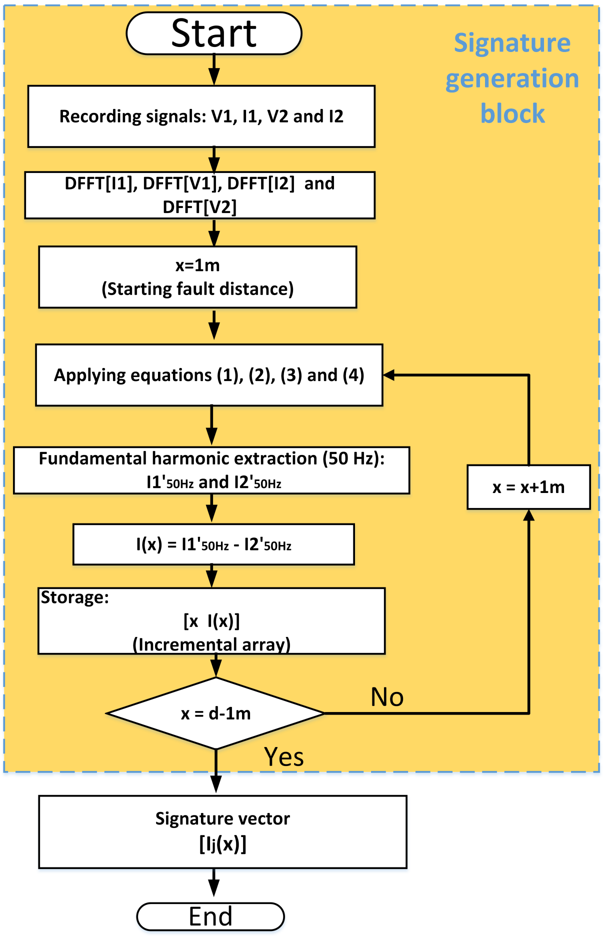

Figure 5: Signature generation block.

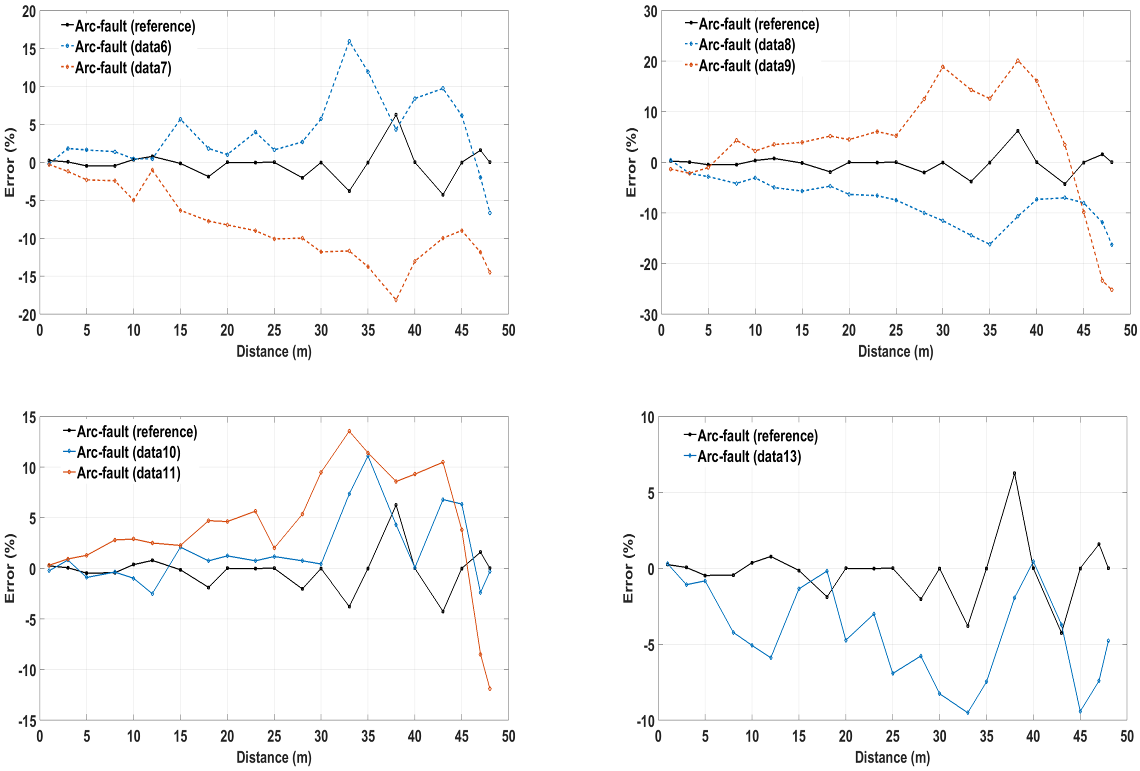

Figure 6: Fault estimation results (data12 used for training).

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