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Fault Location Method Based on Travelling Wave Theory; Case Study in a 20 kV Distribution Network

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Abstract: In this paper proposes a new fault location method based on travelling wave theory and electric system behaviour in time domain. Furthermore, the development of a new protection device where it is implemented is presented. The performance of the proposed method has been evaluated in a 20 kV distribution network modelled in PSCAD/EMTDC. Results from simulations are presented, varying ground resistivity, fault resistance, fault type and the location of the fault; furthermore, harmonic distortion has been considered in the distribution network model.

Keyword: fault location, travelling wave theory, distribution network

INTRODUCTION

In conventional distribution networks, the usual ongoing procedure to locate faults depends on the work of a maintenance crew that moves to the affected area in order to inspect, locate and isolate the faulted section, prior notice of the system operator. In automated or remotely controlled networks, a semiautomatic opening process is applied to isolate the faulted line section. With this procedure, the time of service restoration typically involves several minutes, even hours, depending on the length of the distribution network. Thus, knowing the location of the fault is essential to reduce outage times. Supply continuity is one of the main concepts in power quality and it is measured by the number and duration of interruptions in electrical power systems. Therefore, the enhancement of supply restoration processes after faults is one of the main objectives pursued by DSOs. The key point to achieve this is a fast and accurate fault location.

The main drawback of impedance-based methods is that parameters such as fault resistance and prefault power flow introduce important errors in fault distance estimation. In addition, because of the existence of branches and loads along the distribution feeders, impedance-based algorithms estimate several possible faulty points at the same distance. Nevertheless, these methods are especially attractive because of their simplicity and low implementation cost [3]. Several fault location methods have been proposed and developed in the literature and they can be classified as impedance-based methods [1]-[3], travelling waves and Wavelet transform methods [4]-[6] and knowledge-based methods such as artificial intelligence techniques [7] and statistical analysis [8]. In addition, other authors suggest hybrid methods that combine two or more of these methods [9]-[11]. However, such methods present different problems, briefly described below.

Knowledge-based methods have a low implementation cost. The disadvantages are that they need an accurate and costly training method to consider all possible fault situations and topologies in the distribution network and that the algorithm response absolutely depends on the network topology and the generation/demand scenario, which can vary in unpredictable ways. None of the aforementioned methods achieves a successful solution. Moreover, the expected distributed generation penetration jeopardises even

more their success. Thus, in this paper a new fault location method based on travelling wave theory and electric system behaviour in time domain is presented as well as the development of a new protection device where it is implemented. Travelling waves and Wavelet transform methods provide a high precision in fault location. However, they need a high sampling frequency and time synchronization by means of GPS (Global Positioning System), so their implementation is more expensive than impedance-based methods, being actually unaffordable.

The performance of the proposed method has been evaluated in an underground 20 kV distribution network modelled in PSCAD/EMTDC by varying location, fault type, fault resistance and ground resistivity and considering harmonic distortion. Also, laboratory and field tests have been carried out.

TRAVELLING WAVE

Travelling waves and Wavelet transform methods provide a high precision in fault location. However, they need a high sampling frequency and time synchronization by means of GPS (Global Positioning System), so their implementation is more expensive than impedance-based methods, being actually unaffordable. Knowledge-based methods have a low implementation cost. The disadvantages are that they need an accurate and costly training method to consider all possible fault situations and topologies in the distribution network and that the algorithm response absolutely depends on the network topology and the generation/demand scenario, which can vary in unpredictable ways. When a waveform appears at one of the terminals of an electric line, a voltage is generated at the beginning of the line, whose propagation continues until the wave reaches a discontinuity, such as a fault, where there is an impedance change. At this moment, a wave is transmitted to the next transmission medium whereas another wave is reflected towards the origin.

Fig 1 shows the incident $u^+(x,t)$, reflected $u^-(x,t)$ and transmitted $u_t(x,t)$ waves in a discontinuity due to a change from overhead line to underground cable, and whose origin lies on the difference between the characteristic impedance of the overhead line (Z_{oL}) and that of the underground cable (Z_{oC}).

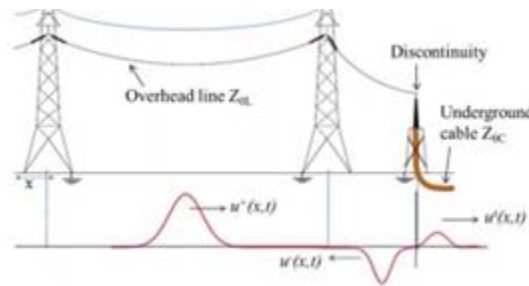


Fig. 1. Transmitted $u_t(x,t)$ waves

DESCRIPTION OF THE METHOD

The fault locator device injects continuously a series of high frequency pulses into the distribution network and records its response in order to create a base image of the system under prefault conditions. Once a fault is detected, the device injects the same high frequency pulse into the faulted electric line, which propagates through the line until it reaches the faulty point, which is a discontinuity for the pulse. At this moment, part of the pulse is reflected and returns towards the device which records the response of the distribution network. Then, the algorithm performs a comparative analysis, as shown in Fig 2, between the responses obtained in prefault conditions and during the fault in order to get the error signal between both responses

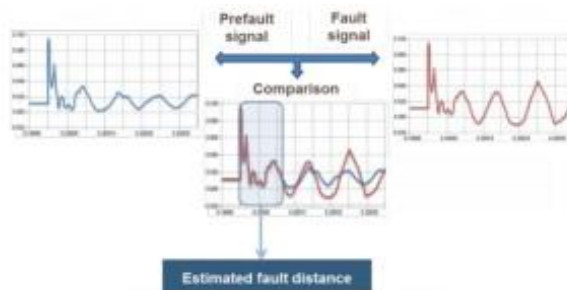


Fig. 2. Fault location distance

Where v is the electrical pulse propagation speed through the line or cable, and it depends on the relative permittivity (ϵ_r) of the medium (the insulation material in case of underground cables and the air in case of overhead lines). The high frequency pulses are injected in the distribution network through a coupling capacitor. At industrial frequency (50 or 60 Hz) the capacitor works as an insulation element between the network and the fault locator device, however, at high frequencies, it acts as a short-circuit that interconnects the fault locator device with the distribution network. The ramp-up and rampdown time of the pulse is about 100 ns and the pulse duration is 1 μ s. The continuous recording of the image of the network in prefault conditions allows getting an up-to-date image of the distribution network in every moment, and thus the localization ability is maintained even when the network undergoes permanent or temporary changes on its topology.

POWER SYSTEM MODELLED

A 20kV underground distribution network has been considered, as depicted in Fig 3, and it has been modelled in PSCAD/EMTDC. The algorithm has been evaluated by varying location, fault type, fault resistance, neutral earthing system and ground resistivity. Also, harmonic distortion has been considered in the distribution network model.

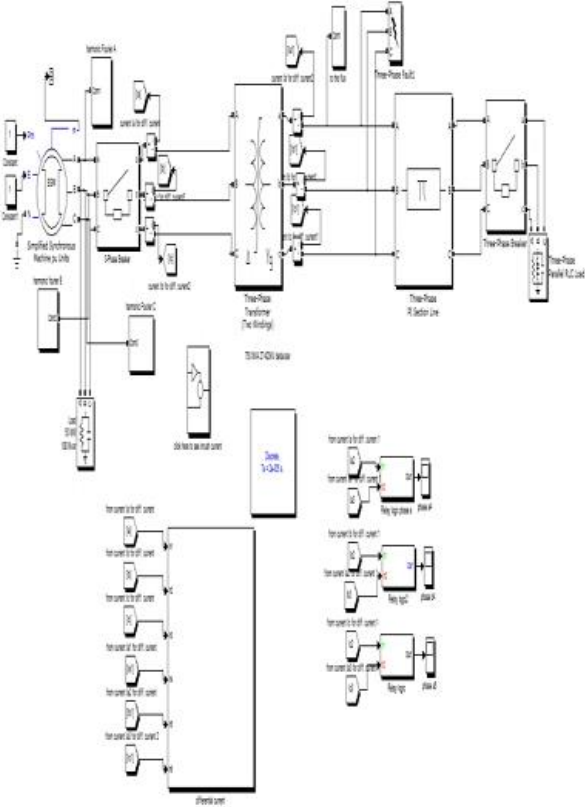


Fig. 3. Power system model

Proposed Protection Algorithm

A Flowchart of the proposed algorithm is seen in Figure 4 [21].

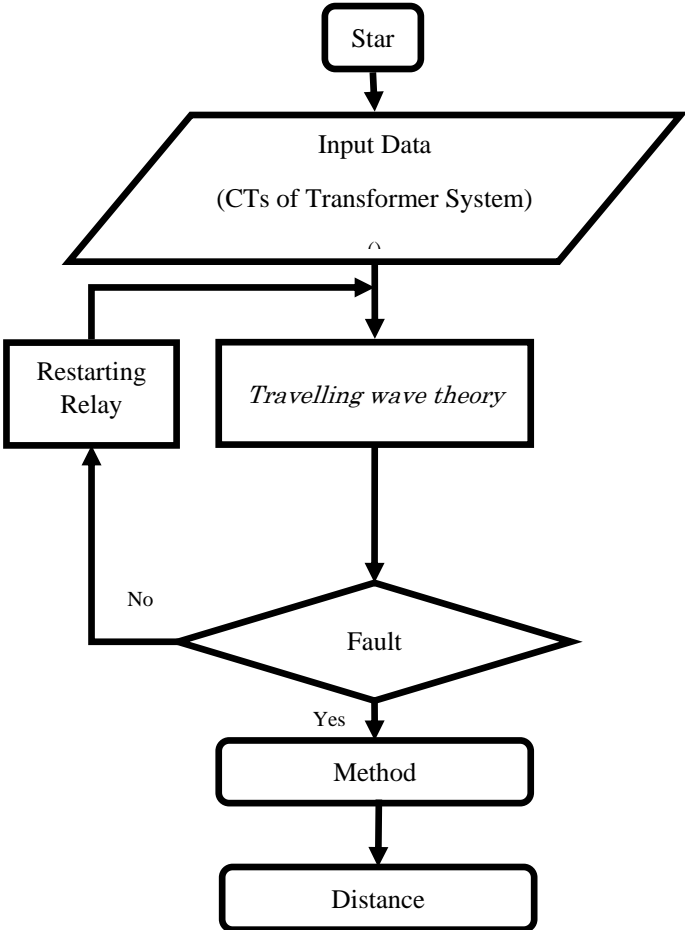


Fig. 4. A flowchart of the proposed algorithm

Results

In order to validate the proposed method and verify accurate distance estimation simulations and laboratory and field tests have been carried out. The operation of the fault locator and the influence of fault resistance on its performance is analysed below. Finally, results from simulations are shown in figure 5.

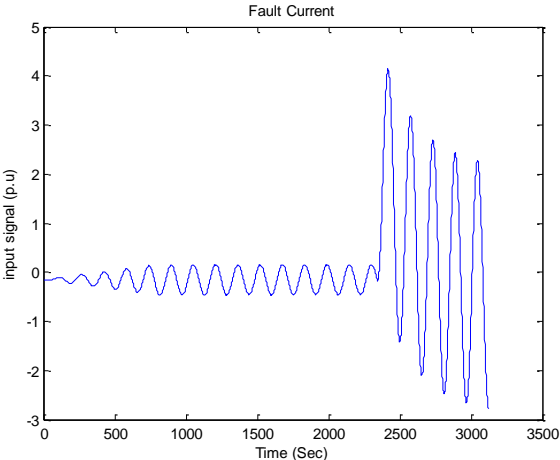


Fig. 5. Fault Current waveform for Phase A

The magnitudes of the power system are not significantly disturbed by such resistive fault, which implies a slight voltage drop of approximately 1.25% of nominal voltage and an increase of 5.4% in the faulted phase current respect prefault conditions. These measurements difficult the correct detection of the fault by any fault location algorithm. The magnitude of the error signal is less than 80% of that obtained when fault resistance is 5 Ω , even so, it provides enough resolution to detect the moment when both responses separate one from each other, so the algorithm estimates the same time difference. Therefore, fault resistance affects the magnitude of the electric system response but the proposed method provides accuracy enough in fault location. The results from the fault location estimation in the electric system modelled in case of single-line-to-ground faults considering variations in fault resistance and distance to fault. Results show the estimated fault distance by the fault locator as well as the deviation, in m, respect to the real fault location.

CONCLUSIONS

A new fault location method and its implementation in a new protection device are presented. The fault locator device records continuously the response of the distribution network to a series of high frequency pulses in order to create a base image of the system under prefault conditions. Once the fault is detected, the algorithm estimates the fault distance by performing a comparative analysis between both prefault and fault responses. The fault location results obtained, varying fault distance, fault resistance and fault type show the independence of the proposed method with the current magnitude, grounding system and ground resistivity.

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