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# Location of faults in power distribution laterals using superimposed components and programmable logic controllers

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ABSTRACT

In this study, a digital fault location and monitoring technique using programmable logic controller (PLC) for primary overhead power distribution networks is presented. This technique employs pre- and post-fault current and voltage information along with data from the laterals. By using lateral current data transferred through shielded coaxial cables to the substation, the possibility of multiple fault point locations are eliminated. The effectiveness of this method is verified through Electromagnetic Transients Program (EMTP) simulations.



## 1. Introduction

Overhead radial distribution lines are simple, very low cost and therefore the most common form of lines that are used in distribution systems. Radial distribution systems branch into various primary laterals. A fault occurrence at any location on a radial distribution system causes a power outage for every consumer on the system unless the fault can be isolated from the source by a disconnecting device such as a fuse, sectionaliser, recloser or circuit breaker [1,2]. The present practice to locate a fault is such that on the occurrence of a fault, each feeder is opened and closed in turn until the faulty circuit is identified. Sectionalising then takes place on the feeder until the fault is located. During this process, the supply to the consumers may be interrupted. Hence there is a requisite for power companies to employ accurate fault locators at substations; this would cut down inspection and service restoration times, minimise outage times and provide a high quality of supply to customers.

Many researchers have developed digital fault location techniques with a major emphasis on transmission lines and relatively less work has been done in distribution lines [3–10]. The fault location algorithms developed for transmission lines are not suitable for distribution networks due to significant differences in physical structures and dimensions between the two systems [11]. The technique developed in [12] requires a communication medium and fault recorded data from all ends of the transmission system need to be synchronised. In this technique by matching the voltage or current phasors obtained by recording devices with those generated in the corresponding simulation studies, the fault is located in an iterative way. Although the approach offers very accurate results, it is not tested for an overhead distribution system. More recently global positioning system (GPS) of satellites for performing data sampling to locate the shunt faults in transmission networks was presented in [13]. Although very accurate results are obtained by this technique, the initial and operational costs are very high.

In the technique reported in references [14,15] to locate shunt faults in power distribution systems, the high frequency (HF) signals which generated under arcing faults are utilised. In this approach, by using line traps and stack tuners any high frequency components over a specific band of frequencies are confined to the protected line and the direction of the fault is found. However, directional fault locators can be useful in inter-meshed distribution networks, but in longer radial distribution lines, the initial costs would be prohibitively high. In [16] a review of impedance-based fault location methods using single point measures available in the literature for radial distribution systems is presented. More recently, some other impedance-based approaches have been proposed for overhead three-phase radial distribution lines with single-ended measurements [17–19]. However, all these have either limited application or they suffer from an increase in inaccuracy due to the combined effect of the load current and fault resistance, inaccurate fault type, load flow unbalance, line loading and the presence of distributed generation (DG) units. Moreover, fault location algorithms based on apparent impedance, may experience difficulty in distinguishing a fault location between a fault on a lateral or the main line [11,16]. The application of artificial intelligence approach on fault location schemes, as Wavelets and

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neuro-fuzzy systems, has also been recently considered [20]. The usage of neural networks, however, needs a specific learning process to each analyzed feeder.

In this study, an alternative approach to accurately locating faults on overhead radial distribution laterals is described. The underlying principles of the presented technique are essentially the same as those developed for the faults on overhead distribution feeders [21] except the algorithm used has been significantly modified to deal with the faults on laterals. In the algorithm, the fault current data transmitted by the PLCs and the data recorded at the local end are processed in off-line mode to locate the shunt faults on the main feeder or in the laterals. The fault location algorithm is based on utilising the fault voltage and current samples as obtained at a single location of a typical radial distribution system. Using the superimposed voltage and current components [21,22] and employing PLCs, the shunt faults in the main feeder or laterals are accurately diagnosed. The required data such as line, load and source parameters and physical network configuration at the time a fault occurs is obtained from a database.

Based on simulating practically encountered faults on a typical 11 kV distribution system, the results obtained clearly show that the fault location technique in this paper is highly accurate. In particular, it is shown that the accuracy of the proposed algorithm is little affected by the presence of laterals and the associated loads, and also in the presence of small-scale DG units connected at the remote end of the network. The latter has a particular importance regarding the fact that the future distribution networks will increasingly become active (i.e. bi-directional power flow) due to the penetration of the renewable energy-based generation systems.

## 2. Fault location algorithm

Fig. 1 shows an overhead primary power distribution network with embedded generation (if present) at end $Q$. As seen from the Fig. 1 each lateral is equipped with a PLC and current sensor by the tap point for load current monitoring. The sub-feeder phase currents are converted to ASCII string and transmitted to the PC at the substation by the PLC using existing utility communication channels or leased telephone lines.

In the fault location algorithm, current and voltage samples are continuously monitored at the locator end (end $P$ in Fig. 1) by the digital fault recorder DFR and upon the inception of a fault, a predefined number of voltage and current samples are captured which contain both pre-fault and post-fault information. In the execution of the fault location program, filtered pre- and post-fault voltage and current phasors are obtained through the employment of discrete Fourier transform (DFT) [23]. Meanwhile the necessary parameters relating to a particular distribution system such as length of the feeder and laterals, distance between the load taps, and load and source information are obtained from a database; this data is then used to set up the distribution system model on a computer.

In order to facilitate and expedite the actual location of a fault, the implementation of the fault location algorithm is fully automated; this involves scanning of overhead distribution system main feeder or faulted lateral at 10 m intervals, initially assuming a fault position at end $P$ or at the tap point of the sub-feeder according to the current information transmitted by the PLCs. Upon the detection of a fault in a sub-feeder, the pre- and post-fault voltage and current data already captured by the DFR are updated to the tap of the prospective feeder for fault location analysis. The fault path currents obtained for each assumed fault position are then written into an output file for further inspection. The data is then interrogated automatically in order to ascertain the minimum values of the fault path currents; the point at which this occurs is then the actual fault position as predicted by the fault locator algorithm.

In the presence of a remote source connected to the distribution system, during the fault, it is disconnected from the system instantly and in post-fault analysis the system is considered as radial.

### 2.1. The theory of superimposed components as applied to a plain feeder

A fault occurring on a distribution line can be considered as superimposing an equal and opposite voltage to the fault point [21,22]. The post-fault voltage and current components $V_{post}$ and $I_{post}$ can thus be considered as the sum of pre-fault and superimposed voltage and current components and are given at the fault point as:

$$V_{post} = V_{pre} + \Delta V_f \tag{1}$$

$$I_{post} = I_{pre} + \Delta I_f \tag{2}$$

The superimposed values $\Delta V_f$ and $\Delta I_f$ are simply the difference between the pre- and post-fault steady-state voltage/current signals. The superimposed voltage is then back injected into the feeder at the assumed fault point to check currents in the healthy phases. Only when the fault point is correct do the sound phase(s) injected currents at the fault point attain a zero value. A very simple example involving a plain feeder with no taps is shown in Fig. 2.

In the simplified faulted distribution system model shown in Fig. 2, $I'_{S_{a,b,c}}$ shows the superimposed current phasor at the measuring end $P$ (which are simply the difference between the measured post-fault and pre-fault values) and $I'_{R_{a,b,c}}$ represents the superimposed currents fed into the fault from end $Q$ (these are also the superimposed currents fed into the fault from end $Q$), $L$ is the total length of the line. The superimposed fault path current phasors at the assumed fault point 'β' are given by:

$$[I'_{F_{a,b,c}}] = [I'_{S_{a,b,c}}] + [I'_{R_{a,b,c}}] \tag{3}$$

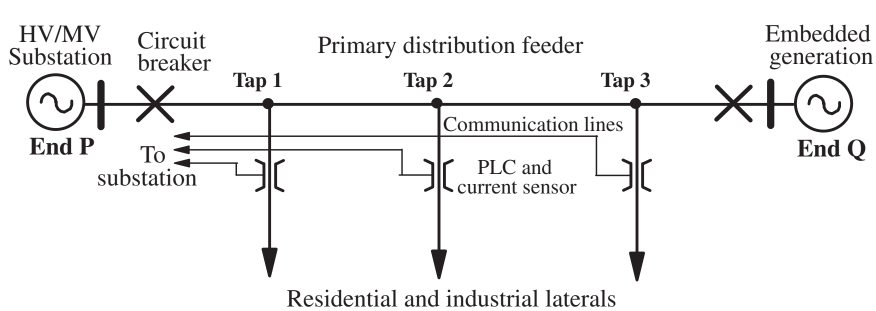


**Fig. 1.** Distribution system with laterals and embedded generation.