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Review of methodologies for earth fault indication and location in compensated and unearthed MV distribution networks

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ABSTRACT

Feeder automation is one of the key features of Smart Grids aiming at developing self-healing systems, able to locate the fault and automatically perform the isolation and supply restoration. Reliable fault indication and location is a prerequisite for this functionality. This paper reviews the state of the art technologies and techniques for determining single-phase earth fault location on MV distribution networks. Accurate information about the faulted line or cable section expedites system restoration following the fault occurrence. This paper presents a review of the principles of fault location and indication techniques and their application considerations. In order to gain further insight into the strengths and limitations of each method, a comparative analysis is carried out. Finally, the paper identifies further research and presents the selected promising approaches.

Contents

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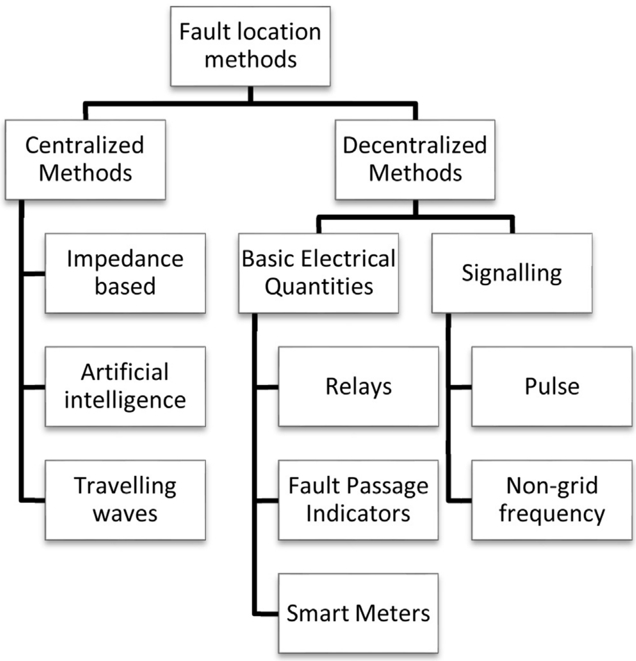

Fig. 1. Classification of earth-fault location methods.

1. Introduction

As the society is increasingly dependent on electricity, higher reliability of power supply is required. Fault distance estimation enables faster fault isolation and restoration of power supply. The ultimate goal is to develop a fully automatic, self-healing system. However, before the switching required by the FLIR (fault location, isolation and restoration) functionality can be automatic, fault indication should be very reliable, and safety issues must be examined. In any case, the information on the fault location must be delivered to the control room. In the control room, the SCADA (supervisory control and data acquisition) system or DMS (distribution management system) processes the information to illustrate the fault location to the operator or to generate an automatic FLIR switching sequence.

For short-circuit faults, there are established methods for fault location. However, there is not a universally accepted, reliable, cost-effective method for earth-fault location on the market for isolated neutral or compensated networks. In this paper, the state-of-the-art methods for determining earth fault location on MV distribution networks are discussed. The topic is very relevant since the most common type of fault is the single-phase-to-earth fault (in the Nordic countries about 50–90% of faults) [1]. The aim is to classify and compare different approaches and particularly to find the most promising approaches either for practical implementation or for further development.

1.1. Classification of fault location methods

A number of earth-fault location methods have been proposed. They can be categorized according to Fig. 1, where the main division is made between centralized and decentralized methods. In centralized methods, the measurements are carried out at the primary substation. In decentralized methods, measurements along the feeders together with suitable communication are utilized. In this paper, various methods are reviewed utilizing this classification.

Based on the above figure, fault location methods are outlined in Sections 2 and 3. In order to gain further insight into the strengths and limitations of each method, a comparative analysis is carried out in Section 4. Finally, the paper identifies further research and presents the promising approaches in Section 5.

2. Centralized earth-fault location methods

2.1. Impedance based methods

These methods are based on measuring the apparent impedance seen looking into the line from either end when a fault occurs. As the line length from the measuring point to the fault location is proportional to the measured impedance, by knowing the line impedance per unit length, the fault distance is obtained.

Accurate location of earth faults in compensated and unearthed networks is a more challenging task as the fault current in those types of networks is often small compared to load currents. In general, perhaps one of the main challenges in fault locating is the fault impedance as it is unknown. Attempts have been made to address the problem [2–5]. Ref. [6] tests a number of impedance methods under same conditions and draw comparisons between them.

In this section, the impedance-based fault locating methods based on fundamental frequency (grid-frequency) phasors are discussed as they have become an industry standard in modern microprocessor-based protective relays.

In practice, numerous methods have been put forward to locate faults on distribution networks using current and voltage phasors. These methods are designed based on the grounding principles of the network, namely:

- Solidly grounded
- Unearthed networks
- Compensated networks
- Resistance grounded

In this section, only unearthed and compensated networks are discussed because fault location is more challenging in those types of networks.

2.1.1. Unearthed networks

In traditional impedance-based fault location [7], the reactance of the line following a fault occurrence is computed and compared to the line reactance measured before the fault occurrence so that the fault distance is estimated. Sometimes, for simplicity, the fault resistance is assumed to be zero. However, that might result in a substantial error especially in overhead lines where the fault resistance is often not zero. Ref. [8] advances the traditional impedance-based method by making assumptions about the fault resistance and the distribution of load current along the feeder. The results show that the method is limited to low impedance faults up to 30 Ω and it is not widely applied in practice.

Another algorithm is presented in Ref. [9]. The analysis relies on the symmetrical components theory. In this method, the whole load of the feeder is modelled as one equivalent load tap located at a certain distance from the substation (in per unit) where the voltage drop due to an earth fault is at a maximum. The soundness of this method is validated by field tests. The method works in faults with low fault resistances.

2.1.2. Compensated networks

The fault location algorithm presented in Ref. [8] determines the reactance from the substation to the fault location by measuring the changes in the zero sequence current and the faulty phase voltage caused by switching the shunt resistor in parallel with the suppression coil during the fault. Subsequently, by knowing the sequence reactance per kilometer of the line, the distance