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Fault location and detection techniques in power distribution systems with distributed generation: A review

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ABSTRACT

Distribution systems are continuously exposed to fault occurrences due to various reasons, such as lightning strike, failure of power system components due to aging of equipment and human errors. These phenomena affect the system reliability and results in expensive repairs, lost of productivity and power loss to customers. Since fault is unpredictable, a fast fault location and isolation is required to minimize the impact of fault in distribution systems. Therefore, many methods have been developed since the past to locate and detect faults in distribution systems with distributed generation. The methods can be divided into two categories, conventional and artificial intelligence techniques. Conventional techniques include travelling wave method and impedance based method while artificial intelligence techniques include Artificial Neural Network (ANN), Support Vector Machine (SVM), Fuzzy Logic, Genetic Algorithm (GA) and matching approach. However, fault location using intelligent methods are challenging since they require training data for processing and are time consuming. In this paper, most of the techniques that have been developed since the past and commonly used to locate and detect faults in distribution systems with distributed generation are reviewed. Research works in fault location area, the working principles, advantages and disadvantages of past works related to each fault location technique are highlighted in this paper. Hence, from this review, the opportunities in fault location research area in power distribution system can be explored further.

1. Introduction

Fault in a distribution system is an unpermitted deviation from its standard operating conditions. It may be caused due to various reasons, such as physical contact between lines that creates a short circuit path, momentary contact of animals or birds, or contact due to wind and trees. Some faults exist for a short period of time and return to normal operating state. They are called temporary faults. Another type of fault is permanent fault, which will remain until the short circuit is identified and removed. If temporary faults are not cleared, eventually they will change into permanent faults sooner or later. Some of the reasons for permanent faults are cable insulation failure due to improper maintenance, objects falling on overhead lines and lines falling on earth.

There are four main types of fault which can occur in distribution systems; they are single line to ground fault (SLGF), double line to ground fault (DLGF), line to line fault (LLF) and three-phase to ground fault (LLLGF). Single line to ground fault occurs when one of the three phase conductors of a distribution system is touching ground due to wind, animal contact or a line falling on the ground. SLGF occurs at the rate of 70% in distribution systems [1]. Line to line fault occurs when high wind causes one phase to touch another phase while 15% of fault in distribution system is due to line to line fault [1]. In DLGF, two phases will be involved instead of one phase as in SLGF scenario, where 10% of fault in distribution systems is due to double line to ground fault [1]. Three-phase to ground fault may be caused by equipment failure, tower falling on ground or a conductor touching the other phases. In general, this type of fault is not common and least frequent at the rate of 5% in distribution systems [1]. Even though the fault is not common, the occurrence of LLLGF is dangerous with very large fault current. Hence, in order to prevent damage to equipment and loss to customer, faults have to be spotted quickly.

From a survey in [2], it was found that more than 80% of the interruptions in distribution systems are caused by faults. When a fault happens at the feeder laterals or at any location along the feeder, a circuit breaker at the main feeder will disconnect the source from the main feeder. Hence, customers connected along the main feeder will experience a power outage. This power outage degrades the quality of power supply. The average cost for an outage duration of 1 h was USD3 for residential customers, USD1200 for commercial and USD82000 for

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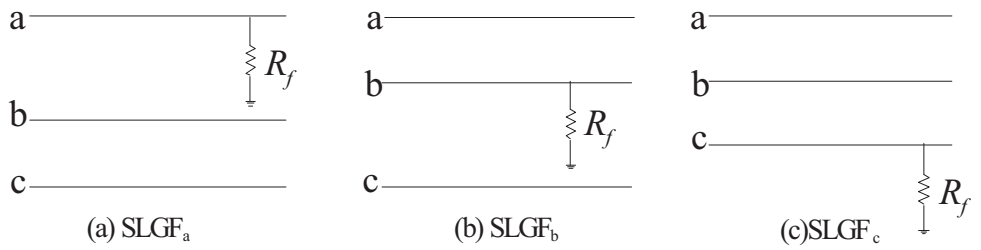

Fig. 1. (a) Single line to ground fault at phase a (SLGF$_a$), (b) single line to ground fault at phase b (SLGF$_b$) and (c) single line to ground fault at phase c (SLGF$_c$).

large industrial customers [3]. Hence, it is very important for the utility to identify the fault as quickly as possible to minimize the impact of fault, power outage and interruption time.

The information about fault in a distribution system can be obtained at the operation centre using protective device operation or using end user information. Since the past, power utilities have been practicing conventional techniques for fault identification. The most common conventional technique is based on visual inspection and trial-and-error switching. For a small area, foot patrol is practiced to search the possible fault location while for a larger scale area, automobile or helicopter is commonly used. This approach of fault location through visual inspection is suitable for overhead lines. However, for underground cables, the fault line is not noticeable. Also, trial and error method is a manual process of switching the relay to on/off condition until the circuit breaker trips. It depends on the network operator's fault finding experience to locate the faulted section. However, this process is time consuming and on long run will damage the performance of cables. Due to these problems, various fault location methods have been introduced for the purpose of expediting the process of locating faults.

In this paper, most of the techniques developed since the past and commonly used to locate and detect faults in distribution systems with distributed generation are reviewed. The working principles, advantages, disadvantages and review of past works related to each technique are described and compared. Hence, from this review, the opportunities in fault location research area in power distribution system can be explored further.

This paper consists of five sections. Section 1 covers the introduction of fault and its types in distribution system. Section 2 describes the types of fault commonly encountered in power distribution systems. Section 3 presents review on the existing conventional fault location techniques, which include travelling wave based and impedance based methods. The working principles of each method with its advantages and limitations are discussed. Section 4 describes some of the existing artificial intelligence techniques in fault location in distribution systems. The advantages, disadvantages and review of past works related to each technique are described and compared. Finally, Section 5 summarises the techniques of fault location and detection methods that have been developed to date.

2. Types of fault

There are two types of fault which are usually encountered in distribution systems, namely balanced faults and unbalanced faults, also known as symmetrical and asymmetrical faults respectively. Many faults that occur in power systems are unbalanced faults. Faults can also be categorised as series and shunt faults [4].

2.1. Series fault

Series fault occurs when unbalanced series impedance presents on a line. It represents an open conductor. Series fault occurs when a power system network has a broken line or impedance in one or more than one lines. Series faults are categorised by using frequency and its voltage rise and current reduction at the faulty phases.

2.2. Shunt fault

Distribution systems generally experience shunt fault. Phase-overcurrent relays and ground-overcurrent relays are commonly used for detecting and isolating the faulted circuit in a distribution system. The important characteristic of shunt fault is the increment in the current and fall in voltage and frequency. For a three phase line, shunt faults are classified as single line to ground fault (SLGF), double line to ground fault (DLGF), line to line fault (LLF) and three-phase to ground faults (LLLGF).

2.2.1. Single line to ground fault (SLGF)

Single line to ground fault (SLGF) is also known as short circuit fault. It occurs when one phase of transmission line makes contact with ground or neutral wire. Some of the reasons for SLGF are wind, falling trees or any other incident. Three types of SLGF are shown in Fig. 1 where a–c represent the phases and R_f represents fault resistance. 70% of faults in network are classified under this category.

2.2.2. Line to line fault (LLF)

Line to line fault occurs due to high winds or when two conductors are short circuited. It may occur at overhead or underground transmission systems. Fig. 2 represents line to line fault on three phase line conductors. One of the characteristics of LLF is the magnitude of fault impedance may vary over a wide range, resulting it difficult to predict its lower and upper and limit. 15% of faults in network are considered as line to line fault.

2.2.3. Double line to ground fault (DLGF)

Double line to ground fault will occur when a falling tree connects

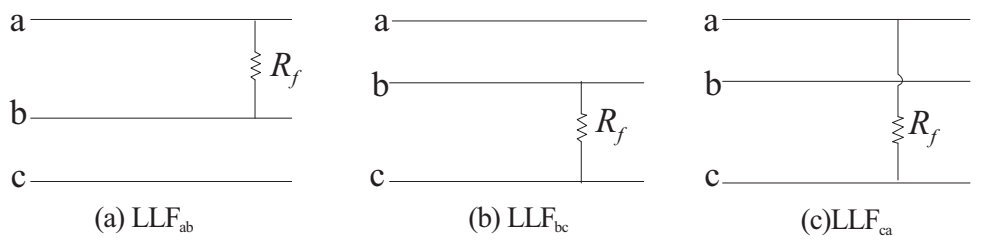

Fig. 2. (a) Line to line fault at phase a and b (LLF$_{ab}$), (b) line to line fault at phase b and c (LLF$_{bc}$) and (c) line to line fault at phase c and a (LLF$_{ca}$).