Electric Power Systems Research 145 (2017) 19–34

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A comparison framework for distribution system outage and fault location methods

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ARTICLE INFO

Article history:
Received 27 April 2016
Received in revised form 2 September 2016
Accepted 17 December 2016
Available online 28 December 2016

Keywords:
Distribution networks
Distributed generation
Fault location
Outage location
Outage management

ABSTRACT

Finding the location of faults in distribution networks has been a long standing problem for utility operators, and an interesting subject for researchers as well. In recent years, significant research efforts have been devoted to the development of methods for identification of the faulted area to assist utility operators in expediting service restoration, and consequently reducing outage time and relevant costs. Considering today's wide variety of distribution systems, a solution preferred for a specific system might be impractical for another one. This paper provides a comparison framework which classifies and reviews a relatively large number of different fault location and outage area location methods to serve as a guide to power system engineers and researchers to choose the best option based on their existing system and requirements. It also supports investigations on the challenging and unsolved problems to realize the fields of future studies and improvements. For each class of methods, a short description of the main idea and methodology is presented. Then, all the methods are discussed in detail presenting the key points, advantages, limitations, and requirements.

Contents

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http://dx.doi.org/10.1016/j.epsr.2016.12.018

1. Introduction

As the final stage of the delivery of electric power, European distribution companies supply 260 million customers of which 99% are residential customers and small businesses [1]. In contrast to their transmission counterparts, distribution networks are made up of branches and tapped laterals delivering electricity to the ultimate point of consumption. Dispersing over vast rural and urban areas, these branched networks are vulnerable to different types of faults initiated by different sources such as adverse weather conditions, bird contacts, vegetation growth and equipment failure [2]. Considering the fact that approximately 80% of all customer interruptions occur due to distribution faults [3], it is essential for every distribution system to efficiently manage the faults, and maintain the quality of service through minimizing the outage time.

These days, the quality of service has emerged as an important issue for residential, commercial and industrial customers, as many functions of modern society depend on electricity. The number and duration of interruptions in European networks are generally low, ranging from about 15 min to 400 min per customer per year [1]; however, a higher performance is both possible and needed. Finding the most affordable and efficient way to enhance the performance of distribution systems is a major concern, and electricity regulators have made considerable efforts to address the issue.

The performance of a network primarily depends on how it is designed and how it performs when a fault occurs. To improve its performance we can either use underground cables instead of overhead lines or replace bare conductors with insulated conductors. We can, moreover, reduce the fault rate by preventative maintenance such as tree trimming or improve network performance following a fault by adding automatic in-line protection and continuous alternative supply. However, in this manner, the improvement to a service quality level is costly. An alternative more cost saving solution would be exploiting better fault management schemes to minimize the outage times.

In a conventional outage management system, upon the occurrence of a fault and subsequent operation of the protection system, outage mapping is carried out. This is traditionally based on activities such as grouping of customer outage calls to determine the protective devices involved in fault clearing in order to find the outage area. Then, a repair crew has to be sent to patrol the area and walk along the power distribution lines, which can be kilometers, in order to find fault evidence and to ensure safety prior to re-energizing the system. The whole restoration process may take from tens of minutes to hours. In contrast, better measurement and switching infrastructure in today's distribution networks provides the possibility of enhanced fault management schemes [4]. In these systems, having a good estimation of the faulted area narrows down the search space and minimizes the required effort and patrolling time to find the fault. Moreover, it provides the possibility of fast service restoration for the interrupted customers connected to the healthy sections. Therefore, considerable studies have been devoted to the development of methods to locate the faulted area and consequently reduce the average outage time and improve the quality of supply.

There are different distribution system operators (more than 2400 companies in case of Europe [1]) having different policies and development philosophies. Accordingly, there are a wide variety of distribution systems in use today, and a method which is the preferred solution for a specific system might be impractical for another one. This article classifies, compares and reviews a relatively large number of works devoted to the fault and outage area location subject [5–73], and aims to serve as a guide to power system engineers and researchers. The requirements, advantages, and limitations of different methods are presented and compared to help power system engineers, and researchers to select the most appropriate method based on their distribution system and requirements.

In Section 2, we classify different algorithms based on their outputs and required inputs. Section 3 reviews and compares different outage area location methods, while fault location methods are discussed in Section 4 where the details of different classes are presented in different subsections. Section 4 presents the future trends and conclusions are given in the last sections.

2. Classification of outage and fault location algorithms

When a short circuit fault occurs, protective devices automatically isolate the faulted area from the rest of the electrical network. However, it is usually hard to realize the interrupted portions of the network and the faulted components. Several studies have been carried out on the subject. As illustrated in Fig. 1, the proposed methods can be considered as algorithms which employ the available inputs (i.e., data, measurements) to make an estimation of the output which is the affected area. In terms of their outputs, the studies can be categorized into two main groups. The first group, known as outage area location methods, includes techniques using various available data sources such as customer outage calls or fault indicator signals to estimate the most likely interrupted area [5–16]. The second group of methods utilizes data and measurements to locate the fault which caused the resulting outage [17–73]. Sometimes, outage area location is performed prior to fault location to improve its accuracy.

As shown in Fig. 1, the inputs can be classified into four groups. The non-electrical data comprises customer calls complaining about the outages, experts' knowledge, historical data about the previously experienced events, and weather data such as typhoon information and satellite images. On the other hand, electrical data includes smart meters "last gasp" messages notifying an outage occurrence, data gathered by supervisory control and data acquisition (SCADA) system such as switches status, fault indication signals, and fault evidence. Network data encompass estimated or measured values of distribution system loads, the type of the overhead or underground conductors in terms of their impedance and capacitance, the length of lines, network topology, and installed devices such as protection components.

In traditional distribution systems, substation voltage and current are the only available measurements mostly having a sampling frequency of 0.4–6.4 kHz. However, implementation of some fault location methods, such as traveling waves-based methods, requires measurements with more than 100 kHz sampling rates. Considering the recent advances in metering and communication systems, it is now possible to collect the sparse values measured by instruments such as power quality meters and digital fault recorders installed throughout the network. Moreover, it is possible to synchronize the measured values using the Global Positioning System (GPS) or computer networks. For each distribution system, a certain set of inputs can be provided giving a qualitative criterion for selecting an appropriate method. For example, in modern distribution networks with advanced measurement and communication infrastructure, methods that have the ability to use the emerging equipment to provide better results in terms of accuracy and reliability, would be the preferred solutions; while the same methods would be impractical for traditional systems. Therefore, the required input data is an important criterion which differentiates fault and outage area location methods and determines their practicality for a certain distribution network.

Hereinafter, different fault and outage area location methods are classified based on their inputs and their main idea. A number of proposed methods in each class are reviewed, and for each work, the key points, pros, and cons are presented to support power