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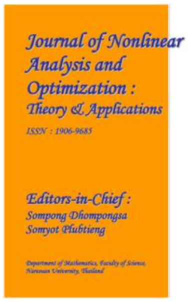

FAULT LOCATION IN RADIAL DISTRIBUTION SYSTEMS BASED ON OPTIMIZED ALLOCATION OF POWER QUALITY METERS

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ABSTRACT

One of the reasons for not achieving satisfactory indices of Power Quality (PQ) is due to the discontinuity of power supply in Distribution Systems (DS), usually caused by the occurrence of short-circuits. In this context, to characterize these occurrences, a database was compiled by simulations in the IEEE 34-bus DS using the ATP (Alternative Transients Program) software. In these simulations, the type, location and fault impedance were used as parameters. The voltages and currents of all three phases of the power quality meters optimally allocated in the DS were considered. Based on these measurements, the J48 decision tree algorithm was used to identify in which area of the 34-bus DS the single-phase faults occurred. In order to use the J48 decision tree, the WEKA (Waikato Environment for Knowledge Analysis) software was used. Promising results demonstrated the effectiveness of the proposed algorithm to locate the single-phase short-circuit situations considered.

INTRODUCTION

Power Quality (PQ) is an area of Electrical Engineering in which its scope is difficult to determine as it covers a wide range of aspects from generation to transmission and electric power distribution, as well as the end consumers of the product ”electricity”. Thus, as PQ affects all end users of the electrical system, power utilities should take into account the relationship between the system users equipment with the available voltage levels. The energy end consumers, mainly the industrial ones, should also respect the other users connected to the Distribution Systems (DS) by controlling the possible sources of disturbances associated with PQ and mitigating the problems that can arise when connecting their linear or nonlinear loads to the network [1].

As presented in [1], PQ is an important aspect for power systems, significantly affecting the operation, safety, efficiency and rehabilitation of the entire system. Among the various definitions, the term PQ has been generally used to express the quality of voltage supply according to pre-established standards. Taking this into account, PQ can be defined as the measurement, analysis and improvement of the voltage in a bus in order to keep its form close to the sine wave, with fixed amplitude and frequency. Utilities and end users agree that more than 60% of PQ problems are caused by natural and unpredictable events, such as: short-circuits, lightning, ferroresonance and geomagnetic induced currents, among others. Short-circuits are among the various causes of PQ disturbances in power systems. In this scenario, in order to reduce the damage to consumer loads, it is essential that these short-circuits are accurately and quickly located [2]. It is worth noting that, depending on the DS protection philosophy applied by many power distributors, the precise location of short-circuits is based purely on information provided by the system users and tests to delimit the area where the disturbance occurred [3].

The initial searches for fault location were aimed at the transmission lines. They were based on the apparent impedance calculations, which were defined based on the current and voltage phasors under analysis. These techniques were developed and improved after the introduction and widespread use of micro processed equipment [4]. Subsequently, techniques based on artificial intelligence were developed aiming at locating the faults as efficiently, or even more, than traditional methods.

Specifically focusing on DS, research carried out by [5] used artificial intelligence techniques for fault location. In this research, signals resulting from short-circuits were processed by using the Wavelet Transform (WT) and were then applied to Artificial Neural Networks (ANN) and Fuzzy Logic to locate faults. [6] presents an approach using ANN and Discrete Wavelet Transform (DWT) considering the fourth level of decomposition with Daubechies 4 as the mother wavelet. [7] used multi-agent systems to determine in which area of the system the faults occurred. [8] developed a methodology based on the decision tree algorithms C4.5, ID3, Gini and Chi, and also used a single measuring point in the substation of the tested system. Regarding an approach based on a previous allocation of power quality meters, [9] developed an analytical method to determine the location of fault occurrence.

Considering that faults must be quickly and accurately located, this research proposes using a J48 decision tree algorithm to locate the area and the fault occurrence zone, based on data extracted from three-phase voltage and current signals recorded by PQ meters optimally allocated in the system. Another point that this research intends to better answer is related to multiple estimations of fault location from a specific point, usually a measurement point on the electrical system of interest [10]. This multiple estimation can occur due to the various paths using the same length that can exist until the actual short-circuit position, considering the main feeder and the various lateral branches that there may be in a distribution system.

Besides this introduction, this paper is divided into three other sections. Section 2 presents the methodology adopted in this research. Section 3 presents the results and

Section 4 draws the relevant conclusions of this research.

LITERATURE REVIEW

”Power quality in power systems and electrical machines”

The term power quality represents new findings and challenges for researchers to full fill the power and energy demands of societal communities. Any researcher with vast experience in power engineering and research will encounter power quality disturbances such as transients, root mean square variation of both long and short duration, imbalance, voltage and current distortions, voltage fluctuations, frequency variations, and power factor compensation. This book will find an enhanced solution for power quality with real-time case studies from the editors and diverse authors. The book covers different areas dealing with: power quality analysis in real time analysis accompanied by practical issues, fault issues and fault monitoring in the transmission network, power quality in electric vehicles and residential buildings, fault detection using artificial intelligence, application of power electronics circuits in the power system E-STATCOM, and present/future trends in power quality. It describes topics with theoretical-based analysis with numerical solutions and hardware experimental results from real-time cases, which will help readers to select power quality as their future research or profession. Exciting results from ABB Power Grids Research, Sweden, will help readers to understand the basics and advancements of power quality industrial innovation. This book mainly focuses on the guidelines followed in the IEEE standards for the presented results and cross-verification from real-time case studies. The chapters cover significant and bottleneck challenges prevailing in modern power systems and enable readers to better understand IEEE standards 1159 -2019, 519-2014, 1547, 1346, etc. The book will be readily available as a reference for IEEE standards and enable the student community to create more interest and take up the challenges of the power quality profession.

Electric power quality is an aspect of power engineering that has been with us since the inception of power systems; however, topics in power quality have risen to the forefront since the advent of high power semiconductor switches and networking of transmission and subtransmission systems. Also, the trends in modern power engineering have been to extract the most from the existing installed power system, and this too has placed stress on issues of sinusoidal waveform fidelity, absence of high and low voltage conditions and other AC waveform distortion. A tutorial introduction to the concepts of electric power quality is presented in this paper.

“ Short circuit power based fault location algorithm in distribution networks,”

This paper presents a novel accurate fault location technique for the radial unbalanced distribution systems, based on measurement of the Short Circuit Power (S/C.P) peak values at the substation. To evaluate the gathered dataset, a Multi-Layer Feed Forward Neural Network (ML-FFNN) with the tuned parameters is designed and the locations of faults are estimated in low, medium and far distances from the source. The estimated distances are compared with the real fault locations to show the accuracy of estimations. The proposed method can work with the small scale datasets and it is capable of being implemented in distribution systems with several laterals.When a short circuit occurs in the distribution system, the distribution of electrical energy interrupts. If this occurrence takes more than a particular time, it will consider as a total outage. Electrical energy is generated in generation units and is transmitted via transmission lines, in order to feed the distribution system. This electrical energy is wasted and cannot be stored at the fault/outage time. Hence locating the fault with an acceptable accuracy and in the minimum possible time is necessary for all distribution systems.

Traditional fault location techniques have been utilized for decades in the distribution systems; such as impedance based methods , traveling wave methods and the methods which use the information of utility outage management system [1]. The speed and accuracy of fault detection in those traditional techniques are not accepted for complex distribution networks.

Nowadays, distribution systems are in the form of radial with several laterals due to the variety of load connections in different locations with the similar distances from the substation. Hence, multi-estimation of the fault location is the When a short circuit occurs in the distribution system, the distribution of electrical energy interrupts. If this occurrence takes more than a particular time, it will consider as a total outage. Electrical energy is generated in generation units and is transmitted via transmission lines, in order to feed the distribution system. This electrical energy is wasted and cannot be stored at the fault/outage time. Hence locating the fault with an acceptable accuracy and in the minimum possible time is necessary for all distribution systems. Traditional fault location techniques have been utilized for decades in the distribution systems; such as impedance based methods , traveling wave methods and the methods which use the information of utility outage management system [1]. The speed and accuracy of fault detection in those traditional techniques are not accepted for complex distribution networks. Nowadays, distribution systems are in the form of radial with several laterals due to the variety of load connections in different locations with the similar distances from the substation. Hence, multi-estimation of the fault location is the common problems between almost all aforementioned techniques. Recent studies have been tried to combine traditional methods with the Intelligent Algorithms (AI) or developing intelligent techniques to improve and speed up the detection of possible fault types in the network. In this paper, a new fault location approach is presented by utilizing the intelligent based technique. Three fault types are applied on the local distribution system and the peak values of Short Circuit Power (S/C.P) are measured at the source bus. Then using a designed Multi-Layer Feed Forward

Neural Network (ML-FFNN) the gathered dataset is evaluated in order to estimate the fault distance from the source. A local 15 bus radial unbalanced distribution system with its all component is simulated in the PSCAD software. The total power of this network is 5MVA and voltage level is 20kV. in this study it is assumed that all spots and distributed loads are fixed in the time. In addition, the resistance of all three fault types -Three Line (LLL), Line to Line (LL) and Single Line to Ground (SLG)- are set to a constant value.

"Automated fault location and diagnosis on electric power distribution feeders,"

This paper presents new techniques for locating and diagnosing faults on electric power distribution feeders. The proposed fault location and diagnosis scheme is capable of accurately identifying the location of a fault upon its occurrence, based on the integration of information available from disturbance recording devices with knowledge contained in a distribution feeder database. The developed fault location and diagnosis system can also be applied to the investigation of temporary faults that may not result in a blown fuse. The proposed fault location algorithm is based on the steady-state analysis of the faulted distribution network. To deal with the uncertainties inherent in the system modeling and the phasor estimation, the fault location algorithm has been adapted to estimate fault regions based on probabilistic modeling and analysis. Since the distribution feeder is a radial network, multiple possibilities of fault locations could be computed with measurements available only at the substation. To identify the actual fault location, a fault diagnosis algorithm has been developed to prune down and rank the possible fault locations by integrating the available pieces of evidence. Testing of the developed fault location and diagnosis system using field data has demonstrated its potential for practical use.

This paper presents a methodology for automated disturbance analysis and fault location on electric power distribution systems using a combination of modern techniques for network analysis, signal processing, and intelligent systems. New algorithms to detect, classify, and locate power-quality disturbances are developed. The continuous process of detecting these disturbances is accomplished through statistical analysis and multilevel signal analysis in the wavelet domain. The behavioral indices of the current and voltage signals are extracted by employing the discrete wavelet transform, multiresolution analysis, and the concept of signal energy. These indices are used by a number of independent Fuzzy-ARTMAP neural networks, which aim to classify the fault type and the power-quality events. The fault location is performed after the classification process. A real life three-phase distribution system with 134 nodes-13.8 kV and 7.065 MVA-was used to test the proposed algorithms, providing satisfactory results, attesting that the proposed algorithms are efficient, fast, and, above all, intelligent.

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.

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 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.

"The application of neural networks and clarke-concordia transformation in fault location on distribution power systems,"

This paper presents a new approach to fault location on distribution power lines. This approach uses an artificial neural network based learning algorithm and Clarke-Concordia transformation. The /spl alpha/,/spl beta/,0 components of line currents resulting from the Clarke-Concordia transformation are used to detect all types of fault. The neural network is trained to map the nonlinear relationship existing in fault location equations. The proposed approach is able to identify and locate all different types of faults (single line to ground, double line to ground, line-to-line and three-phase short-circuit). This approach is subdivided into several main steps: Data acquisition, corresponding on three-phase current signals; Mathematical treatment by the Clarke-Concordia transformation; Fault identification, obtained by the analysis of fault and pre-fault data; Fault location artificial neural network based learning algorithm. The fault position is presented as the output of the neural network on which, as the input, it was considered the eigenvalue of matrix representing transformed line current. Results are presented which shows the effectiveness of the proposed algorithm for a correct fault location on distribution power system networks.

The problem formulation of this thesis will depend on already existing fault location methods for crossbonded cables. Therefore, a literature study is conducted and the most important references are presented in the following chapter. Firstly, however, the mechanisms leading to faults in high voltage cables are briefly covered in order to examine which fault location methods are applicable.

"A new approach to fault location in threephase underground distribution system using combination of wavelet analysis with ann and fls,"

This paper presents the results of investigation into a new fault classification and location technique, using EMTP software. The simulated data is then analyzed using advanced signal processing technique based on wavelet analysis to extract useful information from the signals. The artificial neural network (ANN) and the fuzzy logic system (FLS) is then used to detect the type and the location of the ground high impedance, ungrounded series, ungrounded and ground shunt faults in a practical underground distribution system (UDS). The results indicate that the fault location technique has an acceptable accuracy (error < 1.5%) under the whole variety of different systems and fault conditions. Therefore, the proposed approach can have high performance for the evaluation of the fault location and classification.

The distribution system (DS) provides the infrastructure to deliver power from the substations to the loads. These systems have connection among consumers, generation and transmission systems. Typically radial in nature, the distribution system includes feeders and laterals [1]. The distribution voltages in a specific service territory are likely similar because it is easier and more cost effective to stock spare parts when the system voltages are consistent [2]. In recent years, there have been many activities in using fault generated traveling wave methods for fault location and protection [3]. The traveling wave current-based fault location scheme have been developed for permanent faults in underground low voltage DSs in which the distance to fault is determined by the time differences measured at the sending end between an incident wave and the corresponding wave reflected from the fault by Navanithan, Soraghan, Siew, Mcpherson and Gale in [4]. However, due to the limitation of the band width of the conventional CT (up to a few GHz) and VT (up to 50 kHz), the accuracy of fault location provided by such a scheme is not satisfactory for a UDS. Also there have been many activities in using power frequency (low frequency) for fault location and protection. Aggarwal, Aslan and Johns in [5] present a new technique in single-ended fault location for overhead DSs, which is based on the concept of superimposed components of voltages and currents rather than total quantities and also special filtering technique have been utilized to accurately extract the fundamental phasors from the measured fault signals. However, in such techniques which are based on power frequency signals, some useful information associated with high frequencies in transient condition is missed.

Paper [6], presents the application of calculated non-linear voltage sag profiles and voltage sag measurement at primary substation to locate a fault in distribution networks. The results indicate the possibility of using this method to support automatic fault management system. Ref. [7] introduces a practical approach to power system fault location in power networks using advanced fault signal processing. The simulation results, including single line to ground faults, faults in mixed feeders and high-impedance arcing faults, confirm the accuracy and practical applicability of the proposed approach. In [8], an accurate and efficient method is proposed for fault section estimation and fault distance calculation in distribution systems, based on frequency spectrum components of fault generated traveling waves. Simulation results of various types of faults on a typical distribution system demonstrate high efficiency and accuracy of the proposed method. In [10], an ANFIS (Adaptive Neural Fuzzy Inference System) based fault classification scheme in neutral non-effectively grounded distribution system is proposed. The results show that it has high accuracy and through simulation, the proposed approach exhibits good performance.

This paper presents a new off-line method fault location based on signal processing using wavelet and ANNs and FLSs in UDS. A practical 20 kV underground power distribution system is simulated using the EMTP software; the faulted current and voltage responses are then extracted from the sending end for different faults and fault conditions. The effect of transducers (CTs and VTs) and hardware errors such as anti-aliasing filters and quantization are taken into account; the information processed throughout the fault locator algorithm is thus very close to real-life situation. Finally, the simulated data is processed in order to locate the fault point using ANNs and FLSs.

"Current transients based phase selection and fault location in active distribution networks with spurs using artificial intelligence,"

In electrical distribution networks, short-circuit faults are undesirable since they cause interruption of supply, affect system reliability and influence revenue for distribution companies. This paper investigates the use of current signals to determine the faulted phases during a fault and also proposes a novel approach to distinguish whether the fault lies on the feeder or one of the spurs. The distance of the fault from the substation is also evaluated using artificial neural network techniques and sensitivity tests further demonstrate the robustness of the proposed method.

Fault location is a necessity to realize the self-healing concept of modern distribution networks. This paper presents a novel fault location method for distribution networks with distributed generation (DG) using measurements recorded at the main substation and at the DG terminals. The proposed method is based on an iterative load flow algorithm, which considers the synchronization angle as an unknown variable to be estimated. Therefore, it obviates the need of synchronized measurements. A new fault location equation is also proposed which is valid for all different fault types, hence the fault type information is not required. The developed method can be simply implemented by minor modifications in any distribution load flow algorithm and it is applicable to different distribution network configurations. The accuracy of the method is verified by simulation studies on a practical 98-node test feeder with several DG units.

According to failure statistics, approximately 80% of all customer interruptions are due to faults on distribution networks [1]. It is therefore required to manage distribution faults in an efficient and effective manner to maintain the quality of service by minimizing the outage time. Distribution outage management is closely related to operators ability to find the fault location. In branched distribution networks dispersing over vast rural and urban areas, fault location can be a great help in minimizing the inspection and service restoration times. Accordingly, significant research efforts have been devoted to the subject. The proposed approaches can be classified into outage area location methods [2], [3], and fault location methods. The first class uses data such as customer calls or fault indicating signals to find the most likely interrupted area, while the second class finds the location of the fault, which caused the resulting outage [4].

Based on the required inputs and their computational process, distribution fault location methods can be categorized into: impedance-based methods [5], [6], algorithms based on sparse measurements [7], [8], [9], [10], [11], traveling waves-based methods [12], [13], [14], learning-based methods [15], [16], and integrated methods [17], [18], [19]. Although some of these methods have presented excellent results, most of them are designed for radial networks with a unidirectional power flow. However, the future distribution networks are expected to accommodate a variety of distributed generation (DG) sources, which change the radial nature of distribution systems to multi-source networks with bidirectional power flows. Hence, there is a need for a new class of fault location methods for such systems.

Recently, some fault location methods are proposed for distribution networks with DG. In [20] authors present a learning-based scheme with very short online execution time. However, learning-based methods mostly require several actual or simulated fault cases for training and retraining following to any change in network topology. The methods described in [21], [22], [23], [24] are modified impedance-based algorithms. These methods solve a set of equations for all line sections, one by one, to find all possible fault locations. In [25], [26], authors propose algorithms based on sparse measurements. These algorithms apply the fault at all network nodes, one by one, and calculate the change in three-phase voltages at nodes having measurements. Finally, by comparing the measured and calculated values for all nodes, they identify the node with the minimum difference as the fault location. The genetic algorithm-based technique proposed in [27], optimizes the process of the methods of [25], [26] to decrease their computational time. In [28], an integrated method finds all possible fault locations using an impedance-based algorithm and then uses the measured DG terminal voltages to identify the best solution. The authors of [29] propose a method based on a time-domain numerical analysis using a data window moving from pre-fault to post-fault in time domain. Although this algorithm considers the dynamic behavior of generators during fault transients, it is only applicable to synchronous machine-based DGs.

The above mentioned fault location methods mostly rely on synchronized measurements provided by meters installed at the main substation and at the DG terminals. It is possible to synchronize the measurements using the global positioning system (GPS) or computer networks [30]. However, unavailability of the synchronized measurements, even in some recent smart metering projects [31], limits the application of these methods. Therefore, there is a need for a new method that can employ the non-synchronized measurements to find the accurate location of faults in distribution networks with DG.

To obviate the need of synchronized measurements, this paper presents a new impedance-based fault location method, which considers the synchronization angle as an unknown variable to be estimated. Compared to the previously proposed fault location methods, the main contributions are as follows:

- The proposed method can solve the fault location problem in distribution networks with or without DGs using synchronized and/or non-synchronized measurements;
- A new fault location equation is proposed which is valid for all different fault types. Therefore, in contrast to the previously proposed impedance-based methods [5], [6], [21], [22], [23], the proposed method does not require fault type information;
- Compared to the methods proposed in [21], [29], which are designed for synchronous DGs, the presented method is applicable to all DG types without requiring their models and parameters.
- The proposed method is fully load flow-based and it can be simply implemented by minor modifications in any distribution load flow algorithm.

In the rest of the paper, Section 2 presents the details of the proposed fault location method. Section 3 gives the simulation results for different fault scenarios and finally, Section 4 concludes the paper.

"Fault location and isolation using multi agent systems in power distribution systems with distributed generation sources,"

This paper presents a Multi Agent System (MAS) design with distributed intelligence for fault location and isolation in power distribution systems with the presence of Distributed Generation Sources (DGS). In the proposed MAS, agents all over the feeder communicate with their neighbors and use the local differential current information to locate the faulty zone and isolate the fault. Agents update their local knowledge by exchanging their voltage and current phasor data with their neighbors and monitoring the local current. The distributed generation penetration is considered to be up to 50 percent. The multi-agent models are simulated in Matlab® Simulink using user defined s-functions and the power system is modeled using the Simulink Simpower toolbox. The proposed method has been tested on a model of an existing Mon Power company circuit. Both faulted zone and fault type have been successfully identified.

Traditional Power Distribution Systems (PDS) are almost radial networks with single source of power. In the recent years, with the changes in regulatory markets of the generation, transmission and distribution, interest in using new generation technologies like Distributed Generation Sources (DGS) has increased. Using DGS will affect the operation of PDS and new technical issues will be created. High penetration of DG's changes the traditional passive networks with single direction of power flow to an active network where the power flows in various directions. These changes make the PDS more complicated and more exposed to faults which affect the system's reliability, security, and delivered energy quality. Power utility companies are often faced with the challenge of providing the right level of power quality service to meet the customers need for reliable and high quality power. Reliability of PDS is directly related to the time that utility companies spend on locating and isolating the fault. Fault locating with the minimum time delay can help a fast reconfiguration and restoration for PDS in case of fault occurrence. Therefore fast and accurate fault locating is valuable asset for utility companies to increase their reliability [1].

Considering the existence of multiple laterals and sub laterals tapped of the main feeder in different locations of PDS, time varying unbalanced load profiles, power injection at different location of system by distributed generation, fault locating in PDS is a challenging task.

Several fault location methods have been proposed for PDS. Previous works could be categorized in three main categories; 1) Impedance based methods; these methods usually calculate the apparent impedance sequences using measurement points data and estimate the possible fault

locations based on iterative algorithms [2]-[3]. Considering the multiple fault locations estimation in these methods and existence of many laterals in PDS is the drawback of impedance based methods. 2) Wavelet based methods, in which discrete Fourier transform or wavelet transform are used to analyze the fault waveform. It’s difficult to guarantee

the reliability of these methods because of variety of load characteristics and fault cause in PDS [4]-[5]. 3) Intelligent methods consist of artificial neutral networks (ANN) [6], Expert systems, and multi agent systems (MAS) [7]-[9] and etc., ANN based methods need to be trained after any change in system and update the network weights, the other drawback with ANN based methods is that in case of complicated networks they became slow and may fall in local optimum. Expert system methods have a slow response time since they

involve knowledge base maintenance and conventional inference mechanism.

Recently MAS based approaches became more popular for decentralized management of power systems and are applied to different areas like fault diagnosis, voltage stability,

electricity market pricing, protection coordination, power system reconfiguration and restoration. An agent is defined as

“an autonomous computational entity such as a software program that can be viewed as perceiving its environment through sensors and acting upon this environment through its

effectors”

A multi-agent system is a group of agents, Considering the existence of multiple laterals and sub laterals tapped of the main feeder in different locations of PDS, time varying unbalanced load profiles, power injection at different location of system by distributed generation, fault locating in PDS is a challenging task. Several fault location methods have been proposed for PDS. Previous works could be categorized in three main categories; 1) Impedance based methods; these methods usually calculate the apparent impedance sequences using measurement points data and estimate the possible fault locations based on iterative algorithms [2]-[3]. Considering the multiple fault locations estimation in these methods and existence of many laterals in PDS is the drawback of impedance based methods. 2) Wavelet based methods, in which discrete Fourier transform or wavelet transform are used to analyze the fault waveform. It's difficult to guarantee the reliability of these methods because of variety of load characteristics and fault cause in PDS [4]-[5]. 3) Intelligent methods consist of artificial neutral networks (ANN) [6], Expert systems, and multi agent systems (MAS) [7]-[9] and etc., ANN based methods need to be trained after any change in system and update the network weights, the other drawback with ANN based methods is that in case of complicated networks they became slow and may fall in local optimum. Expert system methods have a slow response time since they involve knowledge base maintenance and conventional inference mechanism. Recently MAS based approaches became more popular for decentralized management of power systems and are applied to different areas like fault diagnosis, voltage stability, electricity market pricing, protection coordination, power system reconfiguration and restoration. An agent is defined as "an autonomous computational entity such as a software program that can be viewed as perceiving its environment through sensors and acting upon this environment through its effectors" [10]. A multi-agent system is a group of agents, which sense the environment and acts in order to achieve its objectives. Most approaches for fault location in the literature consist of a master agent which makes the final decision based on the data received from other agents which cannot be considered as a distributed control since the master agent is behaving like a control center [11]. In some other works [12] each agent is considered to have its special functionalities e.g. acquiring data, analyzing data, managing situations, etc. In other words each step of decision making is done by a special agent. In [13] agents have hierarchical levels and higher level agents coordinate a group of lower level agents. In this work we're using a distributed architecture for our MAS in which agents have access to the voltage and current Phasor data of themselves and their neighbors to a defined neighborhood and use these data to locate the fault. Each agent calculates and monitors its upstream and downstream areas power usage and in case of fault can detect whether the fault is in neighborhood or not. Therefore each agent has a decision making capability. The West Virginia Super Circuit (WVSC) project is part of the Modern Grid Initiative aiming at demonstrating and testing new technologies to enable the deployment and the implementation of Smart Grids. This work is part of the WVSC project which consists of designing

MAS for fault detection and isolation applications. This paper is organized as follows. Section II presents the West Virginia Super circuit (WVSC) and the problem statement. Section III introduces multi agent system structure and details of proposed fault location isolation algorithm. Section IV describes the simulation models. Section V presents simulation results. Finally, section VI concludes the paper and points out future research directions.

"Fault´ location in power distribution systems using a learning approach based on decision trees,"

This paper presents a learning-based strategy that uses decision trees for locating faults in radial power systems, which is aimed to improve the power quality as demanded by the deregulated electrical markets. The proposed method first subdivides the power system into several regions, and then, a classification technique based on decision trees is trained using a fault database. The obtained decision trees are used to assign a faulted zone to a new fault event, which reduces the restoration time and as a consequence helps to maintain good quality indices. The proposed method is validated in the IEEE 34-node test feeder considering several operating conditions, such as variations in load, substation voltage, line length and fault resistances. The obtained results prove the good performance of the proposed fault location method. Finally, the implementation of this method on real power distribution systems helps to maintain good power continuity indices, with a low investment.

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.

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 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.

“Fault location in distribution systems based on smart feeder meters,”

This paper proposes a fault-location method based on smart feeder meters with voltage sag monitoring capability. The main idea is to explore voltage measurements from monitors placed in different buses of distribution systems to estimate the fault location. The estimation is achieved by relating the voltage deviation measured by each meter to the fault current calculated based on the bus impedance matrix, considering the fault in different points. In order to improve the method accuracy, the loads are represented by constant impedance models and included into the bus impedance matrix. The performance of the proposed method is demonstrated by using a real distribution system. Sensitivity studies results show that the method is robust since it has good performance for different values of fault resistance, quantity, and location of the smart meters.

ongoing deployment of smart meters, with data processing and communication features, has provided the opportunity to improve distribution systems performance. This paper presents a state estimation-based method for fault location in distribution networks using the measurements provided by the smart meters. During the normal operation of the system, state estimation methods can handle the errors in real or pseudo-measurements to give the best estimate of the system state and to identify large measurement errors, called bad data. This concept is extended in this paper under fault conditions where the fault is considered as an unknown and temporarily connected load which can be dealt with as bad data. The proposed method uses the changeable weighting matrix bad data identification technique to find the fault location. The method is algorithmically simple and does not require the fault type. The fault location accuracy is verified by extensive simulation tests on a real 13.8 kV, 134-node distribution network for different fault scenarios. The results indicate that the method has a good performance under measurement and load data errors and for different number and locations of the smart meters in the network.

known that over 60% of customer power outages are due to the faults on medium voltage distribution networks. In contrast to transmission lines, distribution networks have several branches and tapped laterals dispersing over vast rural and/or urban areas with much fewer measuring and relaying points. These networks are vulnerable to different types of faults arising from a variety of causes such as adverse weather conditions, equipment failure, bird contacts and vegetation growth [1]. In European networks, durations of supply outages are generally low, ranging from about 15 min to 400 min per customer in a year [2]; however, as societies become more dependent on electrical energy, a higher level of supply continuity is demanded. In this context, fault location offers significant benefits for distribution system operator (DSO) by narrowing down the search area to find the fault point. This potentially improves the continuity of supply and lowers the network operation costs.

Traditional fault location techniques for distribution networks are based on activities such as grouping of customer trouble calls. Then, a repair crew patrols the area looking for fault evidence and ensuring safety prior to re-energizing the interrupted section of the feeder. The whole restoration process can take a long time from tens of minutes to several hours. Therefore, many research works have been devoted to designing more efficient fault location methods.

Deployment of fault indicators can be considered as a reliable solution [3], [4]. However, a large number of them are required to provide accurate results. Impedance-based fault location algorithms are a less expensive option which is based on the calculation of the impedance to the fault from the main substation and finding the points with the same impedance as possible fault locations [5], [6], [7], [8], [9]. These methods are easy to be applied in real systems, but they usually lead to multiple locations for a single fault and, as shown in [7], impedance-based algorithms are also sensitive to load data errors. The travelling wave-based methods in [10], [11] correlate the fault location with some characteristic frequencies associated with specific travelling wave paths. These methods are difficult to be applied in distribution networks with several laterals and load taps [10]. They also require measurements at very high sampling frequency, which limits their practical application. Learning-based methods proposed in [12], [13], [14], [15] use a large set of input-output fault data for training from which any fault data can be mapped to a fault location. The input comprises of some characteristic features extracted from the measured voltage and currents and the output is usually the distance to the fault. Learning-based methods present very short execution times, but they require a large set of training data and retraining following any changes in distribution network topology. The integrated methods proposed in [16], [17], [18] combine different types of fault location methods to overcome their limitations. These methods should meet all the requirements of the individual methods.

The introduction of smart meters has created the opportunity to improve distribution systems operation. Several research projects have reported different system architectures for installation and better exploitation of smart meters [19], [20]. For example, the authors are involved in the Flexmeter project as one of the ongoing European Union Horizon 2020 projects. The aim of Flexmeter is development and demonstration of a flexible smart metering architecture using different types of off-the-shelf smart meters for different general-purpose services [19]. In [20] authors describe a research project to develop a network of high-precision phasor measurement units, termed micro-synchrophasors or μPMUs, providing high-resolution angle measurements at comparatively low cost with easy plug-and-play installation. Motivated by the recent advances in distribution networks measurement and communication infrastructures, several research studies are now exploring the applications of the emerging metering and communication technologies for electric power distribution systems [21], [22].

One of the most interesting applications is in the fault location area. The integrated methods proposed in [23], [24], [25] use an impedance-based fault location algorithm to estimate the fault distance and find all possible fault locations. Then, they exploit the smart meters with voltage monitoring capability to identify the correct solution. Although such integrated methods can overcome the multiple estimation problem of the impedance-based algorithms, the problem of sensitivity to load data inaccuracies still remains unsolved. The voltage sag-based methods proposed in [26], [27], [28] are based on the fact that each fault causes voltage sags with different characteristics at different nodes. These methods consider the fault at each network node, one at a time, and calculate voltage sags at all nodes having voltage measurements.

Then, by comparing the measured and calculated voltage sags, the node with the maximum similarity is identified as the fault location. Although these methods provide acceptable results under ideal conditions, they are sensitive to measurement inaccuracies and load data errors [29]. In [30] the voltages measured by the smart meters installed along the feeder are used to estimate different fault current values for each node. The faulted node is then identified by comparing the calculated currents. This method requires a large number of meters to provide accurate results and it is sensitive to measurement errors. The authors in [31] use the compressive sensing signal processing technique and pre- and during-fault voltages measured by smart meters or phasor measurement units to locate distribution network faults. In [32], the authors extend the application of the idea proposed in [31] to locate simultaneous faults. Compared to the voltage sag-based algorithms [26], [27], [28] and the method proposed in [30], these methods show better performance under measurement inaccuracies and load data errors. However, they require a minimum number of meters to provide acceptable results and cannot be implemented with limited measurements. The method proposed in [33] assumes the fault as a current injection. It considers a fault at each network node, performs state estimation and calculates the fault current. Finally, it selects the faulted node by investigating the obtained state estimation residuals for all the nodes. In [34], the authors review and compare different fault location methods, in terms of their advantages, limitations, and requirements.

This paper presents a new state estimation-based fault location method by considering the fault as an unknown and temporarily connected load which can be dealt with as a bad data. The method uses the changeable weighting matrix technique for bad data identification and hence the fault location [35], [36]. Compared to previously proposed methods in the literature, this method can handle the measurement and load data errors effectively by exploiting a limited number of smart meters. It does not require fault type and can use different types of measurements, i.e. voltage, current or power.

Extensive simulation tests are carried out on a 134-node, radial distribution network. The results show that the proposed method correctly identifies the fault location for different fault types, fault impedances, and fault positions. The results also validate the performance of the method against load data inaccuracies, and for different number and location of the smart meters.

The paper is organised as follows: Section 2 presents the mathematical background of the state estimation theory. Section 3 describes the details of the proposed fault location method. Section 4 gives the simulation results for different fault scenarios and finally, Section 5 concludes the paper and lists its contributions.

CONCLUSION

This research presented promising results using decision trees to estimate the location of single-phase faults on the IEEE 34-bus distribution system. In areas 2 and 3 defined in the distribution system, and for now, considering only single-phase faults, the J48 decision tree algorithm presented excellent False Positive Rate 0 0.2 0.4 0.6 0.8 1 True Positive Rate 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 Zone 7 (AUC = 1.00) Zone 9 (AUC = 0.92) Zone 11 (AUC = 0.97) Fig. 10. ROC curve to locate phase C-to-ground faults which occurred in area 3. False Positive Rate 0 0.2 0.4 0.6 0.8 1 True Positive Rate 0 0.2 0.4 0.6 0.8 1 Zone 2 (AUC = 1.00) Zone 3 (AUC = 1.00) Fig. 11. ROC curve to locate phase B-to-ground faults which occurred in area 2. results in identifying the occurrence zone on the IEEE 34- bus DS. The results were mainly investigated using confusion matrices, as well as ROC curves. The confusion matrix shows where there is a correct location and identifies the errors made by the algorithm. Based on the Area Under the Curve (AUC), analyzing ROC curves, the efficiency of the fault locator could be determined. ACKNOWLEDGMENT The authors would like to acknowledge the Department of Electrical and Computer Engineering, Sao Carlos School of ˜ Engineering, University of Sao Paulo (Brazil), for the research ˜ facilities provided to conduct this project. Our thanks also extend to the financial support received from CAPES and CNPq (Governmental Brazilian Institutions).

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