UNIVERSITI PUTRA MALAYSIA

FAULT LOCATING IN UNBALANCED DISTRIBUTION SYSTEMS INCLUDING DISTRIBUTED GENERATION USING NEURAL NETWORK

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FAULT LOCATION IN UNBALANCED DISTRIBUTION SYSTEM INCLUDING DISTRIBUTED GENERATION UNITS USING MULTI-LAYER FEED FORWARD NEURAL NETWORK

By

PAYAM FARZAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

July 2014

DEDICATION

Dedicated to my father's soul & beloved mother and sister

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: Chandima Gomes, PhD

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Locating a fault in a distribution system has always been a critical issue for electrical utilities. Fast and accurate determination of fault location results in speeding up the restoration operation and preventing waste of generated electricity in the form of undistributed energy. Fault location finding process in distribution network is totally different based on the application of developed algorithms for the transmission lines due to characteristics of distribution system. On the other hand, Distribution Generation (DG) units are increasingly being added nowadays to the distribution network. Considering the imposed impacts of these units on the distribution networks the fault location operation has even become rather complicated than before. This thesis presents a fault location algorithm based on the recording of Short Circuit Power (S/C.P) and Short Circuit Current (S/C.C) values at the source bus of unbalanced radial simulated distribution networks including DG units. The recorded values are gathered in separated datasets to be evaluated by the designed Multi-Layer Feed Forwarded Neural Networks (ML-FFNN) and the fault distances from the source are estimated accordingly.

Two radial unbalanced distribution networks are considered to implement the proposed algorithm ; IEEE 34 bus test feeder as a large scale network with the maximum length of around 60 km and a local 15 bus distribution network as a real network with several laterals. Three fault types; Three Lines (LLL) Line to Line (LL) and Single Line to Ground (SLG) are applied in different locations of distribution systems and the values of S/C.P and S/C.C with their corresponding fault distances are recorded simultaneously. The designed ML-FFNN using the three different datasets; S/C.P,S/C.C and the joined S/C.P and S/C.C, estimates the locations of faults. Finally, the estimated locations are compared with the real fault locations to calculate the difference percentage.

It is explained that the estimated fault locations via S/C.P dataset are rather accurate than using S/C.C dataset and the most precise estimations belong to the joined S/C.C and S/C.P dataset for all the three fault types. Furthermore, it is indicated that the designed fault locator system is able to preserve the accuracy of estimations in presence of DG units in the distribution network using all the three datasets.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

LOKASI KEROSAKAN DALAM SISTEM PENGAGIHAN TIDAK SEIMBANG TERMASUK UNIT PENJANAAN PENGAGIHAN MENGGUNAKAN RANGKAIAN NEURAL

Oleh

PAYAM FARZAN

Julai 2014

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Mencari kawasan kerosakan di dalam sistem pengagihan sentiasa menjadi isu yang penting untuk utiliti elektrik. Kawasan kerosakan yang beroperasi secara cepat dan tepat ini mempercepatkan operasi pemulihan serta mencegah daripada pembuang tenaga elektrik yang dijana dalam bentuk tenaga yang tidak teragih. Proses mengenalpasti kerosakan didalam rangkaian pengedaran adalah sama sekali berbeza dengan aplikasi algoritma yang dibangunkan untuk talian penghantaran disebabkan oleh ciri-ciri sistem pengedaran. Sebaliknya,kini unit Generasi Pengagihan (DG) untuk rangkaian pengedaran semakin bertambah. Unit-unit rangkaian pengedaran operasi kawasan kerosakan ini telah menjadi semakin rumit daripada sebelumnya apabila kesannya ke atas unit ini dipertimbangkan. Tesis ini menerangkan tentang algoritma kawasan kerosakan berdasarkan rakaman nilai Kuasa Litar Pintas (S/C.P) dan Arus Litar Pintas (S/C.C) di rangkaian pengedaran jejarian pada sumber bus yang tidak seimbang termasuk unit DG. Nilai yang direkodkan akan dikumpulkan di dalam set data yang telah dipisahkan untuk dinilai oleh Rangkaian Neural Dikirim Penyuap Pelbagai Lapisan (ML-FFNN) dan jarak kerosakan daripada sumbernya dianggarkan dengan sewajarnya.

Dua jejari rangkaian pengedaran yang tidak seimbang dianggap sebagai algoritma yang dicadangkan iaitu ujian penyuap bas IEEE 34 sebagai rangkaian skala besar dengan panjang maksimum antara 60 km dan rangkaian pengedaran 15 bas tempatan dengan beberapa laterals pula sebagai rangkaian sebenar. Tiga jenis kerosakan iaitu Tiga Talian (LLL), Talian kepada Talian (LL), dan Satu Talian ke Bumi (SLG) adalah digunakan di kawasan yang berbeza sistem pengagihan dan nilai-nilai S/C.P dan S/C.C dengan jarak kerosakan sepadan tersebut yang telah direkodkan serentak. ML-FFNN yang telah direka menggunakan tiga set data yang berbeza iaitu S/CP, S/C.C dan gabungan S/CP dan S/C.C menganggarkan kawasan kerosakan tersebut. Akhirnya, perbandingan anggaran kawasan dengan kedudukan kerosakan sebenar digunakan untuk pengiraan peratusan perbezaan.

anggaran kedudukan kerosakan adalah lebih tepat apabila menggunakan set data S/C.P berbanding set data S/C.C dan anggaran yang paling tepat adalah merupakan gabungan set data S/C.C dan S/C.P bagi ketiga-tiga jenis kerosakan. Tambahan pula, ia menunjukkan bahawa kesalahan sistem pencarian yang telah direka ini dapat mengekalkan ketepatan anggaran unit DG di dalam rangkaian pengedaran yang menggunakan ketiga-tiga set data tersebut.

ACKNOWLEDGEMENTS

I would like to extend my appreciation to my dear mother and sister for their encouragement throughout the years I studied. I would also acknowledge my dear supervisor Prof. Dr .Chandima Gomes for his continuous and endless supervisions and encouragements. My deep gratitude to my co-supervisors Prof. Dr. Mohd Zainal Abidin Ab Kadir and Dr. Mohd Amran Mohd Radzi for their great assistance which would never be forgotten. I hereby would like to extend my special thanks to Dr. Mahdi Izadi for his patient guidance and support. I would also like to express my gratitude to Mohammad Hesam Hesamian and Sima Sadatmir who helped me to complete my thesis. I would also like to thank my friends who have given me moral support and to those who have given me ideas, notes, books etc.

APPROVAL

I certify that a Thesis Examination Committee has met on ………..2014 to conduct the final examination of Payam Farzan on his thesis entitled "Fault Locating In Unbalanced Distribution systems Including Distributed generation using Neural Network " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the relevant degree of Master of Science.

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a	Neural network output
ADP	Average Difference Percentage
AI	Artificial Intelligence
ANN	Artificial Neural Network
b	bias
BP	Back Propagation
CHCP	Combined Heat and Cold and Power
CWT	continuous-wavelet transform
DCR	Differential Current Ratio
DG	Distribution Generation
F	Transfer Function
FCL	Fault Current limiters
FFNN	Feed Forward Neural Network
FC	Fuel Cells
FDTD	Finite Difference Time Domain

FL	Fuzzy logic
GA	Genetic Algorithm
GPRS	General Packet Radio Services
GPS	Global Positioning System
I_i	sequence current at sending bus
i	zero, positive and negative sequence
L	distance between the two terminals
LL	Line to Line fault
LLL	Three Lines
LR	Learning rate
LM	Levenberg-Marquardt
LTC	Load Tap Changing Transformers
MC	Momentum Constant
ML-FFNN	Multi-Layer Feed Forwarded Neural Networks
MLP	Multi-Layer perceptron
MU	Weight Update Rate
$(p_1, p_2, \ldots p_R)$	Neural network inputs

PCA	principal component analysis
PSO	Particle Swarm Optimization
PV	Photovoltaic
R	Resistance
R_{app}	apparent resistance (Ω)
RBFNN	Radial Basis Function Neural Network
RBFNN–OSD	Radial Basis Function Neural Network with Optimum Steepest Descent
RE	Renewable Energy
S/C.C	Short Circuit Current
S/C.P	Short Circuit Power
SLG	Single Line to Ground
SVM	Support Vector Machine
SVR	supporting vector regression
t_a ,t_b	Recorded times at the two terminals.
V	velocity of traveling wave
V_i	The sequence voltage at sending bus
V_{if}	The sequence voltage at fault point

$(w_1, w_2 \ldots w_R)$	weighs
WTMM	Wavelet Transform Modulus Maxima
X	Reactance
X_{app}	the apparent reactance (Ω)
Z_{app}	Apparent impedance
Z_i	the sequence impedance of the line

CHAPTER ONE

INTRODUCTION

1.1 Overview

Over the past decades, electrical distribution networks have rapidly grown due to increase of the residential, commercial and industrial demands. Large number of transformers, regulators and load taps are scattered all over these networks, adding further multifariousness to the power system. Hence, nowadays distribution networks are rather complex than last decades due to existence of many laterals and ramifications including lengthy distribution lines. Moreover, real distribution networks are regularly unbalanced because of feeding the variety of loads with different connections in the form of single, double and three phases at the same time.

In recent years, with the growing electricity consumption, governments have followed the policy of decentralized generation, so that electrical utilities encourage their major consumers to install distributed generation (DG) units to provide their required electricity. Connecting DG units to distribution networks has some benefits like increasing the reliability, reducing the network losses etc. On the other hand, presence of DG units raise some issues in the network such as changing the level and direction of short circuit current and power, voltage fluctuation etc.

Delivering safe and reliable electricity to the customers is the main task of distribution networks. Whenever an interruption or loss of power occurs in the feeder, finding the cause of interruption is crucial in order to minimize the outage duration. Thus, in order to reduce effects on customers due to equipment damage, restoration operation should be done in minimum possible time. Around 80% of interruptions are caused by faults in distribution systems [1] . It means that fast and accurate fault location has a direct impact on hastening up the restoration operation.

Locating the faults in distribution networks has always been a challenging task due to its characteristics. Furthermore, the fault location process becomes rather complicated than before in the presence of DG units, because of their impacts on the distribution network.

1.2 Research background

During the last decades, many studies have focused on fault locating in the distribution systems. Recently, some new fault location approaches have been presented in the literature using data matching technique for matching the measured values of voltage sag with the simulation results [2], [3] . In some other techniques, impedance matrix have been used in order to solve quadratic and nonlinear equations [4], [5] . Apart from the above mentioned approaches, fault location techniques can be categorized into three main approaches; impedance based methods, traveling wave based methods and artificial intelligence based methods. In impedance based methods, the distance between the primary distribution bus and the location of fault is determined using mathematical equations to estimate the apparent impedance which is seen from the measurement points. Measured voltages and currents are the main requirements of this type of fault location approach. Although impedance based techniques have been used during the past decades, due to the presence of several possible faulty locations at the same distances in different laterals, they mostly lead to multiple or inaccurate estimations [6] .

Traveling wave based methods work on reflection and transition of generated waves by faults. In these methods, fault transient detectors should record the time synchronically. Time difference is calculated from the arriving time of waves to two terminals where the fault detectors are installed. Then, the fault location is estimated via mathematical equations using these parameters; velocity of traveling waves, distance between the two terminals and arriving times. The accuracy of travelling wave based methods is rather high than the impedance based techniques. But requirements of these methods are; high sampling rate and installation of expensive devices; the GPS system, some special diagnostic software and fault detectors. Furthermore, discrimination of the reflected waves from the faulty points and the remote ends of the feeder is the other serious issue in this approach [7] .

In recent years, AI techniques have been used and developed in the fault location context. The instances of AI are techniques such as; Genetic Algorithm (GA), Fuzzy logic (FL), Artificial Neural Network (ANN), etc. The main requirement of these approaches is providing appropriate and sufficient datasets for training or developing logical algorithms. Generally, for fault location purpose the datasets are generated through load flow and short circuit analysis and measurement of voltage and current at different points of the distribution system before and during the fault occurrence. Mainly intelligent methods are more accurate, faster and less costly than other approaches. Among the intelligent algorithms, exploitation of ANN in fault location studies has considerably increased due to success and fast progress, ability to design diverse networks and develop various algorithms.

1.3 Problem statement

When a fault occurs in the distribution network, delivering electricity is interrupted for the consumers which are in the downstream of the fault. If this interruption takes more than a specified time it will be considered as a total outage. The result of outage and fault in distribution system will be disturbance and this condition might lead to equipment damage and non-continuous power supply for consumers. Moreover, generated electrical power in the generation units cannot be distributed anymore during faulty condition. This generated electricity is non-storable, thus, inevitably wasted. Hence, accurate fault location in the minimum time enhances the distribution system reliability.

As mentioned before it can be concluded that intelligent techniques are the most appropriate option for fault location studies. Although in recent years, a number of intelligent approaches have been published in this context, there are still some issues which are not addressed effectively. These issues are explained in the following:

i. Non consideration of other electrical parameters except values of short circuit current

In most of the proposed intelligent approaches, only reordered values of Short Circuit Current (S/C.C) at the source bus have been used to evaluate the location of faults. The recorded S/C.C values for the faults which occur in different laterals with almost the same distances from the source are close to each other .These values are also similar to each other for faults which occur in far distances from the source. Using a dataset comprising similar data may lead to multiple or inaccurate estimations in almost all intelligent algorithms. To overcome this problem, a very large scale dataset have been used in most of the intelligent methods [8] . Generally, gathering a large dataset including occurred fault information in several hundreds of locations is not feasible in a real distribution network. Although current is the parameter which is notably affected by the fault, there are other parameters which are also influenced by it. In this regard, voltage and phase angle need to be taken into account.

ii. Presence of DG units in distribution systems

Nowadays, number of connected DG units to the distribution system is growing. Presence of these units in the distribution network is not reflected in most of the previous methods. Regular fault location methods cannot be implemented in networks considering the changes which these units impose to such networks; change in the level and direction of short circuit current, change in in the direction of flowing active/reactive power and etc. Recently, some AI algorithms have been proposed for distribution systems including DGs. The estimation accuracy of these algorithms is highly dependent on the number of DGs [9]. In some cases a very large dataset including recorded S/C.C values in several locations is required [10] .

iii. Unbalanced nature of distribution system in the presence of DG units

Almost all real distribution networks are unbalanced in nature due to the unbalanced loading of different phases and high ratio of resistance to reactance. Indeed, DG units are added to the existing unbalanced distribution networks. Some previous studied have presented fault location methods for unbalanced networks, but few of them have considered the presence of DG units in unbalanced distribution network.

iv. Recording the values of current and voltage at the fault time in all buses

The effects of short circuit are more sensible at closer distances from the source. Hence, the source bus is the best place for measuring electrical parameters. In some previous studies, values of voltage and current have been measured at all buses of the distribution system by applying faults in various locations [11] . This process is highly time consuming and lead to a large redundant dataset.

1.4 Objectives

The aim of this thesis is to present an accurate fault location method for radial unbalanced distribution systems in the presence of DG units. This study is conducted to achieve the following objectives:

i. To propose a fault location method based on the recording of Short Circuit Power (S/C.P) values at the source bus of simulated unbalanced distribution system using Multi-Layer Feed Forward Neural Network
ii. To extend the proposed fault location method in the presence of DG units in the typical unbalanced distribution systems
iii. To improve the proposed fault location method by recording both Short circuit Power (S/C.P) and Short Circuit Current (S/C.C) values at the main bus of unbalanced distribution system in the absence and presence of DG units.

1.5 Scopes of study

Scopes of this thesis are as follow

In this thesis:

i. All spots and distributed loads are constant during 24 hours a day.
ii. The focus is on the low impedance short circuit faults with resistance of 10 Ohm.
iii. Three fault types are evaluated; 3 Lines (LLL), Line to Line (LL) and Single Line to Ground (SLG).

1.6 Thesis Outlines

This thesis is presented in mentioned 5 chapters subsequently:

Chapter 1 consists of overview, background, problem statement and objectives of this thesis.

Chapter2 reveals literature review of this thesis .Following subjects are outlined in this chapter; distribution networks characteristics, different types of fault location methods, DG and its impacts on distribution network and introduction of ANN as the selected method.

Chapter3 describes the research methodology; overview of proposed methodology, results of load flow analysis, Modeling process of distribution networks with their connected DGs, explanation of applying faults in different distances from the source and recording the S/C.P and S/C.C in order to gather the dataset, general steps of applying ANN, designing a ML-FFNN, tuning the ANN parameters and finally the validation strategy.

Chapter 4 discusses the results of the thesis. Tables illustrate the estimated fault locations and difference percentage of estimated distances in comparison with real distances using three different dataset (S/C.C, S/C.P and both S/C.C and S/C.P). They are separately designed for each fault type and into in two main scenarios; in presence and absence of DGs. Bar charts clarify the average difference percentages (ADP) values in order to compare the performance of fault locator system using three different dataset for both scenarios.

Chapter 5 presents the conclusion of thesis and some recommendations for future works.

1.7 Summary

In this chapter firstly the overview of the unblended radial distribution systems including different laterals and in presence of DG units has been presented. It has been highlighted that accurately locating the fault is crucial for the distribution systems. Different fault location approaches were briefly explained and it was concluded that the artificial intelligent based algorithms are more accurate and less costly in comparison with the others. The main study gaps of AI based methods which are not addressed in the literature was presented in the problem statement. Then the objectives of this thesis in order to cover the presented research gaps were described and finally the scopes of study were clarified in the final section.

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