ARTIFICIAL INTELLIGENCE BASED TECHNIQUE FOR SINGLE LINE TO GROUND FAULT IDENTIFICATION AND ARC EXTINGUISHMENT

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I would like to dedicate my work to my husband Abid Musslem Abbas because of his patience, love, and care during my PhD journey. Also, I dedicate it to my sons: Dr. Ahmed, Dr. Hassanain, and Dr. Abbas, due to their support and love, which is always with me to achieve this milestone.

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ABSTRACT

Single line-to-ground fault (SLGF) is the most common fault in the distribution network of the power system (PS). The disadvantage of this fault is to cause residual current (I_{res}) initiating an electrical arc along with a high voltage (HV) of the order of three times the rated voltage in other healthy phases. This HV is caused by the capacitive currents (I_C), which is very dangerous for the insulation of cables as well as the PS appliances, including personnel and protection systems. To solve I_{res} conventionally, Peterson Coil (PC) has been used by connecting it with the neutral point, which reduces it and extinguishes the electric arc, but both not fully, i.e., still some value of fault current $\left(I_{fault}\right)$ remains. If it is not reduced to an extent, initiating the arc again can be more dangerous to the PS. Among them, some researchers were focused on SLGF detection, and only a few were interested in studying the extinguishing time of the electric arc. These solutions are incompatible with the requirement of developing technology due to the increased demand for efficiency, economy, reliability, quality, and electrical energy consumption. Therefore, they were replaced with the advanced/ heuristics methods/algorithms to optimize the results of detection of SLGF and time of extinguishing the electric arc by making PC adaptive (APC). These methods include Fuzzy Logic (FL), Neural Networks (NN), Neural Fuzzy Networks (NFN), etc. Most of the cited heuristic methods application is on reducing the I_{fault} while some of them worked for the detection of SLGF, but no one considered the time of extinguishing the electric arc to minimize and optimize the inductance of the PC for the parallel resonance. Therefore, this research considers the parameters of time of detection of SLGF, reduction of I_{res}, reduction of time of extinguishing the electric arc, sensing & activation of protection devices for the I_{fault}/I_{res} when it is less than 20% using different proposed algorithm-based techniques such as Fuzzy Logic Control (FLC), hybrid Artificial Neural with Fuzzy Inference System (ANFIS), and hybrid Artificial Bee Colony with Neural Network (ABCNN) using MATLAB 2010a. Furthermore, ABCNN is the novel technique introduced in this thesis.

ABSTRAK

Sesar talian ke tanah tunggal (SLGF) ialah kerosakan yang paling biasa dalam rangkaian pengedaran sistem kuasa (PS). Kelemahan kerosakan ini adalah menyebabkan arus sisa (I_{res}) memulakan arka elektrik bersama-sama dengan voltan tinggi (HV) daripada susunan tiga kali voltan terkadar dalam fasa sihat yang lain. HV ini disebabkan oleh arus kapasitif (I_C). yang sangat berbahaya untuk penebat kabel serta peralatan PS, termasuk kakitangan dan sistem perlindungan. Untuk menyelesaikanI_{res} secara konvensional, Peterson Coil (PC) telah digunakan dengan menyambungkannya dengan titik neutral, yang mengurangkannya dan memadamkan arka elektrik, tetapi kedua-duanya tidak sepenuhnya, iaitu, masih terdapat beberapa nilai arus kerosakan (I_{fault}). Jika ia tidak dikurangkan ke satu tahap, memulakan arka sekali lagi boleh menjadilebih berbahaya kepada PS. Ramai penyelidik berminat untuk mengkaji pengesanan SLGF dan memadamkan arka elektrik. beberapa penyelidik tertumpu pada pengesanan SLGF, dan hanya sebilangan kecil yang berminat untuk mengkaji masa pemadaman arka elektrik. Penyelesaian ini tidak serasi dengan keperluan untuk membangunkan teknologi disebabkan oleh peningkatan permintaan untuk kecekapan, ekonomi, kebolehpercayaan, kualiti dan penggunaan tenaga elektrik. Oleh itu, ia digantikan dengan kaedah/algoritma lanjutan/heuristik untuk mengoptimumkan hasil pengesanan SLGF dan masa pemadaman arka elektrik dengan membuat penyesuaian PC (APC). Kaedah-kaedah ini termasuk Logik Kabur (FL), Rangkaian Neural (NN), Rangkaian Kabur Neural (NFN), dll. Kebanyakan aplikasi kaedah heuristik yang dipetik adalah untuk mengurangkan I_{fault} manakala sebahagian daripadanya berfungsi untuk pengesanan SLGF, tiada siapa yang mempertimbangkan masa memadamkan arka elektrik untuk meminimumkan dan mengoptimumkan kearuhan PC untuk resonans selari. Oleh itu, penyelidikan ini mempertimbangkan parameter pengesanan SLGF, pengurangan I_{res}, pengurangan masa pemadaman arka elektrik, penderiaan & pengaktifan peranti perlindungan untuk I_{fault}/I_{res}apabila ia kurang daripada 20% menggunakan teknik berasaskan algoritma yang berbeza. seperti

Kawalan Logik Fuzzy (FLC), Neural Tiruan hibrid dengan Sistem Inferens Kabur (ANFIS), dan Koloni Lebah Buatan hibrid dengan Rangkaian Neural (ABCNN) menggunakan MATLAB 2010a. Tambahan pula, ABCNN merupakan teknik novel yang diperkenalkan dalam tesis ini.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

C_{LN}	-	Line-to-neutral capacitance
C_{SG}	-	Capacitance between S-phase and ground
C_0	-	Zero-sequence capacitance
C_g	-	Ground capacitance
C_R	-	Capacitance of R-phase
C_S	-	Capacitance of S-phase
Fe_1	-	Feeder Number 1
Fe_2	-	Feeder Number 2
Fe_3	-	Feeder Number 3
I	-	Current
I_{0P}	-	Zero sequence Current in a PC
I_2	-	Negative Sequence Current
I_C	-	Charging Current
I_{CF}	-	Charging current in a neutral point
I_{CS}	-	Charging current in the S-phase
I_{CR}	-	Charging current in the R-phase
I_{fault}	-	Fault current
I_L	-	Inductive current
I_0	-	Zero-sequence current in the network
I_N	-	Neutral point current
I_{Rated}	-	Rated current
I_{res}	-	Residual Current
I_{adp}	-	Adaptive current
i_{1RST}	-	Currents of R, S, T- phases in feeder 1
i_{2RST}	-	Currents of R, S, T -phases in feeder 2
i_{3FR}	-	Fault current in R-phase in feeder 3
i_{3RST}	-	Currents of R, S, T- phases in feeder 3

L_{PC} or L	-	Inductor (PC)
V	-	Voltage
V_n	-	Voltage at the neutral point
V_{Rated}	-	Rated Voltage
V_0	-	Zero sequence voltage
V_L	-	Line voltage
V_N	-	Voltage at a neutral point
V_S	-	Phase voltage
Y_g	-	Star connection with the grounding
Y_n	-	Star connection with neutral without grounding
Z_L	-	Impedance of PC
ABC	-	Artificial Bee Colony
AG	-	Arcing Ground
ANN	-	Artificial Neural Network
ASC	-	Arc Suppression Coil
APFM	-	Amplitude-polarity feature matrix
APC	-	Adaptive Petersen Coil
AFLC	-	Adaptive Fuzzy Logic Control
AANFIS	-	Adaptive Neural Fuzzy Inference System
AABCNN	-	Adaptive Artificial Bee Colony with Neural Network
BDT	-	Big Data Theory
BST	-	Bayesian Selectivity Technique
CAET	-	Correlation Analysis of Extension Theory
CoG	-	Centre of Gravity
CT	-	Current Sensor
DLGF	-	Double Line To Ground Fault
DWPT	-	Discrete Wavelet Packet Transform
DWT	-	Discrete Wavelet Transform
DSP	-	Digital Signal Processing
DQ	-	Direct Quadrature
EA	-	Electric Arc
EMTP	-	Electromagnetic Transients Program
FL	-	Fuzzy Logic

FSCWT	-	Fuzzy Subtractive Clustering and Wavelet Transform
FIS	-	Fuzzy Inference System
FLS	-	Fuzzy Logic System
GS	-	Grounding System
GFC	-	Ground Fault Current
GRD	-	Grey Relation Degree
HV	-	High Voltage
HIF	-	High Impedance Fault
LLF	-	Line To Line Fault
TPGF	-	Three-Phase To Ground Fault
TFM	-	Time-Frequency Matrix
TGs	-	Traditional Grids
MISO	-	Multi-Input-Single-Output
MIMO	-	Multi-Input-Multi-Output
MVDN	-	Medium Voltage Distribution Network
MLP	-	Multi-Layer Perceptron
NFN	-	Neural-Fuzzy Network
NN	-	Neural Network
NNWT	-	Neural Network and Wavelet Transform
OV	-	Over Voltage
PC	-	Petersen Coil
PS	-	Power System
PM	-	Prony's Method
PSCAD	-	Power Systems Computer-Aided Design
PDM	-	Polarity Distribution Matrix
RGS	-	Resonant Grounding System
RG	-	Resonant Grounding
LA	-	learning algorithm
RS232	-	Cable (Recommended Serial Connection)
SCI	-	Serial Connection Interface
SLGF	-	Single Line Ground Fault
SVM	-	Support Vector Machines
TFM	-	Time-Frequency Matrix

TI	-	Texas Instruments
WT	-	Wavelet Transform
WFNN	-	Wavelet With a Fuzzy Neural Network

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Rapid urbanization and development are causing an increase in the consumption of electricity. The electricity supply through the grid system is facing many challenges due to numerous faults. Some faults are short-term faults (STF), while others are considered long-term faults (LTF). Typically, STF occurs due to failure of the conductor, fuse, circuit breaker, and protection relays. These faults are easy to repair within short intervals. Whereas LTF mainly occurs due to the failure of main power lines or other massive breakups of electricity supply equipment, therefore it is hazardous and takes time to get fixed. It causes a short circuit and disturbs the electricity supply. There are numerous reasons for LTF in the grid system. The common sources of a short circuit are the contact between two lines through metal, trees, wind, birds, and animals.

Four main faults in a distribution system, namely single line-to-ground fault (SLGF), line-to-line fault (LLF), double line-to-ground fault (DLGF), and three-phase to-ground fault (TPGF), comes under the category of LTF [1]. About 70% of the total faults in the distribution system are SLGF. During this fault, an electrical arc appears in the faulted phase and high voltage (HV) between two healthy phases. It is of the order of three times the phase-to-phase voltage, making network isolators risky to operate [2]. To avoid the leakage of unbalanced capacitance (C) charging current (I_C) at fault position due to SLGF, the neutral point must be grounded so that the unwanted residual current (I_{res}) flows to the ground. Though the application of classical Peterson Coil (PC) inductance (L) is a very old technique.

Even then, it is now being used in between the neutral point and the ground to reduce/compensate/control the I_{res} and extinguish the electrical arc to make the distribution network safer [3, 4]. The current (I) flowing through L is called Inductive Current (I_L).

Normally, the I_{res} is as of the amplitude of 3 times the rated current (I_{Rated}) also known as fault current $\left(I_{fault}\right)$. For this, in practice, the protection system works at the minimum threshold of ≥ 20% above the I_{Rated} counting it as a I_{fault} [2,5,6]. If the amplitude of I_{res} is >100% and <120% (not detected by the protection system), it may cause HV in healthy phases and restriking electric arc. It needs to be controlled otherwise, not only damage to the equipment of the power station but also hazardous to the personnel. This is of great concern and is the focus of this research. The controlled I in this range is known as the adaptive current $\left(I_{adap}\right)$. Based on the foregoing problem, this study seeks to address the issues raised by investigating aspects of SLGF detection and extinguishing electric arcs in a Medium Voltage Distribution Network (MVDN).

For controlling this I_{adap}, certain traditional methods, such as Wavelet Transform (WT), Prony's Method (PM), Time-Frequency Method (TFM), Big Data Theory (BDT), Grey Relation Degree (GRD), Correlation Analysis of Extension Theory (CAET), Bayesian Selectivity Technique (BST) were used at the initial stage and have become obsolete with the time period [5]. One of the reasons is the incompatibility with future demand, especially when it comes to detecting distribution network faults.

Different researchers have used different heuristic methods for the reduction of electric arcs. Such methods include Fuzzy Logic (FL), Neural Network (NN), and WT [4, 6, 7, 8, 9]. Among these methods, the NN possesses better system reliability and provides better network distribution results and safety for devices and personnel [10]. Moreover, [11, 12, 13, 14] identified the nature of faults (SLGF or LLGF), while [15] improved it and used the combination of a fuzzy-neural method to improve the fault detection and problem fixing analysis.

PC can be used with a combination of optimization techniques [16] to tune the L called adaptive PC (APC). In modern technology, the use of Artificial Intelligence (AI) seems to benefit in detecting the fault and thus reducing the electric arc. Therefore, the heuristic methods like Fuzzy Logic Control (FLC), hybrid Artificial

Neural Fuzzy Inference System (ANFIS), and hybrid Artificial Bee Colony Neural Network (ABCNN) can be used to make the APC. Therefore, the techniques applied will be known as adaptive FLC, ANFIS, and ABCNN and abbreviated as AFLC, AANFIS, and AABCNN, respectively.

The proposed techniques of AFLC, AANFIS, and novel AABCNN are used to identify the range of the suggested I_{res}/I_{fault}. For this purpose, a technique of parallel resonance was utilized to compensate for the I_L= I_C. Series resonance is not used for such compensation because it produces dangerous overvoltage (OV), the V_S between lines a bit non-symmetrical and creates a zero-sequence voltage (V_0) during a typical operation case [17, 18, 19, 20]. Moreover, to the best of the knowledge of the writer of this thesis, due to its adverse effects, none of the researchers had ever used it.

The developed algorithms of the proposed techniques were Simulated in Matlab on the real test case developed in Simulink. The real test case is a real MVDN called Babylon, Middle Euphrates power station of Iraq. Furthermore, for the validation purpose, the optimized results of the novel AABCNN were practically simulated on a power distribution simulator lying in the power laboratory of the Electrical Engineering department at the University of Babylon/ Iraq using online Texas Instrument Chip (eZdsp F28335) and compared with other researches as well. Besides, the results of AFLC and AANFIS were also compared with other research in terms of the time of SLGF detection and the time of extinguishing the electricity.

1.2 Problem Statement

It is the responsibility of the electric power utility/supplier to maintain the reliability of the power supply to the consumer. One or the other way, the overhead as well as underground PS faces challenges of faults and, consequently, power interruption [21, 22]. The causes of it can be natural as well as human error. Most of the faults are of SLGF in distribution networks [2]. One of the problems is HV in healthy phases due to I_{res} causing conductor insulators to fail, as well as other short circuits, posing a severe threat to the electrical distribution network [23]. This condition risks the network's operation devices, equipment, and technical personnel. Therefore, they need accurate, fast, dependable protection devices to supply electricity efficiently [24].

As discussed before, the protection system fails to work for the I_{fault} below the threshold of 20%, which makes hazardous conditions (in terms of V rise to three times between two healthy phases and restricting the electrical arc) for the PS if undetected and left unattended. Though a classical PC is still used to control the V at the neutral point (V_n) to make the system stable and extinguish the electric arc, it cannot detect the SLGF. Therefore, multiple heuristic methods, like FL, NN, WT, etc., are used to tune it in parallel resonance (called adaptive) for the detection of SLGF. Consequently, in this research, AFLC, AANFIS, and a novel AABCNN are used to tune PCs. Such algorithms were developed to quickly detect the SLGF and to optimize and reduce the time of extinguishing an electric arc. It was simulated using MATLAB 2010a.

A test case of a real MVDN (33 kV) was used in this respect. An I_L is applied to compensate for the resonance of the PC at the SLGF point. A typical challenging issue on which all this research is based was to observe the optimum value of L to tune the PC, which was solved through an experimental setup in the PS laboratory, department of electrical engineering at Babylon University, Iraq. A parallel resonance condition was chosen to ensure that the greater V, V_n is averted. For complete parallel resonance of the network, PC was made to be comparable to ground capacitance (C_g) that entirely compensates the I_{fault}.

1.3 Research Objectives

To achieve the main objective of this research, the detection of SLGF and optimizing the time of extinguishing the electric arc were studied in this research. For this, the behaviour of SLGF in MVDN was examined. Following are the sub-objectives which were set to obtain the main task.

(i) To develop a detection technique of I_{res} < 20 % of the I_{Rated} using AFLC, AANFIS, and AABCNN in SLGF.

(ii) To formulate a new optimization technique using the algorithm to reduce the time for the self-extinguishing of the electric arc.

(iii) To validate APC in parallel resonance technique, an offline AABCNN was compared with the results of practical/online AABCNN using Texas Instrument chip (eZdsp F28335) in MATLAB.

1.4 Research Scope

For the detection of SLGF and optimizing the time of extinguishing the electric arc, the following scope is set for this research.

(i) A real MVDN test case of 11 kV, 4-busbar at Babylon, Meddle Euphrates power station of Iraq, was selected for the simulation to achieve the set objectives.

(ii) The I_{rated} is set to 100 A for the purpose of the safety of equipment and personnel.

(iii) The SLGF was applied on the R phase in feeder 3 Fe_3 only.

(iv) The selected C, i.e., 0.5, 1.0, 1.5, 2.5, 3.5, 5.0 μF were used for the compensation of various turns of L with respect to the V_n and I_{fault}.

(v) The selected tapings of PC, i.e., 180, 254, 350, 405, 500, 605, 720, 885, 980, 1125, 1280, 1145, 1680, 2000, 2180, 2405, 2605, 2720, 2845 mH, were used to obtain the stable value of $\boldsymbol{V_n}$ as well as the least value of the I_{fault}.

(vi) Parallel resonance was used to limit the PC L.

(vii) The selected threshold value of I_{adap} is <20% of the I_{Rated}.

(viii) The considered threshold value of the I_{fault} for the overcurrent protective relay is 20%.

(ix) The considered total relay operation time is 0.3 Sec.

(x) The simulation tools of Matlab 2010a were used to attain the results.

(xi) Parallel resonance of L and C was selected to obtain the optimal APC.

(xii) The optimizing heuristic techniques of AFLC, AANFIS, and AABCNN were used.

(xiii) For the validity of offline AABCNN results, an online Texas Instrument chip (eZdsp F28335) in Matlab was chosen.

1.5 Research Contributions

This research made many contributions to the main knowledge by achieving the proposed research objectives. The primary purpose of the power protection system in a power system (PS) network is to trap the fault or abnormal situation quickly and take action instantly to remove it while saving the PS network against damage. But, there are certain limitations for the protection system to work efficiently. Due to certain limitations, the difficulty in extracting information from existing devices indicates that either the equipment is malfunctioning or out of reach, i.e., below/above the limits. One of the problems in PC-protected MVDN facing SLGF is the time of detection of fault and the time of arc extinguishing when the threshold value is below 20%. Therefore, in this research, the SLGF in a real MVDN of 11 kV, 4-busbar at Babylon, Meddle Euphrates power station of Iraq, was selected for the simulation in MATLAB. A total of three algorithms, i.e., FLC, ANFIS heuristic adaptive, and one novel ABCNN novel adaptive, were developed. The results were obtained for the time of detection of SLGF and the time of extinguishing the electric arc. For the validity, the FLC and ANFIS were confirmed by comparing with other research and novel ABCNN by testing on an online system using Texas Instrument Chip (eZdsp F28335) in MATLAB. The research contributions of this research are summarised below.

Initially, the compensation of $I_L = I_C$ in the parallel resonance, while the optimized value of L of the PC was obtained experimentally in the PS laboratory of the Babylon University of Iraq. It was found to be $L = 1145\ mH$. It helped to reduce the I_{fault} as well as to obtain the minimum V_n.

Secondly, the time of detection of SLGF in MVDN from 0.0075 Sec has been reduced to 0.005, 0.004, and 0.002 Sec while applying AFLC, AANFIS, and AABCNN, respectively.

Thirdly, the time of extinguishing of the electric arc in the case of SLGF in MVDN from 0.0675 Sec has been reduced to 0.065, 0.051, and 0.045 Sec while applying AFLC, AANFIS, and AABCNN, respectively.

Finally, the validation of the offline novel AABCNN was compared with the practical/online AABCNN using a Texas Instrument chip (eZdsp F28335) in MATLAB. It was found to be almost.

1.6 Organization of Thesis

This thesis is divided into five chapters. The following is a synopsis of each chapter: Chapter one is an introductory chapter that includes the background of the problem of SLGF in MVDN, its consequences, and remedial actions. Furthermore, this chapter

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Journal Article

1. Soomro, D. M., Tawafan, A. H and **Jabbar, F. I**. (2019). Methods in Single Phase to Ground Faults on Power Distribution Systems. Journal of Engineering and Applied Sciences (JEAS), 14 (7), p. 10058- 10066, October 2019. ISSN: 1816-949X.
2. **Jabbar, F. I** et al. (2020). Optimization of detection of SLG fault in distribution grid based on ABCNN Algorithm. International Journal of Artificial Intelligence (IJ-AI), 9 (4), p. 623-629, December 2020, ISSN: 2252-8938.
3. **Jabbar, F. I** et al. (2020). Optimization of detection of a single line to ground ‘SLG’ fault by controlling Peterson Coil through ANFIS. International Journal of Artificial Intelligence (IJ-AI), 9(3), p. 409-416, September 2020, ISSN: 2252-8938.

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