UNIVERSITI PUTRA MALAYSIA

GENETIC ALGORITHM-BASED OPTIMAL OVERCURRENT RELAYS COORDINATION FOR STANDALONE SUSTAINABLE HYDROKINETIC RENEWABLE ENERGY DISTRIBUTION NETWORK

SAIFUL ZUHAIMI AHMAD

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By

SAIFUL ZUHAIMI BIN AHMAD

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

July 2019

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DEDICATION

I would like to dedicate this project to my beloved family, all my supervisors and lecturers in the Department of Electrical and Electronic Engineering and friends and also to Public Work Department (PWD) as my sponsored. Their guidance and relentless support have been a great inspiration to the realization of this project.

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

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July 2019

Chairman : Mohammad Lutfi Othman, PhD, PEng
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The Standalone Sustainable Hydrokinetic Renewable Energy Distribution Network (SHRE-DN) system is a very unique distribution system. SHRE-DN is an off grid system and use a hydrokinetic concept which turn the river stream into a power generation source. The development SHRE-DN is to develop rural electrification system for native long houses along the river. The research study is tested on a DigSILENT develop model of the SHRE-DN and in accordance with all respectively unique parameters and relevant standards such as IEC or IEEE standard which is compulsory to comply for the relay protection scheme. The most commodious protection devices are overcurrent relays (OCRs) which responsible to isolate and clear a fault occurred into the distribution network. Generally, OCRs work in pairs knows as primary relay and backup relay. The primary relay must trip first in order to clear and isolate the fault accordingly. In the event of the primary relay is fail to trip or malfunction, the backup up relay must then took a place to trip and clear the faults. These relay must be set precisely so that the fault clearance can be done as shortest possible time to avoid undesirable tipping of the relays. Since SHRE-DN is a new standalone distribution system, an efficient and properly coordinated overcurrent protection system must be provided and it poses a great challenge to protection coordination scheme setup, due to the unique network topology. Improper and miscoordination among OCRs can result in maloperation of the protection system that can lead to false tripping and an unnecessary outage and power system instability. Thus, the objective of this work is to employ Genetic Algorithm (GA) technique in Matlab/Simulink for optimal overcurrent coordination and settings among all OCRs in the SHRE-DN in order to improve the speed of OCR tripping operation. OCRs depend on its Time Dial Setting (TDS) values which effect the operating time of the relays. This research work

propose the artificial intelligent (AI) solution on the objective function (OF) formulation, with the application of genetic algorithm (GA) optimization solver, to determine each relay best optimal operation for the TDS value and response time to fault accordingly and also eliminate miscoordination among the relays. GA are good at taking larger, potentially huge, search space and navigating them looking for optimal combinations of things and solution. Furthermore, the project is fast track and requiring the simplest method available. In this strategy, all TDS values belonging to the respective relays are given to the algorithm in order to get the optimized value of the TDS. The obtained optimized TDS Values from the GA Optimization Technique in Matlab/Simulink Toolbox produce about 20% and almost 52% improvement for each OCRs respectively. Overall improvement of the operating time for the protection scheme for the distribution network is about 36% of an improvement as compared to the conventional technique and approach in OCRs coordination and setting for the distribution network. Thus, the objective of this work to provide the most proper and efficient for the SHRE-DN is successfully achieved.

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

KORDINASI OPTIMA GEGANTI LEBIHAN ARUS BERASASKAN KEPADA ALGORISMA GENETIK BAGI RANGKAIAN BEBAS HIDROKINETIK TENAGA BOLEH BAHARU YANG MAPAN

Oleh

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Sistem rangkaian tersendiri tenaga boleh baharu yang mapan (SHRE-DN) merupakan sistem penjanaan dan pengagihan bekalan elektrik yang sangat unik. Sistem ini menggunakan konsep hidrokinetik yang mana ianya menukarkan tenaga arus sungai kepada sumber penjanaan tenaga elektrik. Pembangunan sistem ini adalah bagi memberi bekalan elektrik kepada penduduk rumah panjang yang tinggal di kawasan pedalaman di sepanjang dan berhampiran dengan sungai. Kerja-kerja kajian terhadap sistem rangkaian yang unik ini dilaksanakan dengan menggunakan model rangkaiannya yang dibangunkan dengan menggunakan perisian DigSILENT berdasarkan kepada data sebenar yang diukur di tapak kajian, selain perlu mematuhi piawaian berkaitan seperti piawaian IEC atau IEEE dalam penyediaan skim geganti perlindungan terhadap sesuatu rangkaian pengagihan bekalan elektrik. Geganti lebihan arus elektrik (OCR) merupakan peranti perlindungan elektrik yang utama yang bertindak untuk memutus dan mengasingkan kebocoran arus elektrik semasa berlakunya kerosakan elektrik di dalam sesuatu rangkaian pengagihan bekalan elektrik. Secara amnya, geganti lebihan arus beroperasi secara berpasangan yang dikenali sebagai genganti perlindungan utama dan geganti perlindungan sokongan. Peranti perlindungan utama mestilah beroperasi terlebih dahulu berbanding peranti perlindungan sokongan bagi memastikan pengasihan dan pemutusan bekalan elektrik dapat dibuat apabila berlakunya kerosakan arus di dalam sesuatu rangkaian pengagihan bekalan elektrik. Sekiranya geganti perlindungan utama gagal beroperasi, peranti perlindungan sokongan mestilah beroperasi bagi memastikan bekalan elektrik dapat diputuskan semasa berlakunya kerosakan arus elektrik yang sama terhadap sesuatu rangkaian pengagihan bekalan elektrik. Kerja-kerja penyelarasan dan kordinasi terhadap semua geganti perlindungan ini hendaklah dilaksanakan secara tepat dan jitu bagi memastikan pemutus litar

beroperasi sepantas yang mungkin bagi membebaskan kerosakan elektrik yang berlaku serta untuk mengelakkan kejadian bekalan elektrik terputus secara tidak diingini. Memandangkan sistem rangkaian pengagihan elektrik ini (SHRE-DN) merupakan sistem yang baru dan unik, kerja-kerja penyelarasan serta kordinasi geganti perlindungan elektrik yang efektif dan berkesan terhadap rangkaian tersebut merupakan cabaran utama bagi para jurutera ekoran keunikan rangkaiannya. Ketidaksesuaian dan salah kordinasi terhadap semua geganti perlindungan elektrik boleh menyebabkan geganti perlindungan gagal berfungsi dan mengakibatkan kejadian bekalan elektrik terputus secara tidak diingini serta menyebabkan bekalan elektrik yang tidak stabil. Justeru itu, objektif kajian kerja ini adalah untuk mengaplikasikan teknik genetik algorisma yang terdapat di dalam perisian Matlab/Simulik bagi kerja-kerja penyelarasan dan kordinasi geganti lebihan arus elektrik yang optima terhadap rangkaian pengagihan SHRE bagi memastikan masa operasi geganti lebihan arus elektrik dapat ditambah baik. Operasi masa bagi geganti lebihan arus elektrik ini bergantung kepada nilai laras dial masa (TDS) yang mana ianya memberi kesan terhadap masa operasi peranti perlindungan tersebut. Kerja-kerja penyelidikan ini mencadangkan penyelesaian pintar buatan (AI) mengenai fungsi objektif (OF), dengan penerapan pengoptimuman algoritma genetik (GA), untuk menentukan nilai optima terbaik TDS bagi setiap geganti yang memberi kesan kepada masa operasi geganti lebihan arus terhadap kerosakan arus elektrik yang berlaku serta menghilangkan ketidaklarasan dan kordinasi di antara geganti lebihan arus tersebut. Penggunaan GA merupakan kaedah yang baik dalam pencarian untuk mendapatkan penyelesaian yang optima terhadap sesuatu sesuatu carian di ruangan yang sangat besar dan luas. Selain itu, projek pembangunan SHRE-DN ini merupakan projek yang lah pantas dan oleh yang demikian penggunaan teknik tersedia dan efektif adalah diperlukan. Di dalam strategi ini, semua nilai TDS yang dimiliki oleh geganti masing-masing dimasukkan kepada algoritma genetik bagi mendapatkan nilai TDS yang optima. Dapatan nilai TDS yang optima melalui teknik GA menerusi perisian Matlab / Simulink Toolbox menghasilkan masing-masing sebanyak 20% dan 52% penambahbaikan bagi setiap geganti perlindungan lebihan arus tersebut. Secara keseluruhannya, jumlah peratusan penambahbaikan terhadap masa operasi bagi skim perlindungan untuk rangkaian SHRE-DN adalah sebanyak 36% berbanding penggunaan teknik konvensional bagi kerja-kerja penyelarasan dan koordinasi geganti perlindungan lebihan arus tersebut. Oleh yang demikian, objektif kajian kerja ini bagi penyediaan skim perlindungan lebihan arus elektrik yang berkesan dan optima untuk rangkaian pengagihan bekalan elektrik SHRE-DN tercapai dengan jayanya.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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- The research conducted and the writing of the thesis was under our supervision;
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LIST OF ABBREVIATIONS

ABC	artificial bees' colony
AI	artificial intelligence
ANFIS	adaptive network and fuzzy inference system
ANN	artificial neural network
CB	circuit breaker
CD	computational decision
CI	computational intelligence
CS	current setting
CT	current transformer
CTM	coordination time margin
DE	differential evolution
DOCR	directional overcurrent relay
DSP	digital signal processing
EC	evolutionary computation
EP	evolution programming algorithm
FFA	fire-fly algorithm
FBBC	fuzzy bang- bang controller
GA	genetic algorithm
GA-ANN	genetic algorithm –artificial neural network
GA-NLP	genetic algorithm and nonlinear programing
GAMS	general algebraic modelling software
HAS	harmony search's algorithm
HBA	honey bees' algorithm

HSA	harmony search algorithm
IDEA	informative differential evolution algorithm
IED	intelligent electronic device
IHSA	improved harmony search algorithm
LP	linear programming
LXPSO	laplace crossover partical swarm optimization
MDN	meshed distribution network
MLP	multilayer perceptron
MINLP	mixed integer nonlinear programming
MOF	modified objective function
NLP	non linear programing
OCR	overcurrent relay
OF	objective function
PS	plug setting
PSM	plug setting multiplier
PSO	particle swarm optimization
RBFNN	radial basis function neural network
RDN	radial distribution network
SHRE	sustainable standalone hydrokinetic renewable energy
SHRE-DN	sustainable standalone hydrokinetic renewable energy distribution network
TDS	time dial setting

CHAPTER 1

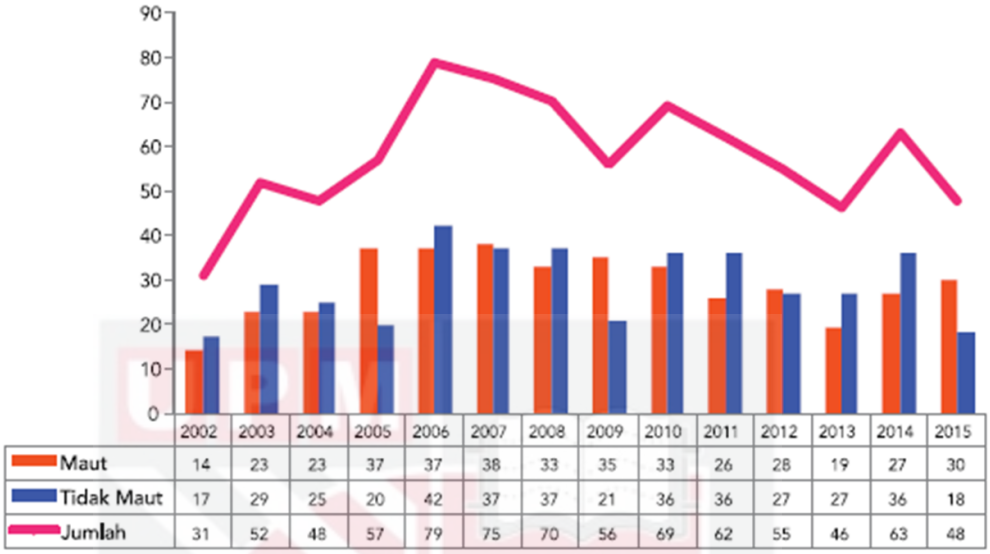
INTRODUCTION

1.1 Background of study

In the past decade, protection engineers and experts have used manual coordination of Overcurrent Relay (OCR) before it was treated as an optimization problem to the protective relays due to system size, system nonlinearity and the complexity of the system (Korde, 2016). The role of a protective relay (OCR) is to detect system abnormalities and to selectively execute appropriate commands in order to isolate the faulty component from the healthy system. For each fault location, in the event that any of these devices were to fail, each should be backed up by another protective device (Zellagui et al., 2015). The protection system should also have the functions of improving system stability, detecting faults, separating or isolating the faulty section from the rest of the system, and restoring normal operation after the fault clearance. A study of the reliability of a protection system is critical and necessary (D. K. Singh & Gupta, 2012; Dy et al., 2012; Masselot et al., 2016)
This study will focus on relay coordination and setting for Standalone Hydrokinetic Renewable Energy Distribution Network (SHRE-DN). The system is an off-grid system which uses the concept of hydrokinetic turbine which converts the river stream into a power generation source. Regardless of what type of power generation is used in any distribution network, several considerations have to be taken into account, especially the reliability and safety of the distribution network. This is to ensure safe, uninterrupted, and sustainable production of power. Among the major power quality issues in any power distribution network is a short circuit and course interruption of the power supply which can damage equipment connected to the power distribution system (D. K. Singh & Gupta, 2012).

According to the Electrical Safety Performance Report 2018 which was published by *Suruhanjaya Tenaga* (ST), a total of 952 accidents involving electricity has been reported and investigated during the period from 2002 to 2018 (July). The highest number of electrical accidents ever reported was 79 cases in 2006, 37 fatal cases and 42 non-fatal cases as shown in Figure 1.1 Electrical Safety and Performance Report (Laporan Prestasi and Keselamatan Elektrik, 'ST 2018')

Trends in the number of incidents of electric accidents (2002 – 2018)



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Maut	14	23	23	37	37	38	33	35	33	26	28	19	27	30
Tidak Maut	17	29	25	20	42	37	37	21	36	36	27	27	36	18
Jumlah	31	52	48	57	79	75	70	56	69	62	55	46	63	48

Figure 1.1 : Number of electrical accidents between 2002 to 2018 (ST safety performance report)

Thus, it is very important to provide a reliable protection scheme for any distribution network. The Overcurrent Relay (OCR) is the most frequently used protection device in a power distribution system. The OCR is connected to the circuit breaker, which receives trip commands to selectively eliminate the fault. Normally, there are two groups of OCR in a power distribution network. The first relay is called a “primary relay” and the other is called a “backup relay”. The backup protection relay is provided if the primary relay fails to operate during fault occurrence. Thus, the primary and backup relay pairs are chosen from the graph theory and relay characteristics to ensure that there is a proper coordination between the pairs. This is so that the backup relay will have sufficient time delay to allow the primary relay and its breaker to clear the fault (Singh et al., 2011). An operating time of backup relay is delayed from primary relay by a fixed margin known as coordination time interval (CTI). Relay malfunction could ptentially occur if they are not properly coordinated (Prashant P. Bedekar & Bhide, 2011). Statistical evidence shows, that large numbers of relay tripping are due to inadequate and improper relay setting and coordination, rather than being genuine fault occurrences (Hussain, Rahim & Musirin, 2013). Thus, a proper setting and coordination of these devices is very important for the protection scheme. Figure 1.2 and Table 1.1 show the basic principles of OCR coordination and protection scheme in a radial distribution network.

Table 1.1 : Primary relay and backup relay

Fault Location	Primary Relay	Backup Relay
I_{F34}	R_{34}	R_{23}
I_{F23}	R_{23}	R_{12}
I_{F12}	R_{12}	-

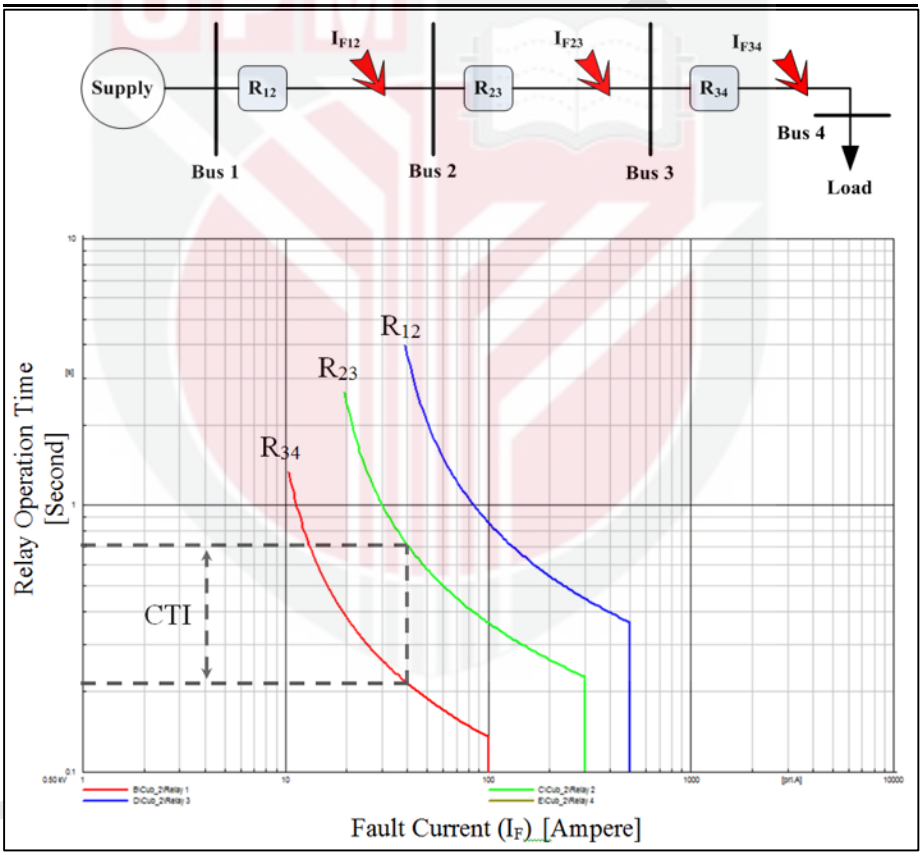


Figure 1.2 : Overcurrent relay coordination

1.2 Problem Statement

The complexities of OCR setting and coordination for this particular distribution system have posed a great challenge to protection engineers. Un-optimized coordination in SHRE distribution network among OCRs can result in wrong tripping of healthy section and subsequently lead to unnecessary outages, compromising power quality, and stability. Furthermore, if the operation time of OCRs (un-optimized) is too long, it also caused damage to power apparatus and, installation, threatening to personnel safety. Thus, it is very crucial to provide optimized OCR coordination in order to have a reliable protection scheme for the SHRE distribution network.

1.3 Research Objectives

In order to address the above stated problem, the following objectives are set out:

i. Improving the protection of the SHRE project by enhancing the coordination among relay, by way of GA based optimization of the relay setting of the TDS value according to IEC 60255-151:2009 which subsequently minimizes the operation time of each relay.

ii. To prove the effectiveness of the above mentioned strategy by comparing the GA based OCR coordination with that of the conventional approach.

1.4 Scope of Research

This study will focus and discuss on protection scheme only for SHRE distribution network which consists of four buses as depicted in Figure 1.3 below. The distribution network was successfully developed using DigSILENT Power Factory tools software.

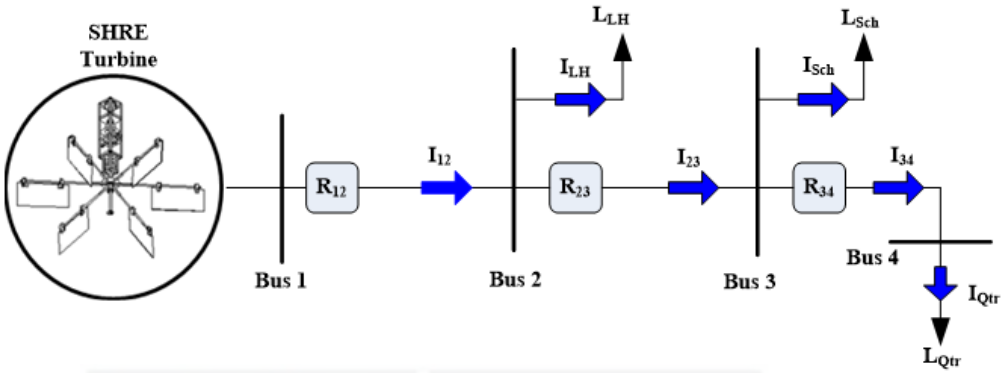


Figure 1.3 : SHRE distribution network

The study will then go on to provide a protection scheme for the distribution network and selection relay pairs appropriate for each station bus and branch protection within the entire system. This is to ensure total protection coverage and overlapping of all protection zones. The following research activities will be performed :

i. Determination of primary and backup relay pair selections for short circuit overcurrent flow within the SHRE distribution network.

ii. Simulation of the distribution network for load flow analysis and three-phase short circuit fault analysis on all buses and lines branch elements in sequence, with conformity to IEC 60909 standard. The simulation data extractions from load flow and short circuit fault analysis test across the test modeled system.

iii. Implementation of GA technique in order to provide better protection scheme for the distribution network.

iv. Result comparison in order to validate the protection scheme in terms of relay operating time.

1.5 Thesis Layout

Chapter 1 (Introduction), provide an overview of the background of this research work, including an overview of the concept of hydrokinetic technology. This is followed by the important of protection scheme, selection of protective

relays, research hypothesis, problem statement, research objective and research contribution.

Chapter 2 (Literature Review) discusses reviews on the conventional approach and several AI optimization techniques for OCR co-ordination and setting in power distribution network. Several AI applied optimization techniques were also considered and reviewed in solving this problem.

Chapter 3 (Methodology) discusses the elaborate steps in achieving the set research objectives, which is to optimize the OCR settings and TDS of each relay in order to provide the most effective and efficient protection scheme for SHRE distribution network. The modeling of the distribution network is the DigSILENT Power Factory Software. The procedures involved in achieving this was illustrated in detail in this chapter, with emphasis placed on international IEC60909 standards. Several simulations of the networks with references to load flow power analysis and three phase short circuit faults were carried out on the modeled networks. Selecting the proper Objective Function (OF) for GA technique, using GA Toolbox from Matlab/Simulink software and the entire sequence of procedures in achieving the set objectives are fully explained in this chapter including calculations and simulation works.

Chapter 4 (Results and Discussions) presents the results obtained and discussions on the outcome of all the findings, validations, and testing. Comparison and validations of result also presented and discussed in detail.

Chapter 5 (Conclusion) summarizes the derived conclusion from the research work, discussion on the research contributions and offers some recommendations for potential future research works, for purposes of bringing improvements.

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