UNIVERSITI PUTRA MALAYSIA

OPTIMAL OVERCURRENT RELAY COORDINATION IN WIND FARM USING GENETIC ALGORITHM

NIMA REZAEI

OPTIMAL OVERCURRENT RELAY COORDINATION IN WIND FARM USING GENETIC ALGORITHM

By

NIMA REZAEI

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

December 2015

DEDICATION

I would like to dedicate this project to my lovely wife, beloved parents, all my supervisors and lecturers in the Department of Electrical and Electronic Engineering and friends. 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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December 2015

Chair : Mohammad Lutfi Othman, PhD, PEng
Faculty : Engineering

Wind farms are ones of the most indispensable types of sustainable energies which are progressively engaged in smart grids with tenacity of electrical power generation predominantly as a distribution generation system. Thus, rigorous protection of wind power plants is an immensely momentous aspect in electrical power protection engineering which must be contemplated thoroughly during designing the wind plants to afford a proper protection for power components in case of fault occurrence. The most commodious protection apparatus are overcurrent relays (OCRs) which are responsible for protecting power systems from impending faults. In order to employ a prosperous and proper protection for wind farms, these relays must be set precisely and well-coordinated with each other to clear the faults at the system in the shortest possible time. These relays are set and coordinated with each other by applying IEEE or IEC standards methods, however, their operation times are relatively long and the coordination between these relays are not optimal. The other common problem in these power systems is when a fault occurs in a plant, several OCRs operate instead of a designated relay to that particular fault location. This, if undesirable can result in unnecessary power loss and disconnection of healthy feeders out of the plant which is extremely dire. It is necessary to address the problems related inefficient coordination of OCRs. Many suggestions have been made and approaches implemented, however one of the most prominent methods is the use of Genetic Algorithm (GA) to improve the function and coordination of OCRs. GA optimization technique was implemented in this project due to its ample advantages over other AI techniques including proving high accuracy, fast response and most importantly obtaining optimal solutions for nonlinear characteristics of OCRs. In addressing the mentioned problems, the main objective of this research is to improve the protection of wind farms by optimizing the relay settings, reducing their operation time, Time Setting Multiplier (TSM) of each relay, improving the coordination between relays after implementation of IEC 60255-151:2009 standard. The most recent and successful OF for GA technique has been used, unique parameters for GA was selected for this research to significantly improve the protection for wind farms that is highly better compared to any research accomplished before for the purpose of wind farm protection. GA was used to obtain improved values for each relay settings based on their coordination criteria. Each relay operation time and TSM are optimized which would contribute to provide a better protection for wind farm. Thus, the objective of this work which is improving the

protection of wind farms by optimizing the relay settings, reducing their operation time, Time Setting Multiplier (TSM) of each relay, improving the coordination between relays, have been successfully fulfilled and solved the problems associated with wind farm relay protection system settings. The new approach has shown significant improvement in operation of OCRs at the wind farm, have drastically reduced the accumulative operation time of the relays by 26.8735% (3.7623 seconds).

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

OPTIMAL OVERCURRENT PENYELARASAN RELAY DALAM LADANG ANGIN MENGGUNAKAN GENETIK ALGORITMA

Oleh

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ladang angin adalah orang-orang satu jenis yang paling penting dalam tenaga mampan yang progresif terlibat dalam grid pintar dengan ketabahan penjanaan kuasa elektrik terutamanya sebagai sistem penjanaan pengedaran. Oleh itu, perlindungan yang ketat loji kuasa angin adalah satu aspek yang amat bersejarah dalam kejuruteraan perlindungan kuasa elektrik yang perlu dipertimbangkan dengan teliti semasa mereka bentuk tumbuh-tumbuhan angin untuk memberi perlindungan yang sesuai untuk komponen kuasa dalam kes kesalahan kejadian. Radas perlindungan paling lapang adalah geganti arus lebih (OCRs) yang bertanggungjawab untuk melindungi sistem kuasa dari kesalahan akan berlaku. Dalam usaha untuk mengambil perlindungan yang makmur dan wajar bagi ladang-ladang angin, relay ini mesti ditetapkan dengan tepat dan diselaraskan dengan baik antara satu sama lain untuk membersihkan kerosakan pada sistem ini dalam masa yang sesingkat mungkin. Ini geganti ditetapkan dan diselaraskan antara satu sama lain dengan menggunakan IEEE atau IEC standard kaedah, bagaimanapun, masa operasi mereka adalah agak panjang dan penyelarasan di antara geganti ini tidak optimum. Masalah biasa lain dalam sistem kuasa adalah apabila berlaku kesalahan dalam tumbuhan, beberapa OCRs beroperasi bukannya relay yang ditetapkan untuk bahawa lokasi kesalahan tertentu. Ini, jika tidak diingini boleh menyebabkan kehilangan kuasa yang tidak perlu dan pemotongan pemakan sihat daripada tumbuhan yang amat mengerikan. Ia adalah perlu untuk menangani masalah berkaitan penyelarasan yang tidak cekap OCRs. Banyak cadangan telah dibuat dan pendekatan yang dilaksanakan, namun salah satu kaedah yang paling menonjol ialah penggunaan algoritma genetik (GA) untuk meningkatkan fungsi dan penyelarasan OCRs. teknik pengoptimuman GA dilaksanakan dalam projek ini kerana kelebihan yang cukup ke atas teknik AI lain yang termasuk membuktikan ketepatan yang tinggi, tindak balas yang cepat dan yang paling penting mendapatkan penyelesaian optimum untuk ciri-ciri tak linear OCRs. Dalam menangani masalah yang dinyatakan, objektif utama kajian ini adalah untuk meningkatkan perlindungan ladang angin dengan mengoptimumkan tetapan geganti, mengurangkan masa operasi mereka, Masa Menetapkan Multiplier (TSM) setiap relay, meningkatkan penyelarasan di antara geganti selepas pelaksanaan IEC 60255-151: standard 2009. Yang baru-baru ini dan berjaya OF untuk teknik GA telah digunakan, parameter unik untuk GA telah dipilih untuk kajian ini dalam meningkatkan perlindungan untuk ladang angin yang sangat lebih baik berbanding dengan apa-apa penyelidikan dicapai sebelum ini untuk tujuan perlindungan ladang angin. GA telah digunakan untuk mendapatkan nilai yang lebih baik untuk setiap tetapan geganti berdasarkan kriteria penyelarasan mereka. Setiap kali operasi relay dan TSM dioptimumkan yang akan menyumbang untuk memberi perlindungan yang lebih baik untuk ladang angin. Oleh itu, objektif kajian ini yang meningkatkan perlindungan ladang angin dengan mengoptimumkan tetapan geganti, mengurangkan masa operasi mereka, Masa Menetapkan Multiplier (TSM) setiap relay, meningkatkan penyelarasan di antara geganti, telah berjaya memenuhi dan menyelesaikan masalah berkaitan dengan tetapan sistem perlindungan relay ladang angin. Pendekatan baru telah menunjukkan peningkatan yang ketara dalam operasi OCRs di ladang angin, telah secara drastik mengurangkan masa operasi terkumpul geganti oleh 26,8735% (3,7623 saat).

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I certify that a Thesis Examination Committee has met on 22 December 2015 to conduct the final examination of Nima Rezaei on his thesis entitled "Optimal Overcurrent Relay Coordination in Wind Farm using Genetic Algorithm" 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 Master of Science.

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This is to confirm that:

- 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 Fuzzy Inference System
ANN	Artificial Neural Network
BP	Breaking Point
CB	Circuit Breaker
CGA	Continuous Genetic Algorithm
CT	Current Transformer
CTI	Coordination Time Interval
DE	Differential Evolution
DFIG	Dual Fed Induction Generator
DG	Distribution Generation
DSP	Digital Signal Processing
EP	Evolutionary Programming
FBBC	Fuzzy Bang Bang Controller
FCL	Fault Current Limiter
FLC	Fuzzy Logic Controller
GA	Genetic Algorithm
GAMS	General Algebraic Modelling Software
HBA	Honey Bee Algorithm
HGAPSOA	Hybrid GA & PSO Algorithm
HSA	Harmony Search Algorithm
IHSA	Improvised Harmony Search Algorithm
LP	Linear Programming
LXPSO	Laplace Crossover Particle Swarm Optimization
NIA	Nature Inspired Algorithm
NLP	Nonlinear Programming
NM	Nelder Mead Simplex Search Method
OCDE	Opposition Based Chaotic Differential Evolution Algorithm
OCR	Overcurrent Relay
OF	Objective Function
PS	Plug Setting of the Relay
PSM	Plug Setting Multiplier
PSO	Particle Swarm Optimization
RBFNN	Radial Basis Function Neural Network
RSI	Relay Setting Current (Intensity)
ST	Slantlet Transform
TSM	Time Setting Multiplier
UFCL	Unidirectional Fault Current Limiter

CHAPTER 1

INTRODUCTION

1.1 Background

Human Activity and exhaustion of fossil fuels as the conventional method of power generation has overloaded our atmosphere with vast emission of carbon dioxide and consequently resulted in global warming, harmful impact on our environment and health. Thus a new supply for power generation that has no adverse effect on the atmosphere and our health must be employed. Renewable energies including wind power, solar energy, hydro power and geothermal energy have shown significant promise as a suitable replacement for fossil fuels. It is expected that in the upcoming future, a large share of power generation is directly derived from renewable energies (particularly wind, solar and hydro power) hence, reliance on fossil fuels will be drastically diminished.

1.1.1 Wind Power Plants

Due to the rapid growth in power demands, the ever increasing air pollution rate in addition to the decrease of unrenewable fossil fuels, there is an imminent necessity to transfer, at least partially, the dependence on fossil fuels to renewable energy resources. Among these resources, wind energy converted to electric energy has emerged as the leader at the present time (Dincer, 2000). Wind power plants have been vastly employed as the means of power generation in smart grids as a distribution generation (DG) systems (Mohd et al., 2008). Undoubtedly, wind power has come to be mainstay of the energy systems in several countries and is regarded as a reliable and financially reasonable source of electricity. The contribution of wind energy to power generation has reached a considerable share even on the worldwide level. Among many countries that are investing hugely on wind power generation, the top 10 leading nations in total power generation capacity are: China, USA, Germany, Spain, India, United Kingdom, Italy, France, Canada and Portugal (Heier, 2014).

The future of wind farms are very remarkable and astonishing since their costs are being dropped annually due to applauding advancement in wind turbine efficient power generation and using lighter and longer blades. Therefore they will attain a much higher share of power generation in many countries in the near future which would buoyantly result in gradual replacement for conventional air pollutant power plants based on fossil fuels including coal, gas and oil which are highly destructive and disparaging toward the environment (Chu et al., 2012).

1.1.2 Why Wind Farms? (Wind Power Plants Advantages)

Wind energy offers many advantages, which explains why it's the fastest-growing energy source in the world. Nowadays wind farms are being extensively implemented by many developing countries due to its ample advantages and financial aspects. Here are the most significant advantages of wind farms stated as the following (Panwar et al., 2011):

i. Wind Energy is an inexhaustible source of energy and is virtually a limitless resource
ii. Electricity created using wind energy do not produce any greenhouse gases and therefore do not pollute the environment
iii. Wind turbines take up less space than the average power station. Wind turbines only have to occupy a few square meters for the base, this allows the land around the turbine to be used for many purposes, for example agriculture
iv. This source of energy has tremendous potential to generate energy on large scale
v. Wind energy can be used directly as mechanical energy
vi. Marginal maintenance and less construction cost required
vii. The cost of wind farms are getting diminished gradually as a result of new technologies and advancement emerged
viii. Capable of getting connected to smart grids as a DG system
ix. Able to produce abundant power energy in GW capacity
x. In remote areas, wind turbines can be used as great resource to generate energy and also reduce costs due to elimination of transmission lines and power energy loss reduction
xi. In combination with solar energy they can be used to provide reliable as well as steady supply of electricity
xii. Land around wind turbines can be used for other uses, e.g. farming

1.1.3 Wind Power Plants Protection Issues

The impressive growth in the utilization of wind energy has consequently spawned active research activities in a wide variety of technical fields. Progressively amplification of grids by wind farms have led to emergence of some significant electrical issues including security, protection, stability, reliability and power quality. Among these issues, protection aspect plays an enormous role which needs a serious attention by researchers. Although protection of wind farms is a crucial issue that needs a huge attention, wind power plants still implement simple protection schemes which lead to different levels of damages to power components in the plant. Moreover, most of the researches conducted regarding wind farm protection have been abundantly restricted to literatures and methodologies (Kawady et al., 2008). As reported by (Bauscke et al., 2006), different levels of damage were recorded resulting occasionally from the drawbacks of the associated protection systems. However an overall protection scheme has yet to come to solve the protection crisis in wind plants (Qureshi et al., 2014).

1.2 Hypothesis of Research

Employing Overcurrent Relays (OCRs) as the proper protection system to provide a suitable protection for wind farms. Adapting the correct settings for OCRs based on IEC 60255-151:2009 standard, provide a proper coordination between the relays in the wind farms to protect apparatus in the presence of fault (Bajánek et al., 2015), (Almas et al., 2012). Implementing Genetic Algorithm (GA) approach as a vigorous and successful method of optimization in order to decrease TSM, operation time of OCRs, consequently optimizing OCRs settings and reaching optimal setting values for OCRs in the wind farm.

1.3 Problems in Wind Farms Protection (The Problem Statements)

As aforementioned, the increasing integration of wind power plants to power grids and their vast utilization have led to emergence of some electrical issues related to security, protection, stability, reliability and power quality. Increase in number of faults in power systems and consequently wind plant protection failures have caused further damages to power systems and accordingly hiked the costs (Kawady et al., 2009), (Yang et al., 2010). The main wind farm protection problems are:

- Improper and non-optimal conventional settings for overcurrent relays in wind farms. The coordination settings between these relays are not optimal (Kawady et al., 2010) which consequently would result in:
    1. Miscoordination in high current faults, cause crucial damages to power apparatus
    2. Operation of Several relays, causing extended power loss, compromised power quality and stability
- OCR operation times are quite long that damage power apparatus, installation and endanger personnel safety.

These problems are resulted from lack of optimization such as failing to implement optimization techniques including GA technique in order to improve and optimize OCR settings. There are much rooms for improvement of wind plants by using optimization techniques in order to reduce the operation time of relays and enhance the relay coordination.

1.4 Objectives of Research

In addressing the above mentioned problems, the main objectives of this research is:

- Improving the protection of wind farms by enhancing the coordination between relays, by way of optimizing the relay settings according to IEC 60255-151:2009 standard through the optimization of TSM and subsequently the operation time of each relay.
- Implementing GA, as a powerful optimization branch of artificial intelligence approach, to obtain improved values for each relay settings based on their coordination criteria. Each relay operation time and TSM are optimized by using GA method which would consequently contribute to provide a better protection for wind farms.

1.5 Scopes of Research

In this study, only protection of power apparatus within the wind farm has been studied and has not discussed the protection outside the wind farm, including power grids. This study has discussed modelling and simulation of wind farm based on SEL, modelling and simulation of overcurrent relays based on IEC 60255-151:2009 standard in Matlab/Simulink software. Moreover, Genetic Algorithm simulation and coding with the purpose of overcurrent relay coordination was carried out in Matlab/Toolbox.

1.6 Thesis Layout

Chapter 1, the current (Introduction), provides an insight on the necessity and importance of providing a proper protection for wind farms by using OCRs and improving their settings, coordination between relays in a feeder from grid to the wind turbines, decreasing T and TSM for each relay by applying GA technique in order to optimize the relays settings.

Chapter 2 (Literature Review) discusses reviews on different artificial intelligence techniques which have been successfully implemented for OCRs in different schemes including in distribution systems, power plants, transmission lines and etc. This chapter also provides a review on GA technique applied by researchers in order to optimize OCRs settings and coordination between them which is so crucial in protection of power components.

Chapter 3 (Methodology and Procedures) discusses the elaborate steps in achieving the research objectives that is to optimize the OCRs settings T and TSM of each relay, improving their coordination by using GA approach. In this chapter, various steps are demonstrated including modelling and simulation of wind farms, modelling and simulation of OCRs, selecting the proper settings for each relay based on the data calculated by wind farms simulation and IEC 60255-151:2009 standard, Selecting the proper objective function for GA technique, using GA Toolbox from Matlab/Simulink software in order to define, program and set the characteristic of the algorithm for the relays in a feeder and finally use these GA settings in order to optimize the relays settings.

Chapter 4 (Results and Discussions) presents the results and explanations on subjects discussed in chapter 3: Modelling and simulation of a typical wind power plant using Matlab/Simulink software, designating the proper location of OCRs protection systems in order to protect the power components from faults, modelling and simulation of OCRs based on IEC 60255-151:2009 standard with Matlab/Simulink software, extracting the data from current magnitudes flowing to each OCR before, during and after fault occurrence, selecting the suitable OCRs settings based on IEC 60255 standard for each relay and considering the coordination of the relays with each other, testing and validating the designed OCRs protection system in order to ensure its reliability to provide the wind farms with proper protection, selecting the appropriate objective function for Genetic Algorithm technique, using Genetic Algorithm Toolbox from Matlab/Simulink software in order to define, program and set the characteristic of the algorithm for the relays in a feeder, optimizing the OCRs settings including T and TSM of each relay by the programmed Genetic Algorithm and improve the protection for the wind farm, testing the new approach and validating the OCRs settings and their coordination from the grid to the wind source in each feeder for variant positions of faults, compare the results of the conventional approach for OCRs coordination with results obtained by applying Genetic Algorithm technique used for optimizing the OCRs settings.

Chapter 5 (Conclusion) shall derive the conclusion on the research work, discuss the research contributions and recommend some potential future researches.

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Nima Rezaei was born in Shiraz, Iran, on July 26, 1990. He received the B.S degree from Science and Research of Fars University in 2012 and he is currently pursuing M.S. Degree in Electrical Power Engineering at Universiti Putra Malaysia (UPM), in Malaysia. His field of interest includes Electrical Power Protection Systems, Wind Power Plants Protection System Design and Calculation, Optimization Tools using Artificial Intelligence, Renewable Energies and Electrical Power Engineering.

He has published several papers in international journals and conferences with the research emphasis on wind power plants protection using overcurrent relay, Coordination of overcurrent relays, Optimizing overcurrent relay coordination using Genetic Algorithm Artificial Intelligence approach, power quality and electrical power protection system improvement. In the course of his master, one of his papers won “the best student paper award” during “PEcon IEEE conference”. Moreover during international conference in South Korea, one of his papers was selected as “one of the most outstanding papers”.

LIST OF PUBLICATIONS

Rezaei, N.; Othman, M. L.; Wahab, N. I. A.; Hizam, H.; Maghami, M. R.; Hajighorbani, S.; & Olufemi, O. E. (2014). Optimal Coordination of Overcurrent Relays in Power Systems Protection: A Review. *Jökull Journal, 64(4).*

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