OPTIMUM DG ALLOCATION CONSIDERING PROTECTION COORDINATION AND NETWORK PERFORMANCE EVALUATION

By

AHMED MOHAMED ABDELBASET AHMED

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
In
Electrical Power and Machines Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

OPTIMUM DG ALLOCATION CONSIDERING PROTECTION COORDINATION AND NETWORK PERFORMANCE EVALUATION

By

AHMED MOHAMED ABD ELBASET AHMED

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
In
Electrical Power and Machines Engineering

Under the supervision of

Prof. Essam M.Aboul-Zahab

Professor of Electrical Power Engineering
Electrical Power and Machines Department
Faculty of Engineering
Cairo University

Prof. Mohamed A. Moustafa Hassan

Professor of Control in Power systems
Electrical Power and Machines Department
Faculty of Engineering
Cairo University

Assoc. Prof. AboulFotouh Abdel Rehiem Mohamed

Associate Professor in Electrical Power Engineering
Electrical Power and Machines Department
The Higher Institute of Engineering
El-Shorouk Academy

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

Engineer: Ahmed Mohamed Abd-Elbaset Ahmed
Date of Birth : 21 / 5 / 1985
Nationality : Egyptian
E-mail : Ahmed_baset2007@yahoo.com
Phone. : 01001617009
Address : 11 sharq El-seka El hadid street Ahmed Essmat, Ain shams, Cairo, Egypt

Registration Date : 1 / 10 /2015
Awarding Date : / / 2020
Degree : Doctor of Philosophy
Department : Electrical Power and Machines Engineering

Supervisors : **Prof. Dr.** Essam Mohamed Aboul-Zahab
Prof. Dr. Mohamed Ahmed Moustafa Hassan
Assoc. Prof. AboulFotouh Abdel Rehiem Mohamed (The Higher Institute of Enginnering at Elshorouk City)

Examiners : **Prof. Dr.** Essam Mohamed Aboul-Zahab (Thesis main advisor)
Prof. Dr. Mohamed Ahmed Moustafa Hassan (Advisor)
Prof. Dr. Hossam Kamal Mohamed Youssef (Internal Examiner)
Prof. Dr. Almoataz Youssef Abdelaziz (External Examiner) (Ain Shams University)

Title of Thesis: Optimum DG Allocation Considering Protection Coordination and Network Performance Evaluation

Key Words:
Distributed Generation, Radial Systems, Optimum allocation, Protection Coordination.

Summary :

This thesis introduces two strategies associated with recloser fuse miscoordination (RFM) that arises due to the presence of DG in the distribution networks.
The first strategy presents an approach to determine the maximum suitable size of DG with certain constraints to avoid the coordination failure between the existing devices in addition to other keys taken into consideration such as improving voltage profile, reducing fault current and minimize system power loss.
The second approach is used to obtain the optimum settings for recloser and fuses in the presence of single/multiple DG units which can coordinate properly with different sizes and location of DGs in the system with suitable time coordination interval. Two multi objective functions are proposed. The first associated with RFM problem to minimize the sum of operating time of all fuses and recloser and the second is consider technical benefits such as voltage profile enhancement and power loss reduction.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: **Ahmed Mohamed Abdelbaset** Date:

Signature: *Ahmed Abdelbaset*

Acknowledgments

Thanks to ALLAH who gives us the power and hope to succeed.

I am honored to record my deepest sense of gratitude and thanks to **Prof. Dr. Essam Eldin M. Abu Elzahab – Cairo University, Prof. Dr .Mohamed A. Moustafa Hassan – Cairo University** and to **Assoc.Prof. Aboulfotouh Abdelrehiem Mohamed – Head of Electrical Power and Machines Department – El-Shorouk Academy** for their valuable supervision, continuous encouragement, stimulating discussion, generous guidance, and scientific support, without which the present study would not have been carried out.

I wish to express my thanks to **Prof. Dr. Essam Eldin M. Abu Elzahab** and **Prof. Dr. Mohamed A. Moustafa Hassan** for their critical readings, guidance, discussion and also the useful suggestions to my thesis.

Furthermore, I would like to express my deepest gratitude and thanks to all staff members of the Electric Power and Machines Department in El-Shorouk Academy for their encouragement and support for contributing to such an inspiring and pleasant atmosphere.

There are not enough words to thank **my parents, my brothers and my sister** for the good family atmosphere, which helped in completing this thesis and encouragement during all time of hard work to complete it.

Very special thanks to **my wife** who stood by me and encouraged me.

Last but not least, special thanks to **my sons Mohamed** and **Moustafa** who are my absolute happiness.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ALO	Ant lion Optimizer Algorithm
BIBC	Bus Injection to Branch Current
BCBV	Branch Current to Bus Voltage
CB	Circuit Breaker
CSA	Crow search Algorithm
DG	Distributed Generation
DSS	Distribution System Substation
FC-MT	Fuel Cell –Micro Turbine
FMM	Fuse Minimum Melting
FTC	Fuse Total clearing
GA	Genetic Algorithm
IPM	Interior Point Method
LDC	Line Drop Compensation
LTC	Load Tap Changing
LV	Low Voltage
MT	Micro Turbine
MV	Medium Voltage
PSO	Particle Swarm Optimization
R	Recloser
RBTs	Roy Billinton Test System
RFM	Recloser Fuse Miscoordination
SI	Standard Inverse
EI	Extremely Inverse
T & D	Transmission and Distribution
THD	Total Harmonic Distortion
WOA	Whale Optimizer Algorithm

List of Symbols

n	Number of buses
F_{loss}	System power loss
P_{lossi}	Active power loss at i-th buses
Q_{lossi}	Reactive power loss at i-th buses
P_{DGi}	Real power from DGs placed at node i
P_{Di}	Load active Power at node i
V_i	Voltage magnitude at bus i
V^{Min}	Minimum Voltage limit
V^{Max}	Maximum Voltage limit
TMS	Time multiplier setting
OLF	Over load factor
t_{rec}	Operating time of recloser
I_f	Recloser fault current
I_{pickup}	Pickup current setting of recloser
M	Ratio of I_f/ I_{pickup}
A,B,P	Constants based on curve characteristics
I_{max}	Max current passing through recloser
t_{fuse}	The operating time of fuse
I_{ff}	The fault current passing through fuse
a, b	Fuse constant
nfuse	Total number of fuses
$t_{recfast}$	Operating time of recloser for fast mode
$t_{recslow}$	Operating time of recloser for slow mode
MFCM	Minimum Fuse coordination margin
MRCM	Minimum Recloser coordination margin

Abstract

Connection of Distributed Generation (DG) units to the distribution systems with proper allocation and size has different affirmative effects such as increasing the reliability of the network, decreasing losses, improving voltage profile, decreasing transmission and distribution energy costs and improving the power quality.

With the widespread of using DG, the connection of DGs in the distribution system might cause difficulties in the operation of protective devices and protection coordination.

This thesis introduces the problems associated with Recloser Fuse Miscoordination (RFM) that arises due to the presence of DG in the distribution networks. Thus two strategies are proposed to avoid the miscoordination between recloser and fuse.

The proposed strategies are based on the general framework to maintain the coordination between recloser and fuse in distribution systems with optimizing DG over certain constraint considering the performance of the distribution system such as voltage profile enhancement and system power loss reduction.

The first strategy presents an approach to determine the maximum suitable size of a DG that can be connected to distribution networks with certain constraints to avoid the coordination failure between the existing devices in addition to other keys taken into consideration such as improving voltage profile, reducing fault current and minimize system power loss. So this scheme has a set of necessary equations to keep the existing protection devices unchanged according to protection coordination constraint. Such equations restrict the sizing of DG sources and permit all the existent protective elements to work normally. Evolutionary Techniques namely Whale Optimizer Algorithm (WOA), Ant lion Optimizer Algorithm (ALO), and Crow Search Optimizer Algorithm (CSA) are applied to find the optimal size and location of DG for radial distribution system considering protection coordination constraints.

The performance of the suggested methodology is examined through its application to two systems. The first one is a modified Roy Billinton Test System (RBTS) BUS2 and the second is a Standard IEEE 33 node test system.

The second strategy presents an approach based on optimum recloser fuse coordination in the presence of single/multiple DG units over a certain constraint with considering power loss reduction and voltage profile enhancement. For this purpose, two multi objective optimization problems are presented. The first is based on technical impacts to determine the optimal size and location of single and multiple DG considering system power loss reduction and enhancement of the voltage profile with certain constraints and the second is used for minimizing the operating time of all fuses and recloser with obtaining the optimum settings of fuse recloser coordination characteristics with suitable time coordination interval. The Whale Optimizer Algorithm (WOA) emulates the RFM as an optimization problem and applied to solve

the formulated problem to attain a fixed recloser and fuse characteristics which can coordinate properly with different sizes, location and operating conditions of DGs in radial distribution systems.

The effectiveness of the presented methodology is examined through its application on Standard IEEE 33 node test system.

The results indicate the robustness of the proposed algorithm compared with other techniques among all the methods considered in this work for solving the RFM problem with achieving system power loss reduction and voltage profile enhancement.

The thesis evinces the importance of selecting the correct size, suitable location of DG for avoiding the miscoordination problem between the protective devices with obtaining good performance of the distribution system.