



Ain Shams University
Faculty of Engineering

An Effective Adaptive Overcurrent Protection Scheme for Microgrids

By

Eng. Mohamed Awaad Abd-elkhalek

A Thesis Submitted for the Requirement of Master
Degree of Sciences in Electrical Power Engineering

Supervised by

Prof. Dr. Almoataz Youssef Abdelaziz

Assoc. Prof. Dr. Said Fouad Mekhamer

Cairo 2018

SUPERVISORS COMMITTEE

Name: Mohamed Awaad Abd-elkhalek

Thesis title: An Effective Adaptive Overcurrent Protection Scheme for Microgrids

Degree: Submitted in partial fulfillment of the requirements for the M.Sc. degree in electrical engineering.

Name, title and affiliation

Signature

1. Prof. Dr. Almoataz Y. Abdelaziz

Electrical Power and Machines Dept.
Faculty of Engineering,
Ain Shams University

2. Assoc. Prof. Dr. Said F. Mekhamer

Electrical Power and Machines Dept.
Faculty of Engineering,
Ain Shams University

EXAMINERS COMMITTEE

Name: Mohamed Awaad Abd-elkhalek

Thesis title: An Effective Adaptive Overcurrent Protection Scheme for Microgrids

Degree: Submitted in partial fulfillment of the requirements for the M.Sc. degree in electrical engineering.

Name, Title and Affiliation

Signature

1. **Prof. Dr. Mousa A. Abdullah**
Electrical Power and Machines Dept.
Faculty of Engineering at Shoubra
Benha University

2. **Prof. Dr. Soliman M. El-debeiky**
Electrical Power and Machines Dept.
Faculty of Engineering
Ain Shams University

3. **Prof. Dr. Almoataz Y. Abdelaziz**
Electrical Power and Machines Dept.
Faculty of Engineering
Ain Shams University

4. **Assoc. Prof. Dr. Said F. Mekhamer**
Electrical Power and Machines Dept.
Faculty of Engineering,
Ain Shams University

Statement

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Sciences in Electrical Engineering.

The work included in the thesis was carried out by the author at the department of Electrical Power and Machines, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

Name: Mohamed Awaad Abd-el khalek

Signature:

Date:

Acknowledgement

All favor is due to Allah, the most Merciful, and the lord of the worlds, who taught human what he doesn't know. I am extremely grateful to Allah for giving me the power to accomplish this work.

I would like to thank **Prof. Dr. Almoataz Youssef Abdelaziz**, one of my two thesis supervisors, for his invaluable supervision directions, and supervision work, his wise advice, his patience and for allowing me the opportunity to develop this work.

Also, I would like to thank **Assoc. Prof. Dr. Said Fouad Mekhamer**, my other thesis supervisor, for his valuable supervision guidance and wise advices during this research work and for his continuous patience in reviewing the drafts during the preparation of this thesis.

Finally, I have to thank my family for the help and support. I regard the encouragement of my parents, my wife and my friends, to whom I dedicate this thesis.

Table of Contents

ABSTRACT	XIII
CHAPTER (1): INTRODUCTION	1
1.1-Background	1
1.2-Objectives of the present research	3
1.3-Importance of the present research	4
1.4-Thesis outline	4
CHAPTER (2): LITERATURE REVIEW	6
2.1- Conventional power system description	6
2.2- DG definitions	7
2.3- Advantages of DG interconnection to distribution system	7
2.4- Disadvantages of DG interconnection to distribution system	8
2.5- MicroGrid definition and operating philosophy	9
2.6- MicroGrid advantages	9
2.7- MicroGrid islanding	10
2.8- Protection challenges or issues due to DG insertion in distribution system	10
2.9- DG disconnection when fault happens	15
2.10- DG impact on Protection Coordination	19
2.11- Traditional attempts to solve protection coordination issue	19
2.11.1- Time grading with directional element	19
2.11.2- Flywheel storage unit in series with DG	20
2.11.3- Single setting method	20
2.11.4- Usage of FCL in series with DG	20
2.11.5- Using a static series compensator in series with utility grid	20
2.12- Reasons for a new protection technique for MicroGrids	21
2.13- Requirements in technique used for MicroGrid Protection	22
2.14- Different protection techniques for MicroGrid	22
2.14.1- Adaptive techniques	23
2.14.2- Differential protection	23
2.14.3- Distance protection	24
2.14.4- MG protection based on voltage	24
2.14.5- External devices deployment	25
2.14.6- Protection techniques depend on symmetrical components and overcurrent	25

CHAPTER (3): ADAPTIVE PROTECTION TECHNIQUES	27
3.1- Adaptive protection meaning.	27
3.2- Requirements for adaptive protection practical implementation	27
3.3- Different adaptive techniques	29
3.4- The proposed adaptive idea	36
 CHAPTER (4): NETWORK MODELS	 37
4.1- Radial system case study	37
4.1.1- <i>System sources</i>	37
4.1.2- <i>Radial system parameters selection</i>	39
4.1.2.1- <i>Current Transformers (CTs)</i>	40
4.1.2.2- <i>Switches</i>	42
4.1.2.3- <i>Circuit Breakers (C.Bs)</i>	43
4.1.2.4- <i>Transmission Lines (T.Ls) and Cables</i>	45
4.2- Looped system case study	45
4.2.1- <i>System sources</i>	46
4.2.2- <i>Looped system parameters selection</i>	47
4.2.2.1- <i>Current Transformers (CTs)</i>	47
4.2.2.2- <i>Switches</i>	50
4.2.2.3- <i>Circuit Breakers (C.Bs)</i>	51
4.2.2.4- <i>Transmission Lines (T.Ls) and Cables</i>	52
4.3- General overcurrent relay characteristics:	52
4.3.1- <i>Different Relays characteristics</i>	52
4.3.2- <i>General Pickup settings</i>	54
4.3.3- <i>General Coordination Time Interval (CTI)</i>	56
4.4- Steps for planning coordination study	62
 CHAPTER (5): SIMULATION AND RESULTS	 65
5.1- Steps of work done	65
5.2- Load flow analysis results for both models (radial and looped)	66
5.3- Short-Circuit analysis results for both models (radial and looped)	71
5.4- Event tables for different configurations for both models (radial and looped)	74
5.5- Action tables for relays settings in different configurations for both models (radial and looped)	76
5.6- Results that clarify DG impact on S.C.	82
5.7- Radial model coordination results	88
5.8- Looped model coordination results	106
5.9- Comments on results	116

CHAPTER (6): CONCLUSION AND SUGGESTIONS	117
6.1- forward	117
6.2- Main conclusion and features	118
6.3- Suggestions for future work	118
LIST OF REFERENCES	120

List of Tables

Table2.1. Response of interconnected network to abnormal voltage....	16
Table2.2. Response of interconnected network to abnormal frequency.	17
Table.2.3 Comparison of available MG protection techniques.....	26
Table3.1. Two approaches to deal with OC coordination issue associated with DG installation.....	35
Table4.1 Current Transformers CTs ratio selection table for radial system.....	40
Table4.2 Single ratio Current Transformers CTs.....	41
Table4.3 Switch selection table for radial system.....	42
Table4.4 Basic Insulation Level (BIL) for switch selection	43
Table 4.5 M.V.C.Bs selection table for radial system	44
Table 4.6 NEC fuse and breaker standard ampere rating	44
Table4.7 Current Transformers CTs ratio selection table for looped system	48
Table4.8 Switch selection table for looped system	50
Table 4.9 M.V.C.Bs selection table for looped system.....	51
Table 4.10 Relay characteristics according to IEC 60255	54
Table 4.11 IEEE standard CTI	61
Table 5.1 FLA seen by system parameters in different configurations for radial model.....	67
Table 5.2 FLA seen by system parameters in different configurations for looped model.....	69
Table 5.3 Minimum 3ph fault seen by each relay in different configurations for radial model.....	72
Table 5.4 Minimum 3ph fault seen by each relay in different configurations for looped model.....	73
Table 5.5 Event table for radial case study.....	75
Table 5.6 Event table for looped case study.....	76
Table 5.7 Relays settings in different configurations for radial case study.....	77
Table 5.8 Relays settings in different configurations for looped case study.....	80
Table 5.9 Average change in fault current w.r.t system without DG in radial model.....	85
Table 5.10 Average change in fault current w.r.t system without DG in looped model.....	87

List of Figures

Fig.2.1 Fault current values in both grid-connected and islanded modes	11
Fig.2.2 Radial case study OLD including all DGs.....	12
Fig.2.3 Fault current wave shape from CSG.....	14
Fig.2.4 Fault current wave shape from IIDG	14
Fig.2.5 Differential protection structure.....	24
Fig.3.1 Directional element operating principle as presented in [32] ..	29
Fig.3.2 Adaptive scheme block diagram as presented in [15]	31
Fig.3.3 Distributed system divided into zones as presented in [10]	32
Fig.4.1 Capability curve of DG1.....	38
Fig.4.2 Capability curve of DG2.....	39
Fig.4.3 Looped case study OLD including all DGs.....	46
Fig.4.4 Capability curve of DG3.....	47
Fig.4.5 Combination of inverse and IDMT Relay characteristics.....	53
Fig.4.6 IDMT Relay characteristics.....	54
Fig.4.7 Typical time/current curves for a very inverse relay.....	56
Fig.4.8 CTI at instantaneous value of downstream relay, not at maximum fault level.....	60
Fig.4.9 CTIs between two numerical relays at instantaneous element and maximum fault.....	60
Fig.4.10 How to select circuit to be coordinated.....	63
Fig. 5.1 % of fault magnitude (3ph, 1ph) for all nodes of radial model w.r.t fault currents of system without DGs:(a) config.2, (b) Config.3, (c) Config.4 , (d) Config.5, (e) Config.6.....	84
Fig. 5.2 % of fault magnitude (3ph, 1ph) for all nodes of looped model w.r.t fault currents of system without DGs:(a) config.2, (b) Config.3, (c) Config.4 , (d) Config.5, (e) Config.6, (f) Config.7.....	87
Fig.5.3 Fault at Bus 684 for Config.1(PG only) radial: (a) Operating sequence OLD (b) Time Current Characteristics (TCC)	89
Fig.5.4 Fault at Bus 675 for Config.1(PG only) radial: (a) Operating sequence OLD (b) Time Current Characteristics (TCC)	91
Fig.5.5 Fault at Bus 692 for Config.2(PG+ all DGs) radial: (a) Operating sequence OLD (b) Time Current Characteristics (TCC)	92
Fig.5.6 Fault at Bus 632 for Config.2(PG+ all DGs) radial: (a) Operating sequence OLD (b) Time Current Characteristics (TCC)	94
Fig.5.7 Fault at Bus 611 for Config.3(Is+ all DGs) radial: (a) Operating sequence OLD (b) Time Current Characteristics (TCC)	95
Fig.5.8 Fault at Bus 675 for Config.3(Is+ all DGs) radial: (a) Operating sequence OLD (b) Time Current Characteristics (TCC) ...	97

Fig. 5.9 Fault at Virt. Bus1for Config.4(Is+ no WTG) radial: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	98
Fig.5.10 Fault at Bus 692 for Config.4(Is+ no WTG) radial: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	100
Fig. 5.11 Fault at Virt. Bus 2for Config.5(Is+ no DG1) radial: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	101
Fig.5.12 Fault at WTG Bus for Config.5(Is+ no DG1) radial: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	103
Fig.5.13 Fault at Bus 692 for Config.6(Is+ no DG2) radial: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	104
Fig.5.14 Fault at Bus 671 for Config.6(Is+ no DG2) radial: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	106
Fig.5.15 Fault at Bus 611 for Config.1(PG only) looped: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	108
Fig.5.16 Fault at Bus 671 for Config.1(PG only) looped: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	109
Fig.5.17 Fault at Bus 684 for Config.2(PG + all DGs) looped: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	111
Fig.5.18 Fault at WTG Bus for Config.2(PG + all DGs) looped: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	112
Fig.5.19 Fault at Bus 600 for Config.3(Is + all DGs) looped: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC) ...	114
Fig.5.20 Fault at Bus 692 for Config.3(Is + all DGs) looped: (a)	
Operating sequence OLD (b) Time Current Characteristics (TCC)	115

List of Abbreviations

BIL	Basic Insulation Level
C.B	Circuit Breaker
CSG	Conventional Synchronous Generators
CT	Current Transformer
CTI	Coordination Time Interval
DER	Distributed Energy Resources
DG	Distributed Generation
DOCR	Directional over Current Relay
FCL	Fault Current Limiter
FLA	Full Load Ampere
GTG	Gas Turbine Generator
HIF	High Impedance Fault
Ic.u	Maximum breaking capacity of LVCB
IEA	International Energy Agency
IIDG	Inverter Interfaced DG
IS	Islanded
L.F.	Load Flow
LOM	Loss of Main
LRC	Locked Rotor Current
LVMG	Low Voltage MG
LVPCB	Low Voltage Power CB
MG	Microgrid
MGCC	MG Central Controller
MGMS	MG Management System
MGCPU	MG central protection unit
MMG	Multi Microgrid
M.V.	Medium Voltage
MVAs.c	Mega Volt Ampere short circuit
MVCB	Medium Voltage C.B
O.C.	Overcurrent
OCR	Over Current Relay
O.L.	Overload
OLD	One Line Diagram
PDS	Power Delivery System
PG	Power Grid
PSM	Plug setting Multiplication
PV	PhotoVoltaic
RES	Renewable Energy Resources
S.C.	Short Circuit

TCC	Time Current Characteristic
TDS	Time Dial Settings
TMS	Time Multiplying Settings
WTG	Wind Turbine Generator

ABSTRACT

Conventional distribution systems have some concerns related to the finite availability of conventional power sources and the green house impacts of these sources. These concerns create a significant interest in the research and development in renewable energy fields and encourage the generations from clean sources at the customer area. Basically renewable energy sources interfaced with the distribution system are called Distributed Generators (DGs) and hence forming a Microgrid (MG), which can operate either in grid connected or islanded modes.

As a result of the major benefits that DG brings to distribution systems, its proliferation is anticipated to be increased, and this inevitably will change the traditional operation and protection principles of power distribution systems. This leads to some protection challenges such as difference in fault current level among different operating modes and bidirectional power flow which will lead to loss of coordination between protection devices.

Based on challenges that face conventional protection systems due to DG insertion, new protection techniques have to be developed to mitigate negative impacts of DGs on protection system. One of these techniques is the adaptive overcurrent protection technique, in which the relays settings are automatically adapted to be continuously suitable for the current prevailing condition. Practical implementation of adaptive protection require relays with multi switch group factors and communication networks to connect relays and DGs with the system monitoring and controlling unit.

In this thesis, an adaptive protection technique, based on topological analysis method, is presented to adapt relay settings for each configuration. The proposed adaptive protection scheme is applied to a part of the IEEE 13 bus radial system and also to the same system but after converting it to a looped one. The results obtained by using ETAP software show the effectiveness of the proposed adaptive method in maintaining coordination between protective relays among different operating topologies, and also in achieving system selectivity and stability.

CHAPTER 1

INTRODUCTION

1.1 Background

The generated energy in conventional power system is mainly depending on huge hydro-electric plants or fossil fuel sources, which are existed normally at suitable places remote from the consumer entities. Therefore, transmission systems are required to handle this generated power to loads at the distribution area. During power long travel from generation to utilization, a considerable power is lost in transmission systems [1].

Due to the wide spread of loads, the eager need for an uprising amount of generated power, the high cost for constructing transmission and distribution (T&D) networks to feed these loads, besides the large amount of power loss in long transmission networks, as well as the environmental impacts of traditional power sources, all these reasons make the notion of generating a nearby energy from the consuming area to found an acceptance from power system operators, which finally leads to the expression of MicroGrids (MG).

MG can be defined as a collection of distributed generators (DGs) and loads with some local storage [2], which is operated as a unique system to provide electricity and heat energies to nearby customers. Although MG has a multi generators and loads, it appears to the broader network as a total generator or a total load. Also MG can operate in two modes either islanded or grid connected [3]. MG uses different DG technologies such as wind turbine, hydroelectric, combined heat and power, photovoltaic (PV). Basically, not only green technologies are used in MG, but also combustion engines and fuel cells may be used.

Even though DG connection to distribution system brings numerous benefits for MG, it poses significant challenges due to unforeseen short circuit (S.C.) increase in radial distribution system [4], different fault levels during different topologies due to source change [5], [6], bidirectional Power flow [7], lack or in some cases completely loss of coordination in the existed protection scheme which leads to undesired islanding and untimely tripping of DGs protection relays [4], [7]. Further a high DG penetration has resulted in the possibility of operating the distributed system in an island mode which