



Ain Shams University  
Faculty of Engineering  
Electrical Power and Machines Department

# **Adaptive Protection Scheme for Low-Voltage DC-Bus Microgrid Systems**

A thesis Submitted to the Faculty of Engineering, Ain Shams University  
in partial fulfillment of the requirements for the Degree of Master of  
Science in Electrical and Machines Engineering

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## **ABSTRACT**

Low voltage direct current (LVDC) power distribution systems (or so called LVDC microgrids) are of wide interest for various power applications. This is owing to their advantages over traditional AC power microgrids with regard to power density, power distribution efficiency and ability to increase penetration of distributed renewables such as wind turbines (WTs) and photovoltaic systems (PVSs), electric vehicles, and heat pumps. Further, short-circuit faults have enormous levels of current. There is a problem in utilizing conventional circuit breakers (CBs) to break DC faults. This problem is the nonexistence of natural points cross the zero reference of DC current. Moreover, utilizing the DC breakers is not an ideal solution this is because they are very pricy and bulky. So, protection systems adopted differential or over-current protection schemes. However, they must have robust communication network and need fully-distributed schemes. Along with that, there are additional challenges, for instance locating a fault in a microgrid, and surely the lack of standards, guidelines, and experience.

In this thesis, the problems of fault protection in DC microgrids are reported and a protection scheme is proposed. The goals of the proposed

scheme are to detect the fault in the bus among devices and to separate the segment that contains a fault so the system retains operating without complete shutdown. To achieve these goals for robust protection system against short-circuit faults, a loop-type dc-bus-based microgrid system is considered. In addition, differential protection scheme is proposed that includes snubber circuits and solid-state bidirectional switches.

The suggested protection scheme for LVDC microgrid is designed using differential protection concept and is simulated using MATLAB Simulink. The obtained results are presented and discussed.

**Key words:** DC power distribution, fault location, loop-type microgrid, power systems protection, solid-state switch.

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## **List of Symbols**

$C$	Capacitance ( <i>Farad</i> )
$C_{eq}$	Equivalent capacitance ( <i>Farad</i> )
$C_g$	Grounding capacitor ( $\mu F$ )
$C_s$	Capacitor of the snubber circuit ( <i>Farad</i> )
$D_{2x}$	Freewheeling diode
$di/dt$	Rate of change in current
$D_s$	Diode of the snubber circuit
$G$	Ground
$i_{diff}$	Difference of two current readings of current sensors ( <i>Ampere</i> )
$i_{diffn}$	Differential current of faulted negative line ( <i>Ampere</i> )
$i_{diffp}$	Differential current of faulted positive line ( <i>Ampere</i> )
$i_{fault}$	Fault current ( <i>Ampere</i> )
$I_{fpi}$	Source – side fault current ( <i>Ampere</i> )
$I_{fpo}$	Load – side fault current ( <i>Ampere</i> )
$i_{in}$	Incoming line current of the bus segment ( <i>Ampere</i> )
$i_{line}$	Line current ( <i>Ampere</i> )

## List of Symbols

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$i_{load}$	Load current ( <i>Ampere</i> )
$i_{out}$	Outgoing line current of the bus segment ( <i>Ampere</i> )
$L$	Inductance ( <i>Henry</i> )
$L_{eq}$	Equivalent inductance including source, line and component ( <i>Henry</i> )
$R$	Resistance ( $\Omega$ )
$R_c$	Equivalent series resistance ( $\Omega$ )
$R_{eq}$	Equivalent resistance including source, line and component ( $\Omega$ )
$R_s$	Resistor of the snubber circuit ( $\Omega$ )
$S_{1x}$	Bidirectional solid-state switch
$S_{1ni}$	Switch at the beginning of section 1 for negative line
$S_{1no}$	Switch at the end of section 1 for negative line
$S_{1pi}$	Switch at the beginning of section 1 for positive line
$S_{1po}$	Switch at the end of section 1 for positive line
$t$	Time ( <i>Second</i> )
$V_{bus}$	DC bus voltage ( <i>Volt</i> )

## **List of Abbreviations**

ABB	ASEA Brown Boveri
AC	Alternating Current
ANSI	American National Standards Institute
CB	Circuit Breaker
DC	Direct Current
DG	Distributed Generator
EMCBs	Electro-Mechanical Circuit Breakers
EPRI	Electric Power Research Institute
FCs	Fuel cells
GTOs	Gate Turn-off Thyristors
HVDC	High Voltage Direct Current
ICTSs	Information and Communication Technology Systems
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	<b>I</b> nstitute of <b>E</b> lectrical and <b>E</b> lectronics <b>E</b> ngineers
IGBTs	Insulated-Gate Bipolar Transistors
IGCTs	Insulated-Gate Commutated Thyristors

## *List of Abbreviations*

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L-G	Line-to-Ground Fault
L-L	Line-to-Line Fault
LVAC	Low Voltage Alternating Current
LVDC	Low Voltage Direct Current
MCCBs	Molded Case Circuit Breakers
N	Negative Pole
P	Positive Pole
PVs	Photovoltaic Systems
RCD	Resistor-Capacitor-Diode Snubber Circuit
RMS	Root Mean Square
UPS	Uninterruptible Power Supply
VSCs	Voltage Source Converters
WTs	Wind Turbines

# Chapter One

## Introduction

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### 1.1 General

New developments and trends in the power consumption obviously show a large usage of dc in end-user devices. Electronic devices utilize LVDC acquired through a single phase rectifier and a dc voltage regulator. Some of renewable sources which can produce dc electrical energy require two transformation stages like photovoltaic systems (PV) [1] and fuel cells (FCs) [2]. But if DC is utilized for distribution systems, it is possible to shorten a stage of conversion, with resultant savings and high reliability in consequence of the decrease in the components. Also, utilizing DC gives another merit in LVDC, this merit is losses and voltage drops will be decreased.

Furthermore, as the hospitals, industrial congregations require continuous supply without any interruptions. So, utilizing a DC distribution system link batteries to the DC network directly to obtain back up energy storage for significant loads and is currently executed through Uninterruptible Power Supply (UPS).

Designing a dc microgrid refers also dealing with affairs, as the selection of voltage regulation, transformation and voltage level, electrical safety and system protection, are well-known in ac systems, but slight

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