DESIGN OF MODULAR MULTILEVEL CONVERTER FOR ENHANCEMENT OF ELECTRICAL ENERGY EFFICIENCY IN SMART GRID SYSTEM

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02-281191-001

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Department of Electrical Engineering

BAHRIA UNIVERSITY ISLAMABAD

FEBRUARY 2025

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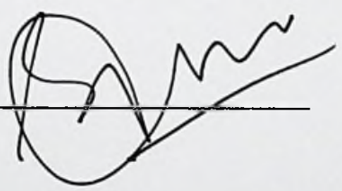
Supervisor's Signature: 

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Acknowledgement

I am grateful to my PhD thesis supervisor, Prof.Dr. Haroon Rasheed, for his endless support, stimulating suggestions, and encouragement during my entire PhD research work. His kind and positive attitude contributed a vital role in the journey of my research work and during my overall Doctoral Engineering Program at Bahria University Karachi Campus, Pakistan.

I am also thankful to my research advisory committee members Dr. Muhammad Raza and Dr. Abdul Qadir for their courageous and useful technical suggestions during my entire Doctoral research work at Bahria University Karachi Campus, Pakistan.

I am solemnly thankful to the Higher Education Commission (HEC) of Pakistan for financial support during my doctoral studies. Without the financial support of the Higher Education Commission of Pakistan, this research work would not have been possible.

I, therefore, would like to thank all faculty members and friends at BUCK and BUITEMS, Quetta for their endless support during my studies. I also solemnly appreciate the patience, sacrifice and support of my family during my entire Doctoral Engineering Program.

I also owe my deepest regards to Prof.Oriol Gomis-Bullmunt, Dr. Eduardo Prieto-Araujo, Dr. Daniel Westerman Spier, and administrative staff of the School of Industrial Engineering of Barcelona (SEIB), Technical University of Catalonia (UPC), Barcelona, Spain for their support during my stay in Spain for research collaboration with UPC Barcelona.

Abstract

Power distribution networks frequently experience power quality issues due to transient voltage sag originating from the upstream grid. Voltage sag is one of the major concerns of modern industry, as it can interrupt sensitive electrical loads and in the worst case cause production problems. Various technologies are used to mitigate power quality issues due to transient voltage sag such as DVR, SVC, and UQPC but they increased the complexity and cost of the system. MMC is a state-of-the-art power electronics-based technology with outstanding features of power quality and low cost. The aim of this thesis is to explore the feasibility of the power quality conditioning system based on a back-to-back Modular Multilevel Converter (MMC) to overcome voltage sag and ensure satisfactory power delivery to the distribution network. In this thesis, an MMC is designed to mitigate voltage sag due to symmetrical and asymmetrical faults in the upstream AC grid using the integrated energy of its sub-modules. In addition, the designed MMC is highly scalable and reliable, having low harmonic distortion and reactive power support. The significant outcomes of the proposed MMC-based voltage sag mitigation are cross-referenced with the other methods adapted for voltage sag mitigation in the literature. The designed converter is also one of the best options for future DC grids due to its many advantages. The designed converter is fault-tolerant and meets the challenges of Fault Ride-through (FRT) capability to avoid short-term outages caused by faults in AC or DC networks. In this research, a Fault Ride-through (FRT) strategy is proposed by converting 10% redundant submodules to full-bridge submodules during a fault scenario. The proposed strategy is framed in conjunction with the DC circuit breaker to accomplish economically viable operations and respond quickly to the system during the pole-to-pole and pole-to-ground DC faults. It is concluded that the proposed FRT strategy is economically viable. Moreover, the power loss of semiconductor devices within the submodules of the designed MMC, losses of the IGBT module, and the free-wheeling diode are analyzed when the switching frequency, power factor (p.f) and modulation index of the system are changed. The

power losses of MMC have been examined for the four-quadrant operations i.e. inverter (inductive), rectifier (inductive), rectifier (capacitive), and inverter (capacitive). The evaluation of the power losses has been carried out employing PLECS to examine the losses of the designed MMC. In addition, the power loss of the designed MMC is compared with the power loss of the other conventional MMCs. It is concluded that the power losses of the designed MMC are less than those of the other conventional MMCs. Finally, it is concluded that the contributions of this research can be used in many practical and industrial applications. In terms of industrial specifications, this research meets the power quality requirements of industrial load for its efficient and economical operation meeting power quality standards. It provides a FRT strategy that economically overcomes the short-term outages caused by faults in AC and DC distribution networks. It can also be used for HVDC Back-to-back systems operating in islanded mode.

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Nomenclature

MMC	Modular Multilevel Converter
DVR	Dynamic Voltage Restorers
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
UPQC	Unified Power Quality Conditioner
ANFIS	Adaptive Neuro-Fuzzy Inference System
DSRF	Dual Synchronous Reference Frame
HVDC	High Voltage Direct Current
SG	Smart Grid
AMC	Adaptive Modulation and Coding
NLC	Nearest Level Control
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEE	Institution of Electrical Engineering
LLC	Line Commutated Converters
CSC	Current Source Converters
ESCR	Effective Short Circuit Ratio
CCC	Capacitor Commutated Converters
IGBT	Insulated Gate Bipolar Transistor
PPL	Phase Locked Loop
SRF	Synchronous Reference Frame
DSRF	Dual Synchronous Reference Frame
HBSM	Half Bridge Submodule
FBSM	Full Bridge Submodule
FBSM	Full Bridge Submodule

RFBSM	Redundant Full Bridge Submodule
ACFRT	AC Fault Ride-Through
DCFRT	DC Fault Ride-Through
CCSC	Circulating Current Suppression Controller
ICCL	Inner Current Control Loop
OCCL	Outer Current Control Loop
WS	Working State
BS	Bypass State
BS	Blocking State
CS	Circulating Current
ICCL	Inner Current Control Loop
SL	Switching Losses
PLECS	Piecewise Linear Electrical Circuit Simulation
CDSM	Clamped Double Submodule
RRLD	Reverse Recovery Power Loss of Diode
COF	Co-efficient of Performance
APFI	Active Power Flow Injection
THD	Total Harmonic Distortion
PQCS	Power Quality Conditioning System
Dq0	Direct Quadrature Zero
SCR	Short Circuit Ratio
THI	Third Harmonic Injection

List of Symbols

ω	Frequency expressed in rad/s
N	Number of sub modules
L_{arm}	Inductance of arm
v_d	DC link voltage
C_{SM}	Submodule capacitor's capacitance
ω_r	Resonance frequency
m_a	Modulation indix
EP	Energy to power ratio
v_u	Upper arm voltage
v_L	Lower arm voltage
P	Active power
Q	Reactive power
t_{ri}	Rise time
t_d	Delay time
t_{fv}	Voltage fall
E_{sw}	Switching energy loss
E_{on}	Turn ON energy loss
E_{off}	Turn OFF energy loss
R_c	On state resistance
R_d	Ratio of change in voltage over the change in the current
V_{nom}	Nominal voltage
Kg	Correction factor