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Advanced Control Strategies for Multilevel Power Converters in Hybrid Microgrid Applications

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Advanced Control Strategies for Multilevel Power Converters in Hybrid Microgrid Applications

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Certificate of Original Authorship

I, Shakil Ahamed Khan declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Publications and Conference Contributions

The following publications are part of the thesis.

Peer reviewed international journal publications

[1] **S. A. Khan**, Y. Guo, Y. P. Siwakoti, D. D. Lu and J. Zhu, "A Disturbance Rejection Based Control Strategy for Five-Level T-Type Hybrid Power Converters with Ripple Voltage Estimation Capability," ***IEEE Transactions on Industrial Electronics***. doi: 10.1109/TIE.2019.2942550 (Early access version is available in online: https://ieeexplore.ieee.org/document/8848848)

[2] **S.A. Khan**, Y. Guo and J. Zhu, "Model Predictive Observer Based Control for Single-Phase Asymmetrical T-type AC/DC Power Converter," ***IEEE Transactions on Industry Applications***, vol. 55, no. 2, pp. 2033-2044, March 2019, Doi: 10.1109/TIA.2018.2877397 (Published)

[3] **S. A. Khan**, M. R. Islam, Y. Guo and J. Zhu, "An Amorphous Alloy Magnetic-Bus-Based SiC NPC Converter With Inherent Voltage Balancing for Grid-Connected Renewable Energy Systems," ***IEEE Transactions on Applied Superconductivity***, vol. 29, no. 2, pp. 1-8, March 2019, doi: 10.1109/TASC.2018.2882448 (Published)

[4] **S. A. Khan**, M. R. Islam, Y. Guo and J. Zhu, "A New Isolated Multi-Port Converter With Multi-Directional Power Flow Capabilities for Smart Electric Vehicle Charging Stations," ***IEEE Transactions on Applied Superconductivity***, vol. 29, no. 2, pp. 1-4, March 2019, Doi: 10.1109/TASC.2019.2895526 (Published)

[5] **S. A. Khan**, Y. Guo, Yam. S, M. N. Habib Khan and J. Zhu, "Topology, Modeling and Control Scheme for a New 7-Level Inverter with Reduced DC-Link Voltage," ***IEEE Transactions on Industrial Electronics***. (Under review)

[6] **S. A. Khan**, Y. Guo, and J. Zhu, "A Robust Method for Fast Estimation of Grid Voltage Parameters under Distorted Grid," ***IEEE Transactions on Power Electronics***. (Preparing)

Peer reviewed international scientific conference publications

[7] **S. A. Khan**, Y. Guo, M. N. Habib Khan, Y. P. Siwakoti and J. Zhu, "Model Predictive Control without Weighting Factors for T-type Multilevel Inverters with Magnetic-Link and Series Stacked AC-DC Modules," ***2019 IEEE Energy Conversion Congress and Exposition (ECCE)***, Baltimore, MD, USA, 2019, pp. 5603-5609. doi: 10.1109/ECCE.2019.8912486 (Published)

[8] **S. A. Khan**, M. N. Habib Khan, Y. Guo, Y. P. Siwakoti and J. Zhu, "A Novel five-Level Switched Capacitor Type Inverter Topology for grid-Tied Photovoltaic Application," ***In proc. 2020 IEEE Applied Power Electronics Conference and Exposition (APEC)***, New Orleans, LA, USA, 2020, (Accepted).

[9] **S. A. Khan**, Y. Guo and J. Zhu, "Model predictive control applied to a single phase seven-level active rectifier," ***2017 20th International Conference on Electrical Machines and Systems (ICEMS)***, Sydney, NSW, 2017, pp. 1-6. doi: 10.1109/ICEMS.2017.8056405 (Published).

[10] **S. A. Khan**, Y. Guo and J. Zhu, "A high efficiency transformerless PV grid-connected inverter with leakage current suppression," ***9th International Conference***

on Electrical and Computer Engineering (ICECE), Dhaka, 2016, pp. 190-193. doi: 10.1109/ICECE.2016.7853888 (Published)

[11] **S. A. Khan**, Y. Guo, N. Chowdhury and J. Zhu, "A Least Mean Square Algorithm Based Single-Phase Grid Voltage Parameters Estimation Method," ***International Conference on Electrical, Computer and Communication Engineering (ECCE)***, Cox'sBazar, Bangladesh, 2019, pp. 1-5. doi: 10.1109/ECACE.2019.8679384 (Published)

[12] **S. A. Khan**, M. N. Habib Khan, Y. Guo, Y. P. Siwakoti, and J. Zhu, "A novel single source three phase seven-level inverter topology for grid-tied photovoltaic application." ***In proc. International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia)***, Nanjing, 2020. (Accepted)

Abstract

In recent years, the traditional electrical power grids are gradually changing into smart grids and emerging as the next-generation power systems. The application of power electronics is playing a vital role in these changes. The recent advancements in power electronics have provided significant momentum for high penetration of renewable energy sources, energy storages, and modern loads into the hybrid microgrid associated with the smart grid. Nevertheless, it also introduces several challenges in terms of reliability and robustness, power quality, and cost. Developing advanced control strategies and converter architecture to mitigate these challenges will be vital. This thesis presents advanced control strategies and circuit architectures for the grid-connected system in hybrid-microgrid applications. The system parameter variations and uncertain disturbances are critical for achieving the control objectives in AC/DC power conversion. In this thesis, disturbance rejection based control strategies have been proposed and implemented to ensure improved steady-state and dynamic performances to follow the references. The control of power converters connected with the electrical grid requires fast and accurate estimation of grid voltage parameters (i.e., amplitude, phase, and frequency), which are carried out using the grid synchronization method. The performance of synchronization methods is affected by the growing power quality issues. This thesis presents novel methods for fast and accurate estimation of the grid voltage parameters. These methods demonstrate enhanced performance to eliminate the disturbances, such as the presence of DC-offset, harmonically distorted grid, grid frequency variations, voltage sag and swell, etc. This thesis also presents a novel single-source three-phase multilevel converter with voltage boosting capability for medium-voltage photovoltaic applications. The new circuit structure significantly reduces the DC-link voltage requirements, the number of components and their voltage stresses in comparison to traditional topologies. It can reduce the dc-link voltage requirements by 75% in comparison to the traditional neutral point clamped (NPC), flying capacitors, active NPC (ANPC), hybrid and hybrid clamped ANPC topologies, and 50% to advanced ANPC topologies. It can also reduce the number of required switches and capacitors as well as their voltage stresses compared to these state-of-the-art topologies reported in the literature so far. The performance

of the proposed control techniques and circuit topologies have been validated by simulation and experimental results.

Keywords: Advanced Control; Hybrid Microgrid; Model Predictive Control; Multilevel Converter; Observer Design; Sliding Mode Control.

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Nomenclature

Global abbreviations used in this thesis

AC	=	Alternating Current
ANPC	=	Active Neutral Point Clamped
APF	=	Active Power Filters
AHB	=	Asymmetrical H-Bridge
ANF	=	Adaptive Notch Filter
AFE	=	Active Front End
BW	=	Bandwidth
CMBMC	=	Common Magnetic-Bus Multilevel Converter
CHB		Cascaded-H-bridge
DC	=	Direct Current
DES	=	Distributed Energy Source
DG	=	Distributed Generation
DSP	=	Digital Signal Processor
DPC	=	Direct Power Control
EV	=	Electric Vehicle
ES	=	Energy Storage
ESS	=	Energy Storage Systems
ESO	=	Extended State Observer
EMI	=	Electromagnetic Interference
EMC	=	Electromagnetic Compatibility
FCS	=	Finite Control Set
FIR	=	Finite Impulse Response
FLL	=	Frequency-Locked Loop
FLC	=	Fourier Linear Combiner
FC	=	Flying Capacitor
G2V		Grid-to-Vehicle
IIR	=	Infinite Impulse Response
IPT	=	Inverse Park Transformation
LPF	=	Low Pass Filter
LMS	=	Least Mean Square
MLI	=	Multilevel Inverter
MC	=	Multilevel Converter
MPC	=	Model Predictive Control
MMC	=	Modular Multilevel Converters
MAF	=	Moving Average Filter
MMPD	=	Modified Mixer Phase Detector
MWFLC	=	Modified Weighted-Frequency Fourier Linear Combiner
NPC	=	Neutral Point Clamped
NF	=	Notch Filter
PI	=	Proportional Integral

PR	=	Proportional Resonant
PV	=	photovoltaic
PCC	=	Point of Common Coupling
PLL	=	Phase-Locked Loop
PD	=	Phase Detector
PWM	=	Pulse Width Modulation
QSG	=	Quadrature Signal Generation
RES	=	Renewable Energy Source
RECS		Renewable Energy Conversion System
SMC	=	Sliding Mode Controller
SVR	=	Step Voltage Regulator
STATCOM	=	Static Synchronous Compensator
SOGI	=	Second-Order Generalized Integrator
SRF	=	Synchronous Reference Frame
THD	=	Total Harmonic Distortion
TD	=	Transfer Delay
UPS		Uninterruptible Power Supplies
VSC	=	Voltage Source Converter
V2G	=	Vehicle-to-Grid
VOC	=	Voltage Oriented Control
VCO	=	Voltage-Controlled Oscillator
WES	=	Wind Energy System
WFLC	=	Weighted-Frequency Fourier Linear Combiner