



THE UNIVERSITY OF ADELAIDE

School of Electrical and Electronic Engineering

Investigation and Analysis of Decentralised Multilevel Modular Integrated Converters in Small Scale Grid-Tied PV Systems

A Thesis Submitted for the
Degree of Doctor of Philosophy

By

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I dedicate this thesis to Yuli Chen.

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I. Abstract

This research focuses on the analysis of multilevel voltage interleaving for decentralised cascaded micro inverters in small scale photovoltaic (PV) grid tied applications. These decentralised cascaded micro inverters, otherwise known as modular integrated converters (MICs), have previously been implemented both with multilevel voltage interleaving (requires fast and reliable communications for PV power tracking) and without (requires no communications). The approach proposed by this research utilises a hybrid of both multilevel and non-multilevel switching, which reduces the communications requirement down to less than one system-wide update per second (whilst still allowing for a reduced filter size and lower switching frequency). In addition to the benefits of multilevel switching, the cascaded topology does not require a high gain DC-DC boost stage and maintains the ability to track the power of each PV panel independently.

It was found that the optimal number of MICs for a cascaded system should be between 4 and 8 and that such a system should utilise a 1st order inductive filter. Prototype MICs were developed and a comparison was made between a parallel and 2-MIC cascaded system that found an increase in both the efficiency (94.8% to 95.9%) and the total harmonic distortion (THD) (4.8% to 5.2%) for the cascaded system. Additionally, a grid zero-crossing detection error of just 4° in the cascaded system generated enough harmonics to exceed allowable THD limits. The implemented 4-MIC decentralised cascaded system utilised a round robin greedy sorting algorithm to sort power blocks for PV multilevel power tracking with an allocation error generally below 2%. Accounting for typical solar irradiance transient conditions and harmonic standards, it was found that a communications update rate of 0.7Hz is required. Additionally, it was found that grid-tied cascaded MICs have fundamental power sharing ratio limitations that restrict the maximum shading of one MIC to 74% in the 4-MIC system.

II. Statement of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Signed: David Scholten

Date: 26/03/17

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IV. Publications

- [1] D. Scholten, N. Ertugrul, Wen L. Soong, “Micro-Inverters in Small Scale PV Systems: A Review and Future Directions”, Australasian Universities Power Engineering Conference, (AUPEC 2013), 29th September, 2013.
- [2] D. Scholten, N. Ertugrul, Wen L. Soong, “Analysis and Control of Decentralized PV Cascaded Multilevel Modular Integrated Converters”, IEEE Energy Conversion Congress and Exposition (ECCE 2016).

Pending Publications:

- [3] D. Scholten, N. Ertugrul, Wen L. Soong, “Detailed Analysis of Decentralised Multilevel Cascaded and Parallel Photovoltaic Converters”, International Journal of Electrical Power & Energy Systems (2016).
- [4] D. Scholten, N. Ertugrul, Wen L. Soong, “Analysis and Control of Decentralized PV Cascaded Multilevel Modular Integrated Converters”, Journal of Emerging and Selected Topics in Power Electronics (2017).

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VII. Abbreviations & Acronyms

AC	Alternating Current
ADC	Analogue to Digital Converter
BOM	Bill Of Materials
CEC	California Energy Commission
CHB	Cascaded H-Bridge
DAC	Digital to Analogue Converter
DC	Direct Current
DMC	Decentralised Multilevel Cascaded
DIP	Dual In-line Package
DPP	Differential Power Processing
EOP	Ethernet Over Power
FC	Flying Capacitor
HF	High Frequency
HVDC	High Voltage Direct Current
IDE	Interactive Development Environment
IEEE	Institute of Electrical & Electronic Engineers
MIC	Modular Integrated Converter
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
NPC	Neutral Point Clamped
PCB	Printed Circuit Board
PF	Power Factor
PLC	Power Line Communications
PV	Photo-Voltaic
PWM	Pulse Width Modulation
RMS	Root Mean Squared
SPWM	Sinusoidal Pulse Width Modulation
THD	Total Harmonic Distortion

VIII. Symbols

C	Capacitance
f	Frequency
I_D	Diode Current
I_{DC}	Average Current (DC)
I_{MPP}	Maximum Power Point Current
I_{photon}	Photon-Influenced Current
$I_{Ripple(pp)}$	Peak-to-Peak Current (AC)
I_{RMS}	Root Mean Squared Current
I_{SC}	Short Circuit Current
IV	Current-Voltage
L	Inductance
P_{Avg}	Average Power
ϕ	Phase Angle
P_{Max}	Maximum Power
p-n	Positive-Negative
R_s	Series Resistance
R_{sh}	Shunt Resistance
V_{DC}	Average Voltage (DC)
V_{MPP}	Maximum Power Point Voltage
V_{OC}	Open Circuit Voltage
$V_{Ripple(pp)}$	Peak-to-Peak Voltage (AC)
V_{RMS}	Root Mean Squared Voltage
ω	Angular Velocity
Z_C	Capacitive Impedance
Z_g	Grid Impedance
Z_L	Inductive Impedance
Z_{th}	Thevenin's Equivalent Impedance