Development of a Direct Matrix Converter for Micro-grid Applications

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Matrix converter is a direct ac-ac converter topology which does not contain a dc-link passive component, unlike conventional ac-ac frequency converters. Electrolytic capacitors which are used as the energy storage component have a limited lifetime. They are also bulky and unreliable at very high temperatures. Matrix converter is able to generate controllable sinusoidal ac outputs regarding magnitude and frequency directly from an ac power supply. The other significant advantages offered by matrix converters are the capability of regeneration and adjustable input power factor.

The main objective of this thesis is design, implementation and the stability analysis of the matrix converter for power flow control applications in the context of the microgrids. In this regard, different applications with bidirectional or unidirectional power flow capabilities are considered as the case study. These include using the matrix converter as an interface link between a microgrid and the utility grid, between a variable frequency source such as wind turbine and the microgrid ac bus, and between a variable frequency load such as induction machine and microgrid ac bus.

As bidirectional power flow control between the utility grid and the microgrid is significantly affected by the stability issue, the stability analysis has become an essential part of this research. Details of the input filter design are presented due to the considerable effect of the filter components on the system stability. The effects of the system parameters on the matrix converter stability are investigated using the small-signal model of the converter. Two methods of stability improvement using the damping resistor and the digital filter are studied in detail. In order to increase the efficiency of the converter, an optimum solution based on the combination of the damping resistor and the digital filter is suggested, and the performance of the proposed method is analyzed. The operation of the matrix converter as an interface between the utility and a microgrid for bidirectional active and reactive power flow control is studied in detail. To control the active and reactive bidirectional power flows, a vector-oriented control method is used.

Two main modulation strategies, the Venturini and space vector modulation, are analyzed and the simulation and experimental results are compared. Due to the better performance of the space vector modulation, this technique is selected for modulation of the designed matrix converter. Different current commutation methods are studied in detail and the simulation and experimental results of four-step semisoft current commutation are presented as the selected commutation method in this work.

Furthermore, a comprehensive simulation study is carried out to investigate the operation of the proposed strategies for modulation, protection, stabilisation and bidirectional power flow control of the matrix converter. To validate the proposed stability analysis and numerical simulations, a prototype direct matrix converter has been developed. The simulation results related to each of the research sections are confirmed through the experimental tests.

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LIST OF SYMBOLS

q	Voltage gain
i_x, i_y, i_z	Instantaneous output currents, A
v_x, v_y, v_z	Instantaneous output voltages, V
i_A, i_B, i_C	Instantaneous input currents, A
L_f	Input filter inductance
C_f	Input filter capacitance
R_f	Resistance of the input filter inductance
ω_{coff}	Cut-off frequency of the input filter
ζ	The damping factor of the input filter
R_d	Damping resistance
R_s	Line resistance
L_s	Line inductance
L_l	Load inductance
R_l	Load resistance
C_c	Clamp capacitance
$\tilde{\beta}_i$	Phase angle of the input current vector
$\tilde{\alpha}_o$	Phase angle of the output voltage vector
$i_i(t)$	Instantaneous input current, A
$v_{si}(t)$	Instantaneous output voltages, V
$v_{im}(t)$	Input voltage amplitude, V

$I_{im}(t)$	Input current amplitude, A
$v_{om}(t)$	Output voltage amplitude, V
$I_{om}(t)$	Output current amplitude, A
P_i	Input power
P_o	Output power
φ_i	Input displacement angle
φ_o	Output displacement angle
PF_{in}	Input power factor
ω_i	Input angular frequency
ω_o	Output angular frequency
S_{kj}	Switching function of a single switch
m_{kj}	Duty cycle of the switch S_{kj}
t_{kj}	Conduction time of the switch S_{kj}
T_s	Switching period
$v_{o,ref}$	Output reference voltage
k_i	Input current sector
k_v	Output voltage sector
f_i	Input frequency
f_o	Output frequency
f_s	Switching frequency
$\vec{V}_o$	Output voltage space vector
$\vec{I}_i$	Input current space vector
P	Active power
Q	Reactive power

LIST OF ABBREVIATIONS

ac	alternative current
ac	direct current
ADC	Analog to Digital Converter
BBVSC	Back-to-Back Voltage Source Converter
CD	Current Direction
CSR	Current Source Rectifier
DB-VSI	Diode-Bridge Voltage Source Inverter
DAC	Digital to Analog Converter
DMC	Direct Matrix Converter
DSP	Digital Signal Processor
DSVM	Direct Space Vector Modulation
FCC	Forced Commutated Cycloconverter
FFT	Fast Fourier Transform
FPGA	Field Programmable Gate Array
IC	Integrated Circuit
IGBT	Insulated-Gate Bipolar Transistor
ILMC	Inverting Link Matrix Converter
IMC	Indirect Matrix Converter
ISVM	Indirect Space Vector Modulation
LPF	Low-Pass Filter

MC	Matrix Converter
NCC	Naturally Commutated Cycloconverter
OC	Over Current
OV	Over Voltage
PC	Personal computer
PCB	Printed Circuit Board
PF	Power Factor
PI	Proportional and Integral
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
RBIGBT	Reverse Blocking Insulated-Gate Bipolar Transistor
rms	root mean square
SMC	Sparse Matrix Converter
SVM	Space Vector Modulation
THD	Total Harmonic Distortion
TL	Threshold Level
USMC	Ultra Sparse Matrix Converter
VHDL	Very high peed integrated circuit Hardware Description Language
VOC	Voltage Oriented Control
VSI	Voltage Source Inverter
VSMC	Very Sparse Matrix Converter
3LVSI	Three-Level Voltage Source Inverter
ZOH	Zero Order Hold

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