University of Technology Sydney

Advanced Control of Three-Phase Full-Bridge Converter in Microgrids

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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LIST OF SYMBOLS

C	Filter capacitance [μF]
$d_a^{'}, d_b^{'}$	Duty ratio of voltage vector $V_a^{'}, V_b^{'}$
dp, dq	Digitized signals of tracking errors of active and reactive power
e_a, e_b, e_c	Three-phase AC source voltages [V]
$e_{\alpha\beta}$	Input source voltage vector [V]
f	Source voltage frequency
H_1 H_2.... H_5	Three-phase full-bridge converter module
I_a, I_b, I_c	AC source three phase current [A]
$I_{\alpha\beta}$	Line current vector [A]
i_L	AC inductor current [A]
L	Line inductance [mH]
P_i, Q_i	Active and reactive power with i-th voltage space vector
$P^* Q^*$	Active and reactive power reference value.
Q_1, Q_4	Switches in IBDC converter
R	Line resistance [Ω]
R_L	Load resistance [Ω]
S_1, S_2	Switches of power converter.
S_{ia}, S_{ib}, S_{ic}	Switching states of three-phase full-bridge converter.
S_n	Sector number
T_c	Computing time of control strategy [μs]
T_s	Sampling period [μs]
t_a, t_b, t_c	Duration time of space voltage vector [μs]
V_a, V_b, V_c	AC terminal voltages of the three-phase bridge [V]
$V_{\alpha\beta}$	Three-phase converter input voltage vector [V]
$V_{i\alpha}$,$V_{i\beta}$	Voltage space vector for each switching state [V]
V_0,V_1..V_7	Voltage space vector

V_{-a}, V_{-b}	Reverse vector of V_a, V_b
V_{dc}	DC terminal Voltage [V]
V_1, V_2	Input and Output Voltage [V]
V_α, V_β	Voltage vectors in the stationary reference frame [V]
ΔP ΔQ	Variation of active and reactive powers
ΔI_α ΔI_β	Variation of AC source current.
δ_{pi}, δ_{qi}	Active and reactive power slopes of i-th voltage space vector
δ_{pa}, δ_{qa}	Active power and reactive power slopes of the voltage vector
λ, λ_1, λ_2, λ_3	Weighting factors

LIST OF ABBREVIATIONS

AC	Alternating Current
BIL	Basic Insulation Level
CDPC	Conventional Direct Power Control
CEC	California Energy Commission
CFPP	Current Fed Push-pull
CMPC	Conventional Model Predictive Control
CPUC	California Public Utilities Commission
CPDCC	Conventional Predictive Duty Cycle Control
CSVMDPC	Conventional Space Vector Modulation based Direct Power Control
DAB	Dual Active Bridge
DC	Direct Current
DFIG	Doubly-Fed Induction Generator
DER	Distributed Energy Resource
DG	Distributed Generation
DPS	Dual-phase-shift
DSP	Digital Signal Processor
DTC	Direct Torque Control
ESS	Energy Storage System
ESPS	Extended Single-Phase-Shift
EPRI	Electric Power Research Institute
FCS-MPC	Finite Control Set MPC
IC	Internal Combustion
IBDC	Isolated Bidirectional Full-bridge DC-DC Converter
ISVMDPC	Improved SVM based Direct Power Control
IPDCC	Improved Predictive Duty Cycle Control
ISS	International Space Station
MPC	Model Predictive Control

MPCDDC	Model Predictive Control based Direct Duty Control
MMPC	Multi-functional Model Predictive Control
MPDCC	Model Predictive Duty Cycle Control
MPDPC	Model Predictive based Direct Power Control
MPCPDCC	Model Predictive Control based Predict Duty Cycle Control
MPPT	Maximum Power Tracking Point
MV	Medium Voltage
PEI	Power Electronic Interface
PDCC	Predictive Duty Cycle Control
PV	Photovoltaic
PWM	Pulse Width Modulation
RTDX	Real Time Data Exchange
STDPC	Switching Table based Direct Power Control
SST	Solid State Transformer
SIWG	Smart Inverter Working Group
SVM	Space Vector Modulation
SVMDPC	Space Vector Modulation based Direct Power Control
RES	Renewable Energy Sources
RPDCC	Reversible Predictive Duty Cycle Control
RMPCPDCC	Reversible Model Predictive Control based Predict Duty Cycle Control
SPDDC	Simplified Predictive Duty Cycle Control
SMPDDC	Simplified Model Predictive Direct Duty Cycle
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
VOC	Voltage-Oriented Control
VSC	Voltage Source Converter
ZVS	Zero Voltage Switching

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ABSTRACT

This thesis focused on application and control of three-phase full-bridge converter in renewable energy system (RES). Current challenges and application of the converter are reviewed, novel concept of smart converter and novel microgrid topology with modular design are proposed. Various kinds of control strategies are comprehensively researched and proposed to improve the performance.

Through review of power electronic interface (PEI) and control strategies in RES, it is concluded that three-phase full-bridge converter is generally utilized for AC/DC bi-directional conversion and could realize DC/DC conversion with high frequency transformer. Novel topology of microgrid is proposed with modular structure and wireless communication ability by using three-phase full-bridge converter modules, which is extremely reliable, expandable and flexible. The control modes, the control strategies for each module and system control strategy are discussed. Meanwhile, the smart converter concept is proposed for RES to improve the utility power quality and system stability.

For ancillary services and advanced functions, control strategies of three-phase full-bridge AC/DC converter play an important role. Firstly, the conventional switching table based direct power control (STDPC) and model predictive based direct power control (MPDPC) are compared. Though MPDPC has advantages such as fast dynamic response and lack of modulator, the mutual influence of control objectives is obvious and switching frequency is high. Thus novel advanced multi-functional MPDPC for improving both the dynamic and steady state performances simultaneously is proposed. Not only the novel control can improve the steady-state performance while impeding switching frequency increment, but it can also eliminate mutual influence between active and reactive powers during dynamic instant.

Due to finite number of vectors, the single vector selection based method still bears with variable switching frequency, relatively higher power ripple and spread spectrum nature of harmonics. Therefore, the three-vector based conventional predictive duty cycle control (PDCC) uses prediction value of power slope and square error minimization method to calculate duration time of adjacent two none-zero vectors, which are selected based on sector information. However, incorrect vector selection cannot be avoided and negative duration time exists. Improved PDCC is presented to solve this issue by reselection of none-zero vector and recalculation of duration time, while the complexity and computation burden increase significantly. Finally, reversible PDCC method is proposed, which does not recalculate the power slope and duration time, it reduces the control complexity significantly while achieving better dynamic and steady performance.

However, there are still some inherent disadvantages of above mentioned methods. Firstly, the mutual influence inherits. Secondly, the calculated negative duration time cannot be wholly eliminated. Thirdly, the computation burden is quite high. Lastly, it limits the method to three vectors based approach only. Therefore, model predictive based vector selection is proposed to avoid incorrect vector selection, simplified duration time calculation method without power slope calculation is proposed, the dynamic and steady-state performance are further improved. Two vector based simplified model predictive duty cycle control (SMPDCC) is proposed with comparison of conventional two vector based approach, improved space vector modulation based DPC (ISVMDPC) is presented. Three vector based approaches with mutual influence elimination and simplified calculation are proposed. Comprehensive comparisons of each methods with simulation and experimental results are conducted.