Control and Performance of a Cascaded H-Bridge Photovoltaic Power System

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Declaration

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Abstract

This thesis presents the control and performance of a Cascaded H-Bridge photovoltaic power system. The cascaded H-Bridge multilevel converter offers a number of attractive features for use in photovoltaic power systems. They provide opportunities for increases in efficiency, superior tracking of the maximum available power and direct connection to higher voltages. This system topology is a relatively immature technology and a number of key areas exist for research. In particular, the individual maximum power point tracking performance requires further analysis and development, the operation of the system in the presence of variable power generation in the photovoltaic arrays requires further investigation and the ability of the system to maintain operation under different array configurations is an interesting area for investigation.

The details and the performance of a heuristic model predictive control scheme are presented, as well as the control techniques used to compensate for the power variability. The operation of the system when some arrays have zero power is also investigated. Two new maximum power point tracking techniques are proposed and the performance relative to the established Perturb and Observe technique is evaluated. A photovoltaic array current sensorless technique is also developed to exploit the switching characteristics produced by the model predictive control scheme.

Finally, simulation and experimental results are presented that evaluate and validate the performance of the proposed control techniques. The results show that the proposed control techniques offer excellent performance.

Nomenclature

α_0	Angle of the injected zero sequence voltage, page 81
Δv_{MPPT}	Voltage perturbation size , page 123
ω_0	Fundamental system frequency in rad/s, page 44
$\underline{i}_{k+1}$	Predicted instantaneous current vector at the end of the control interval from $kT \rightarrow (k+1)T$, page 50
$\underline{i}^*_{k+1}$	Reference instantaneous current vector at the end of the control interval from $kT \rightarrow (k+1)T$, page 50
$\underline{i}^*_P$	Demanded current vector for real power, page 66
$\underline{i}^*_Q$	Demanded current vector for reactive power, page 66
$\underline{v}_{k+1}$	Applied voltage vector for the interval $kT \rightarrow (k+1)T$, page 49
C_k	Nominal capacitance of the kth H-Bridge, page 76
f_{MPPT}	MPPT update frequency , page 123
i_q	Instantaneous synchronously rotating frame q axis current, page 44
i_{cap}	H-Bridge capacitor current, page 148
i_d	Instantaneous synchronously rotating frame d axis current, page 44
$i^*_{k+1_{\alpha/\beta}}$	Reference instantaneous two phase stationary currents at the end of the control interval $kT_s \rightarrow (k+1)T_s$, page 72

$i_{k-1_{\alpha/\beta}}$ Sampled instantaneous two phase stationary currents at time $(k-1)T_s$, page 72

$i_{k_{\alpha/\beta}}$ Estimated instantaneous two phase stationary currents at time kT_s, page 72

I_{pv_k} Mean capacitor voltage for the kth H-Bridge over a fundamental period, page 64

K_I Integral Gain, page 43

K_P Proportional Gain, page 43

L Connection inductance between CHB converter and the grid, page 45

N Number of H-Bridge modules per phase, page 98

N_C Number of capacitors in a flying capacitor multilevel converter, page 28

N_D Number of diodes in a diode clamped multilevel converter, page 25

N_H Number of H-Bridge cells per phase in a cascaded h-bridge multilevel converter, page 29

N_M Number of half H-Bridge modules per arm in a modular multilevel converter, page 32

$N_{C_{bulk}}$ Number of bulk capacitors partitioning the DC bus in a multilevel converter, page 24

$N_{C_{clamp}}$ Number of clamping capacitors in the flying capacitor multilevel converter , page 27

N_{cell} Number of cells in a flying capacitor multilevel converter, page 27

N_{pv} Number of H-Bridge modules with PV arrays connected per phase, page 99

N_{sw} Number of semiconductor devices in a multilevel converter, page 24

N_V	Number of voltage levels in a multilevel converter, page 24
P_{avg}	Average desired phase leg power, page 68
P_{grid}	Average power transferred to the grid over one fundamental period per phase, page 63
P_{jleg}	Power component required to regulate the total voltage of the jth phase leg, page 67
P_j^*	Desired power for jth phase leg, page 67
P_{pv_j}	Sum of the incoming PV array power in the jth phase leg, page 67
P_{pv}	Average PV array power over one fundamental period, page 64
Q^*	Demanded reactive power, page 67
T_g	Length of the grid period, page 63
T_s	Length of the control period, page 46
T_{MPPT}	MPPT update period , page 123
V_0	RMS magnitude of the injected zero sequence voltage, page 81
V_k	Mean capacitor voltage for the kth H-Bridge over a fundamental period, page 64
$V_{cap_{error}}$	Cumulative capacitor voltage regulation error, page 74
$v_{cap_{min}}$	Minimum capacitor voltage within a phase leg, page 74
v_{comb}	Voltage applied by a switching combination, page 74
$V_{conv}[0,T]$	Average converter voltage over the time interval from $0 \rightarrow T_s$, page 46
v_{conv}^*	Instantaneous reference converter voltage, page 74
$V_{grid_{av}}[0,T]$	Average grid voltage over the time interval from $0 \rightarrow T_s$, page 46
$v_{j_{leg}}$	Measured total voltage of the jth phase leg, page 68

v^*_{jleg}	Desired total voltage of the jth phase leg, page 68
$v^{sys}_{k+0.5_{\alpha/\beta}}$	Predicted instantaneous two phase stationary grid voltages at time $(k+0.5)T_s$, page 72
$v^*_{k+1_{\alpha/\beta}}$	Reference instantaneous two phase stationary converter voltages for the control interval $kT_s \rightarrow (k+1)T_s$, page 72
$v^{grid}_{k-0.5_{\alpha/\beta}}$	Sampled two phase stationary grid voltages at time $(k-0.5)T_s$, page 72
CHB	Cascaded H-Bridge multilevel converter, page 28
DCC	Diode Clamped Converter, page 22
DLL	Dynamic Link Library, page 161
EPLD	Electrically Programmable Logic Device, page 281
FCC	Flying Capacitor multilevel converter, page 25
FCS-MPC	Finite Control Set Model Predictive Control, page 49
HDL	Hardware Description Language, page 162
HVDC	High Voltage Direct Current, page 30
INC MPPT	Incremental Conductance Maximum Power Point Tracking, page 9
MMC	Modular Multilevel Converter, page 30
MPC	Model Predictive Control, page 48
MPP	Maximum Power Point, page 6
MPPT	Maximum Power Point Tracking, page 8
P&O MPPT	Perturb and Observe Maximum Power Point Tracking, page 9
PCI	Peripheral Component Interconnect, page 282
PS-P&O MPPT	Phase Shifted Perturb and Observe Maximum Power Point Tracking, page 137

RC-MPPT	Ripple correlation Maximum Power Point Tracking, page 152
RCC	Ripple Correlation Control, page 152
RTX	Real Time Extension, page 286
TCP/IP	Transmission Control Protocol/Internet Protocol, page 287