LOW FREQUENCY MODULATION TECHNIQUES FOR TRANSISTOR-CLAMPED H-BRIDGE BASED CASCADED MULTILEVEL INVERTER

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ABSTRACT

This thesis is concerned with the transistor-clamped H-bridge (TCHB) based cascaded multilevel inverter to produce an AC output voltage with low total harmonic distortion (THD). It is one of several distinct static power converter circuits that can produce three and more voltage levels. For example, when the adopted inverter is designed with three TCHB cells, a thirteen levels of output voltage is produced.

This work also contributes to several of the issues regarding the multilevel inverter, mainly with low-switching frequency modulation. Two modulation methods for obtaining the optimum switching angles have been proposed. The first method is a selective harmonic elimination (SHE) modulation by means of an offline angle calculation using the Newton-Raphson method. The second method is closed-loop control also for low-switching frequency modulation using proportional-integral (PI) controller through online angle determination.

The analytical results are validated using both simulation and experimental results. Simulations of the adopted inverter with a wide range of modulation indices for various load arrangements and reference frequencies are presented. The experimental and real implementation of SHE modulation and closed-loop operation for the adopted inverter using an Altera field-programmable gate array (FPGA) are presented. An in-depth investigation of the modulation strategies and hardware implementation issues has been carried out. Results show that the adopted inverter operates correctly under all forms of modulation strategies. The relative merits of the SHE modulator and closed-loop control operation are assessed based on output quality. Investigations of SHE modulation have revealed that the switching pattern can reduce the harmonics contents of the staircase output voltage. Meanwhile, the successful closed-loop control of the adopted inverter was capable of producing output voltage with minimal THD.

ABSTRAK

Tesis ini adalah berkenaan dengan transistor-diapit jejambat-H berdasarkan penyongsang bertingkat lata untuk menghasilkan voltan keluaran AU dengan jumlah herotan harmonik yang lebih rendah. Ia adalah salah satu daripada beberapa litar penukar kuasa statik yang berlainan yang boleh menghasilkan tiga dan lebih tingkat voltan. Sebagai contoh, apabila penyongsang yang digunakan direka dengan tiga sel transistor-diapit jejambat-H, tiga belas tingkat voltan keluaran akan dihasilkan.

Kerja ini juga menyumbang kepada beberapa isu berkenaan penyongsang bertingkat, terutamanya dengan modulasi frekuensi pensuisan rendah. Dua kaedah modulasi untuk mendapatkan sudut-sudut pensuisan yang optimum telah dicadangkan. Kaedah pertama adalah modulasi penghapusan harmonik terpilih melalui pengiraan sudut luar-talian dengan menggunakan kaedah Newton-Raphson. Kaedah kedua adalah kawalan gelung tertutup juga untuk modulasi frekuensi pensuisan rendah menggunakan pengawal berkadaran-kamiran melalui penentuan sudut dalam talian.

Keputusan analisis disahkan menggunakan kedua-dua simulasi dan keputusan eksperimen. Simulasi penyongsang yang digunakan dengan pelbagai indeks modulasi untuk pelbagai penyusunan beban dan frekuensi rujukan telah dibentangkan. Ujikaji dan pelaksanaan sebenar untuk modulasi penghapusan harmonik terpilih dan operasi gelung tertutup bagi penyongsang yang menggunakan Altera tatasusunan get boleh aturcara medan telah dibentangkan. Suatu penyiasatan yang mendalam untuk strategi modulasi dan isu-isu pelaksanaan perkakasan telah dijalankan. Keputusan menunjukkan bahawa penyongsang yang digunakan beroperasi dengan betul di bawah setiap bentuk strategi modulasi. Merit relatif modulator penghapusan harmonik terpilih dan operasi kawalan gelung tertutup adalah dinilai berdasarkan kualiti output. Penyiasatan bagi modulasi penghapusan harmonik terpilih telah mendedahkan bahawa corak pensuisan boleh

mengurangkan kandungan harmonik bagi voltan keluaran bertangga. Sementara itu, kejayaan kawalan gelung tertutup bagi penyongsang yang digunakan mampu menghasilkan voltan keluaran dengan jumlah herotan harmonik yang minimum.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

η	Efficiency
Θ	Switching angle
32-b/Q27	32- bit/ 27 fractional bits
C	Capacitive
CR_v	Conversion ratio
C_s	Snubber capacitor
di/dt	Rate of rise of current
dv/dt	Rate of rise of voltage
$E(s)$	Error signal
f_{out}	Output frequency
f_r	Resonant frequency
f_{ref}	Reference frequency
f_s	Switching frequency
i	The number of H-bridge/TCHB cells
I_o	Load current
K_i	Integral gain
K_p	Proportional gain
L	Inductive
M	Modulation index
P	Real power
pf	Power factor
Q	Reactive power
R	Resistive
$R(s)$	Reference input of the closed-loop system

R_i	Input resistance
RL	Resistive-inductive
RLC	Resistive-inductive-capacitive
R_o	Output resistance
R_s	Snubber resistor
S	Apparent power
S_{i1}-S_{i5}	Power switches
T_s	Settling time
$U(s)$	Control variable
V_1	Rms value of the fundamental component
V_H , V_L	Triggered voltage levels
v_i	Input voltage
V_{inv}	Inverter output voltage
V_m	An arbitrary (peak) value
V_n	Rms value of harmonic components
V_o	Load voltage
V_{ref}	Sinusoidal reference waveform
$Y(s)$	Output signal