Abstract

Small, highly efficient and low cost photovoltaic (PV) system can be achieved when the transformer is removed from the PV inverter. Nevertheless, transformerless PV inverters generates dangerous leakage currents. Therefore, various transformerless PV inverters topologies are proposed recently to reduce the leakage current to meet the requirement of the standard.

In this project, two types of recently proposed transformerless PV inverters are investigated, i.e., single-phase and three-phase inverters. A common-mode model circuit for each type is developed to study the common-mode behavior of the transformerless PV inverters. It is shown that the leakage current is directly depending on the common-mode voltage (CMV). Based on the analysis of the studies, a novel transformerless PV inverter topology is proposed for both single-phase and three-phase PV systems respectively.

For single-phase PV systems, a simple modified H-bridge zero-voltage state rectifier (HBZVR-D) is proposed to eliminate the leakage current. A fast-recovery diode is added to the existing HBZVR topology to improve the clamping branch performance. It is shown that the improved clamping branch of the proposed topology completely clamps the CMV to constant to eliminate the leakage current.

On the other hand, a three-phase transformerless inverter (H7), adapted from the single-phase H5 topology, is investigated. An additional switch is added to the conventional full-bridge structure to provide galvanic isolation. Here, a novel modulation technique based on conventional discontinuous pulsewidth modulation is proposed. It is shown that the proposed topology is able to reduce the CMV in order to reduce the leakage current.

The validity of the proposed inverters are verified via simulations and laboratory prototypes. DSP TMS320F28335 is used to program the modulation techniques. The

performances of the proposed topologies, in terms of CMV, leakage current, total harmonic distortion (THD) and efficiency, are compared with various recently proposed transformerless PV inverters. It is experimentally proven that the proposed transformerless single- and three-phase inverters are able to reduce the leakage current with superior overall performance among the recently proposed topologies.

Abstrak

Sistem photovoltaic (PV) yang ringan, berkecekapan tinggi dan berkos rendah boleh dicapai apabila transformer dikeluarkan dari penyongsang PV. Walau bagaimanapun, penyongsang PV tanpa transformer menjana arus bocor yang berbahaya. Oleh itu, pelbagai topologi penyongsang PV tanpa transformer dicadangkan baru-baru ini untuk mengurangkan arus bocor untuk memenuhi piawaian.

Dalam projek ini, dua jenis penyongsang PV tanpa transformer yang baru-baru ini diusulkan akan disiasat, iaitu, penyongsang PV fasa tunggal dan tiga fasa. Satu model mod sama digunakan untuk mengkaji tingkah laku mod sama sistem PV tanpa transformer. Ia menunjukkan bahawa arus bocor bergantung secara langsung kepada voltan mod sama (CMV). Berdasarkan analisis kajian, suatu topologi penyongsang PV tanpa transformer yang novel telah diusulkan untuk sistem PV fasa tunggal dan juga tiga fasa.

Bagi sistem PV fasa tunggal, "H-bridge zero-voltage state rectifier" (HBZVR-D) telah dicadangkan untuk menghapuskan arus bocor. Diod cepat-pulih ditambah kepada topologi HBZVR yang sedia ada untuk meningkatkan prestasi cabang pengapitan. Ia menunjukkan bahawa cabang pengapitan HBZVR-D yang dicadangkan dapat mengapit CMV untuk menjadikannya malar supaya dapat menghapuskan arus bocor.

Selain itu, penyongsang tiga fasa (H7), yang diubahsuaikan daripada topologi fasa tunggal H5, turut disiasat. Suis tambahan diintegrasikan kepada struktur tetimbang penuh konvensional untuk mewujudkan pengasingan galvanik. Di sini, teknik novel pemodulatan berdasarkan pemodulatan lebar denyut tidak berterusan konvensional telah dicadangkan. Ia menunjukkan bahawa topologi yang dicadangkan mampu mengurangkan CMV untuk mengurangkan arus bocor.

Kesahan penyongsang yang dicadangkan disahkan melalui simulasi dan prototaip makmal. DSP TMS320F28335 digunakan untuk memprogram teknik

pemodulatan. Prestasi topologi yang dicadangkan itu, dari CMV, arus bocor, herotan harmonic seluruh (THD) dan kecekapan, dibandingkan dengan pelbagai penyongsang pengubah PV yang dicadangkan baru-baru ini. Uji kaji telah membuktikan bahawa penyongsang PV fasa tunggal dan tiga fasa yang dicadangkan dapat mengurangkan arus bocor dengan prestasi keseluruhan yang unggul antara topologi baru-baru ini dicadangkan.

Acknowledgement

I would like to praise and thank the Almighty God by giving me the opportunity to successfully complete this thesis in fulfillment of the requirement for the Doctor of Philosophy in Electrical Engineering.

I wish to express my gratitude to my supervisor, **Professor Dr. Nasrudin Abd Rahim** and **Professor Dr. Hew Wooi Ping** for their constructive advice and guidance, which have undoubtedly motivate me throughout my research.

I also would like to thank all staffs in the UM Power Energy Dedicated Advanced Centre (UMPEDAC) particularly Dr. Che Hang Seng and my colleagues Tan Chin Yew, Lee Jhee Fong, Siti Rahimah and Farihah Shariff for their support and encouragement.

Also, not forgetting my church members and friends, who are praying and supporting me all the time. Last but not least, my sincere gratitude goes to my family and my girlfriend, Lee Soo Yee, who never fail to support and motivate until the completion of this thesis.

Table of Contents

Contents

Chapter III: Transformerless PV Inverters: An Overview

Chapter IV: Proposed Single-Phase Transformerless PV Inverter

List of Figures

List of Tables

LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

V_{DC}	Direct current supply voltage
V_{AN}, V_{BN}, V_{CN}	Load node voltage with respect to the neutral of the dc bus
V_{FP}	Freewheeling path voltage
C_1, C_2	DC bus capacitor
C_{PV}	Stray capacitance
L_f	Filtering inductance
R_G	Ground resistance
f	Grid frequency
f_s	Switching frequency
L_f	Filter inductor
I_g	Grid current
V_g	Grid voltage
V_{DM}	Differential-mode voltage
V_{CM}	Common-mode voltage
V_{ECM}	Equivalent common-mode voltage
I_L	Leakage current
m	Modulation Index
η_{CEC}	Californian efficiency
V_a, V_b, V_c	Original sinusoidal reference signals
V_a*, V_b*, V_c*	Resultant modulation signals after injecting of zero-sequence signal
V_0	Zero sequence signal
V_{max}	Original sinusoidal reference signals with maximum magnitude
$V_{CE(SAT)}$	Saturation voltage
I_C	On-state current

V_F	Diode forward voltage
I_F	Freewheeling current
E_{ON}, E_{OFF}	Turn-on and turn-off energy losses of the IGBT
$V_{DC\_DATASHEET}$	Dc bus voltage in the E_{ON} and E_{OFF} characteristic of the datasheet
P_{CON_IGBT}	Conduction losses of IGBT
P_{SW_D}	Conduction losses of freewheeling diode
P_{SW_ON}	Turn on losses of IGBT
P_{SW_OFF}	Turn off losses of IGBT
P_{SW_IGBT}	Total switching losses of IGBT

Abbreviations

PV	Photovoltaic
PWM	Pulse-Width Modulation
EPWM	Enhanced Pulse-Width Modulation
RCMV-PWM	Reduced Common-Mode-Voltage Pulse-Width Modulation
SPWM	Sinusoidal Pulse-Width Modulation
SVPWM	Space-Vector Pulse-Width Modulation
DPWM	Discontinuous Pulse-Width Modulation
AZPWM	Active Zero-State Pulse-Width Modulation
NSPWM	Near-State Pulse-Width Modulation
MDPWM	Modified Discontinuous Pulse-Width Modulation
THD	Total Harmonic Distortion
DC	Direct Current
AC	Alternating Current
EMI	Electromagnetic Interference

MPPT	Maximum Power Point Tracking
CMV	Common-Mode Voltage
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal-Oxide Semiconductor Field Effect Transistor
DSP	Digital Signal Processor
NPC	Neutral-Point Clamped