Abstract

When a transformer is taken out of a photovoltaic (PV) inverter system, the efficiency of the whole system can be improved. Unfortunately, the additional ground leakage current appears and needs to be considered. The problem of ground leakage current is that it poses an electrical hazard to anyone touching the photovoltaic (PV) array's surface. For safety issues, the ground leakage current should be less than 300 mA, which follows the VDE-0126-1-1 German standard. To minimize the ground leakage current in the transformerless PV grid connected inverter system, the proposed inverter topologies (SC-HB inverter, bipolar H-Bridge inverter with CD-Boost converter, modified unipolar H-Bridge inverter with CD-Boost converter and modified unipolar H-Bridge inverter with modified boost converter) are analyzed, verified and compared in this thesis. In order to analyze the effect of unbalanced filter inductance on the transformerless bipolar H-Bridge inverter topology, the matching ratio of inductance (L_r = L_{f1}/L_{f1n} and L_{f2}/L_{f2n}) is investigated. In addition, the effect of parasitic capacitance value on the transformerless bipolar H-Bridge inverter topology is studied. The effect of modulation techniques using bipolar SPWM and unipolar SPWM on the transformerless H-Bridge inverter topology is compared and analyzed in terms of common-mode voltage and ground leakage current. TMS320F2812 is used as a controller to generate the PWM control signal, maximum power point tracking (MPPT) based on power balance and Proportional-Integral (PI) controller. PSIM 9.0 simulation software is used to design the proposed transformerless inverter topologies. Simulation and experimental results verified the proposed inverter's feasibility in addressing issues of transformerless DC/AC converters in grid-connected PV systems.

Abstrak

Apabila pengubah diambil daripada sistem *photovoltaic* (*PV*) penyongsang, kecekapan keseluruhan sistem boleh diperbaiki. Malangnya, tambahan arus kebocoran bumi akan muncul dan perlu dipertimbangkan. Masalah kebocoran arus bumi ialah ia menimbulkan bahaya elektrik kepada sesiapa menyentuh permukaan *photovoltaic* (*PV*) array. Untuk isu-isu keselamatan, kebocoran arus bumi hendaklah tidak kurang daripada 300 mA, yang mengikuti VDE-0126-1-1 standard Jerman. Untuk mengurangkan arus bocor bumi di grid yang berkaitan sistem penyongsang pengubah PV, topologi-topologi penyongsang dicadangkan (penyongsang *SC-HB*, penyongsang *bipolar H-Bridge* dengan penukar *CD-Boost*, penyongsang *modified unipolar H-Bridge* dengan penukar *CD-Boost* dan penyongsang *modified unipolar H-Bridge* dengan penukar *modified boost*) dianalisis dan disahkan di dalam tesis ini. Untuk menganalisis kesan tidak seimbang penapis kearuhan pada pengubah bipolar H-Bridge penyongsang topologi, nisbah kearuhan (L_r = L_{f1}/L_{f1n} dan L_{f2}/L_{f2n}) disiasat. Juga, kesan nilai kapasitan parasit pada pengubah *bipolar H-Bridge* penyongsang topologi dikaji. Kesan teknik modulasi (*SPWM bipolar* dan *SPWM unipolar*) pada pengubah *H-Bridge* penyongsang topologi dibandingkan dan dianalisis dari segi *common-mode* voltan dan arus bumi bocor. TMS320F2812 digunakan sebagai pengawal untuk menjana isyarat lebar denyut modulasi, maksimum pengesanan titik kuasa berdasarkan pembahagian kuasa dan kawalan Berkadar-Integral. Perisian simulasi PSIM 9.0 digunakan untuk merekabentuk topologi-topologi penyongsang pengubah yang dicadangkan. Keputusan simulasi dan ujikaji mengesahkan bahawa cadangan penyongsang memenuhi isu-isu yang berkaitan dengan penukar Arus Terus/Arus Ulang-Alik (AT/AU) di dalam sistem penyambungan *PV* ke *grid*.

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TABLE OF CONTENTS

CHAPTER 6: EXPERIMENTAL RESULTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

V_{ab}	Inverter output voltage
V_{grid}	Grid voltage
C_{pv}	Parasitic capacitance
η_{mppt}	Efficiency of MPP tracker
η_{conv}	Efficiency of conversion
V_A	Array voltage
I_A	Array current
N_1, N_2	Primary winding turn ratio, Secondary winding turn ratio
I_g	Ground-leakage current
I_{grid}	Grid current
V_{cmm}	Common-mode voltage
C_b,C_{dc}	DC-link capacitors
P_{pv}	Rated power of PV module
ω_{grid}	Grid frequency in (rad/sec)
V_c	Rated input DC-link capacitor voltage
Δu_c	Ripple voltage of DC-link capacitor
$\Delta_{ILripple, max}$	Maximum Ripple Current
V_{pv}	Photovoltaic voltage
V_i	Input voltage
V_{dc}	Output DC-DC converter and input inverter voltage
V_{inv}	Output inverter voltage
V_{rms}	Root mean square voltage
P_{ac}	AC output power
P_{dc}	DC output power

η_{conv}	DC / AC converter efficiency
S_a, S_1, S_2, S_3, S_4	IGBT devices
C_1,C_2	Cuk-derived converter capacitors
D_1, D_2, D_3	Diode devices
V_{C1},V_{C2},V_C	Capacitor voltage
V_L	Voltage across input inductor (L)
L	Input inductor
L_m	Magnetizing inductance
DT	Time interval when IGBT *Sa* is closed
$(1\text{-}D)T$	Time interval when IGBT *Sa* is opened
$\Delta_{iL(on)}$	Rate of change of inductor current when S_a is closed
$\Delta_{iL(off)}$	Rate of change of inductor current when *Sa* is opened
M	Conversion ratio
M_s	Normalized switch voltage stress
m_a	Modulation index
V_a	Leg 1 inverter output voltage
V_b	Leg 2 inverter output voltage
V_{ao}	Voltage pulses generated at leg a to common reference point “0”.
V_{bo}	Voltage pulses generated at leg B to common reference point “0”.
V_{ref}	Sinusoidal reference
V_c	Triangular carrier
V_{oc}	open-circuit voltage
L_{f1} , L_{f2}	Line inverter inductance, Line grid inductance
L_{f1n} , L_{f2n}	Neutral inverter inductance, Neutral grid inductance
I_{pv}	Photovoltaic current

I_{sc}	short-circuit current
w_{res}	Resonant fequency
$\Delta V_{Cpv(t)}$	Potential parasitic capacitance voltage
D	Duty cycle
t_r	Rise time
t_f	Fall time
T	Switching period
d_1, d_2	Duty cycle of V_{ao} and V_{bo}
f_{grid}	Grid frequency
f_s	Switching Frequency
f_{res}	Resonance Frequency
$f_{s,uni}$	Switching frequency for unipolar PWM
$f_{s,bi}$	Switching frequency for bipolar PWM
V_{mpp}	Maximum point voltage
I_{mp}	Maximum point current
P_{mp}	Maximum power point
L_r	Common-mode inductor filters matching ratio
C_{B1}, C_{B2}	Two Series dc-link Capacitors
PSIM	PowerSim

LIST OF ABBREVIATIONS

SPWM	Sinusoidal Pulse Width Modulation
PV	Photovoltaic
rms	Root mean square
PWM	Pulse Width Modulation
CD-Boost	Cuk-Derived Boost
DC	Direct Current
AC	Alternating Current
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
SC	Switched - capacitor
THD_i	Total harmonic distortion current
THD_v	Total harmonic distortion Voltage
TWh	Terawatt hour
GW	Gigawatt
MII	Module Integrated Inverter
PI	Proportional Integral
DSP	Digital Signal Processor
SC-HB	Split Capacitor H-Bridge
HB-ZVR	H-Bridge Zero Vector Rectifier
EFG	Edge-defined Film-fed Growth
APEC	All perovskite Capacitor
I-V	Current-voltage
STC	Standard Test Conditions
SF	Sizing factor

HF	High frequency
P&O	Perturbation and observation
IC	Incremental conductance
CV	Constant voltage
DG	Distributed generator
UVP	Under voltage protection
OVP	Over voltage protection
UFP	Under frequency protection
OFP	Over frequency protection
PCC	Point of common coupling
IEC	International Electrotechnical Commission
PF	Power factor
BJT	Bipolar Junction Transistors
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
GTO	Gate-turn-off thyristor
IGBT	insulated bipolar junction transistors
SITH	static induction thyristor
VSI	voltage source inverter
CSI	current source inverter
CCM	continuous current mode
CICM	continuous inductor current mode
RCD	Resistor, Capacitor and Diode
LCDD	Inductor, Capacitor, Diode and Diode
NPC	neutral point diode clamped
MIC	module integrated converter
ADC	analogue-to-digital converter

S/H	Sample-and-hold
GP	General-purpose