

## 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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## LIST OF SYMBOLS

$V_{ab}$	Inverter output voltage
$V_{grid}$	Grid voltage
$C_{pv}$	Parasitic capacitance
$\eta_{mppt}$	Efficiency of MPP tracker
$\eta_{conv}$	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
$\omega_{grid}$	Grid frequency in (rad/sec)
$V_c$	Rated input DC-link capacitor voltage
$\Delta u_c$	Ripple voltage of DC-link capacitor
$\Delta I_{Lripple, max}$	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

$\eta_{conv}$	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 $S_a$ is closed
$(1-D)T$	Time interval when IGBT $S_a$ 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 $S_a$ 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
$\omega_{res}$	Resonant frequency
$\Delta V_{C_{pv}(t)}$	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
OFF	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