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 pulsedwidth 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 menghapuskkan 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 menghapuskkan 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.
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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

$\eta_{CEC}$  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
<table>
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<tr>
<td>MPPT</td>
<td>Maximum Power Point Tracking</td>
</tr>
<tr>
<td>CMV</td>
<td>Common-Mode Voltage</td>
</tr>
<tr>
<td>IGBT</td>
<td>Insulated Gate Bipolar Transistor</td>
</tr>
<tr>
<td>MOSFET</td>
<td>Metal-Oxide Semiconductor Field Effect Transistor</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital Signal Processor</td>
</tr>
<tr>
<td>NPC</td>
<td>Neutral-Point Clamped</td>
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