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A Modular Medium-Frequency Transformer-Based Converter for Current-Source Wind Energy Conversion System

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***Abstract*— A medium-frequency transformer (MFT)-based current source converter (CSC) was recently proposed for medium-voltage (MV) generator-based wind energy conversion systems, offering reduced size and weight compared to conventional solutions. However, this approach cannot be directly applied to low-voltage (LV) generator-based wind systems. To address this problem while preserving the advantages of the MV conversion system, this work proposes a new converter for LV generator-based wind systems. Because the proposed converter employs a modular converter, it introduces a current imbalance issue, and a current balancing control scheme is therefore developed to address this problem. Simulation results demonstrate that the proposed converter retains the benefits of the MV-based solution while extending its applicability to LV generators.**

Keywords—Current source converter, medium-voltage generator, low-voltage generator, medium-frequency transformer, wind energy conversion system

I. INTRODUCTION

Current source converters (CSCs) featuring reliable short-circuit protection and simple topology are a promising candidate for the next generation of wind energy conversion systems [1-12]. Compared with the low-frequency transformer (LFT)-based solutions, the medium-frequency transformer (MFT)-based power conversion systems offer smaller size and weight [13-18]. An MFT-based power conversion system was recently proposed for the CSC-based wind energy conversion system. This MFT-based CSC offers superior generator stator current harmonic performance and exhibits reduced size and weight compared to conventional solutions. However, it was proposed for the medium-voltage (MV) generator systems and cannot be directly applied in low-voltage (LV) generator-based wind systems. To address this problem, this work proposes a novel converter. The proposed system integrates an active rectifier and a modular MFT-based converter on the generator side and utilizes conventional CSC on the grid side. Because the proposed converter employs a modular converter, it introduces a current imbalance issue, and a current balancing control scheme is therefore developed to address this problem. Simulation results demonstrate that the proposed converter retains the benefits of the MV-based solution while extending its applicability to LV generators.

II. PROPOSED MODULAR MEDIUM-FREQUENCY TRANSFORMER-BASED CONVERTER

Fig. 1 shows the recently proposed MFT-based converter for the MV generator-based wind energy conversion systems [19]. It consists of a two-stage converter on the generator side and a conventional CSC on the grid side [20-23]. The conventional 2-level active converter connected to a modular MFT-based converter is employed on the generator side. The MFTs are used to isolate the MV generator from high voltage. The modular MFT-based converter is composed of m identical H-bridge converters connected in series at both input and output. The series connection at input is to withstand the MV voltage. This converter offers a smaller size and weight compared with conventional solutions [13-18]. While the converter is well-suited for MV generator systems, modifications are required to adapt it for LV systems.

Fig. 2 illustrates the newly proposed modular MFT-based converter for LV generator-based wind energy conversion systems, adapted from the MV version to accommodate the LV generator systems. The difference between the two converters is the connection of the modular MFT-based converter on the generator side. For the MV version shown in Fig. 1, the modules of the MFT-based converter are connected in series at input to withstand MV voltage, while they are connected in parallel to accommodate the LV voltage in the LV system as shown in Fig. 2. The proposed converter retains all the advantages of the MV conversion system, while extending its application to LV conversion systems.

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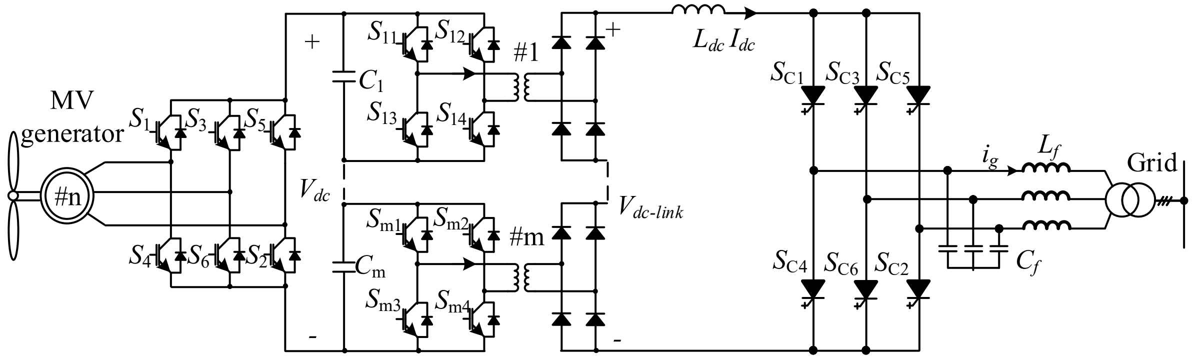

Fig. 1 Conventional MFT-based converter for MV generator systems [19].

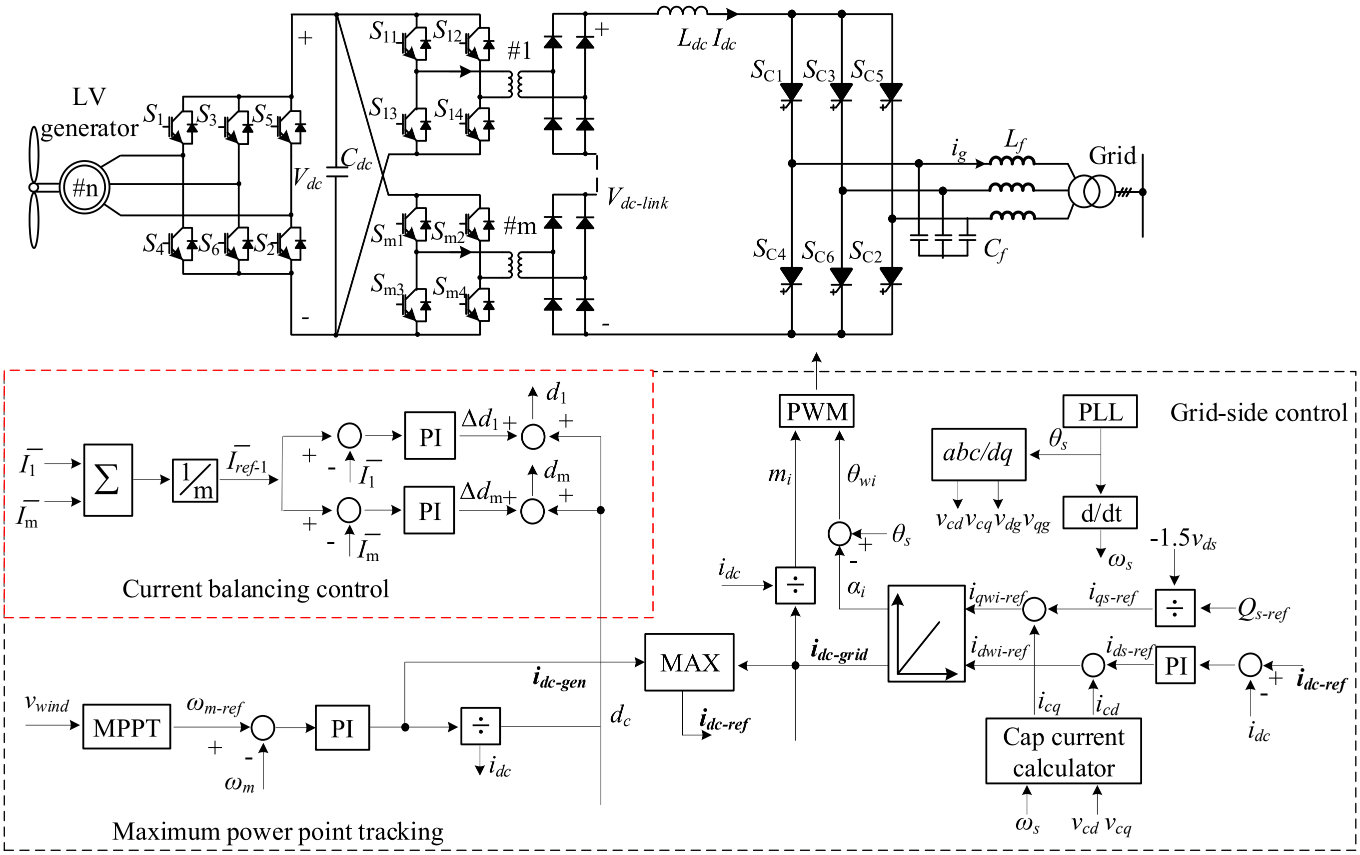

Fig. 2 Proposed modular MFT-based converter for LV generator systems and proposed current balancing control.

III. Proposed Control Scheme

Compared with the MV converter, the proposed LV converter has a unique structure of a modular MFT-based converter consisting of m modules that are connected in parallel at input and in series at output. This structure introduces a current imbalance issue. As a result, a current balancing control is proposed in this work as shown in Fig. 2. For example, shown in Fig. 2, the average current of each module of the modular converter is measured and compared with the reference average current to generate the error. The error is then sent to the PI controller which outputs an additional duty cycle, Δd1 for module #1, and Δd6 for module #m. This additional duty cycle is the one needed to achieve the current balance for module #m. The reference average current is obtained by averaging the average currents of all modules. Finally, after applying the duty cycles (d1, d2 …, and dm) including the common duty cycle dc and the additional one Δd1, Δd2 …, and Δdm, both MPPT and current balancing are achieved. The MPPT is achieved by the common duty cycle dc, while the current balancing is achieved by Δd1, Δd2 …, and Δdm. Controls including both generator-side maximum power point tracking and grid-side DC-link current and reactive power controls remain the same as those of the MV conversion system [5] and are not repeated here.

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IV. Simulation Results

MATLAB-based simulations are conducted to verify the performance of the proposed converter and the effectiveness of the proposed control scheme. Key parameters used for simulations are listed in Table I. Note that transformer turn ratios as listed in Table I are purposely set to be different to consider parameter mismatches in practice due to manufacturing tolerance.

TABLE I
SIMULATION PARAMETERS

Nominal power	$P_g = 1$ MW
Generator voltage	$V_g = 690$ V
Grid voltage	$V_s = 4160$ V
Generator rated speed	22.5 rpm
Number of modules	m = 6
Transformer turn ratios	1:1 (#1); 1:1.04 (#2); 1:1.08 (#3); 1:12 (#4); 1:1.6 (#5); and 1:1.2 (#6)

Fig. 3 shows the simulated waveforms of the proposed converter with and without the proposed current balancing control under both steady and dynamic states. Fig. 3 (a) shows the simulated waveforms with and without the proposed current balancing control under rated conditions. As shown in Fig. 3 (a), under rated conditions, the average input currents of the six modules of the MFT-based modular converter (I_1 - I_6) are imbalanced without the proposed current balancing control, while they are well balanced with the proposed current balancing control. Other waveforms including generator output voltage (V_g), generator output current (i_a), dc-link voltage (output voltage of the generator-side active rectifier, $V_{\rm dc}$), dc-link current ($I_{\rm dc}$), and captured real and reactive power (P_g and Q_s) show the successful operation of the converter under rated conditions. Fig. 3 (b) shows the simulated waveforms with the proposed current balancing under dynamic state: a change in wind speed from 1 pu to 0.5 pu. As shown, the six modules of the MFT-based modular converter with the proposed current balancing control have balanced average currents under dynamic states. The dc-link current ($I_{\rm dc}$) is reduced from 1 pu to around 0.5 pu correspondingly to ensure both control objectives and reduced power losses, while the dc-link voltage (output voltage of the generator-side active rectifier, $V_{\rm dc}$) is controlled as a constant. The reactive power (Q_s) is controlled at zero achieving unity power factor, while the real power (P_g) is reduced from 1 pu to 0.125 pu as the wind speed reduced from 1 pu to 0.5 pu.

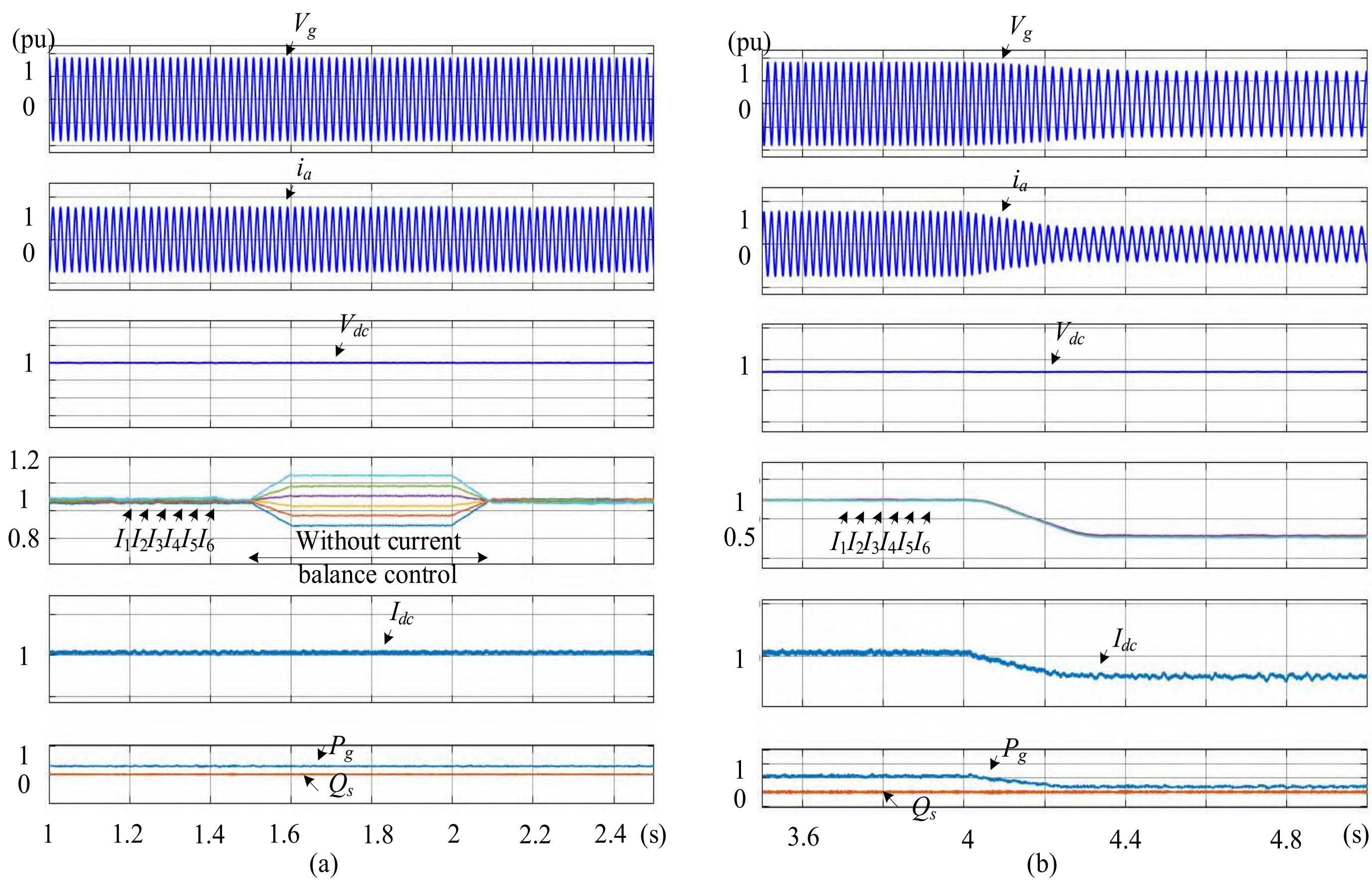

Fig. 3 Simulated waveforms of the converter: (a) steady state with and without the proposed current balancing control, and (b) dynamic state with the proposed current balancing control.

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V. Conclusions

A modular MFT-based CSC is proposed for the LV generator-based wind energy conversion system. It consists of an active converter connected to a modular MFT-based converter on the generator side and a conventional CSC on the grid side. A current balancing control scheme is also developed to solve its current imbalance issue. Simulation results have verified the proposed converter retains all advantages of the MV system, while extending its application to the LV system.

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