THREE-LEVEL IMPROVED FULL-BRIDGE DC-DC CONVERTER FOR WIND ENERGY CONVERSION SYSTEMS

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ABSTRACT

The global demand for electric energy has continuously increased over the last few decades. As far renewable energy is concerned wind energy production plays a major role. A DC-DC converter is needed to connect the wind turbines to a DC grid. In general, three level full-bridge converter (TLFB) is employed for this purpose. This paper proposes a three level improved full-bridge (TLIFB) DC-DC converter for a wind turbine in a DC grid by inserting a passive filter into the DC-DC converter to improve the performance of the converter. The passive filter can effectively reduce the voltage stress of the medium frequency transformer (MFT) in the TLIFB DC-DC converter. This is very significant in the medium-voltage and high-power applications.

Keywords- DC-DC converter; dc grid; three-level full-bridge (TLFB).

I. INTRODUCTION

The dc grid, with the advantages such as reactive power, harmonics [2], seems to be a promising solution of power collection system for growing demand in the offshore wind power development. The offshore wind turbines may be directly connected into a dc grid to deliver dc power to a medium- or high-dc voltage network [6]. To realize the dc power delivery and connection, a high-efficient DC-DC converter is required. Normally, the voltage level of the dc network would be dozens of kilovolts which is too higher than the input voltage of the dc-dc converter [6]. Hence, a medium frequency transformer (MFT) operated at hundreds of hertz to several kilohertz could be installed in the DC-DC converter, which not only ensures that the input voltage can be boosted to a desired output voltage, but also achieves the galvanic isolation between the source and grid.

While considering the series parallel resonant converter, the peak current is high and the number of modules in the input switches is increased compared with the FB converter. Also, the voltage-stiff output limits the demanded voltage rating for the output bridge compared with the FB converter [10]. Besides, owing to the high-voltage level in the dc network, the usage of the diode bridges in the DC-DC converters could be advantageous.

A number of converters are presented in [12]–[17]. Among various configurations the two level and three-level configurations are mainly considered here, since both of the two configurations have been widely used in the wind energy conversion systems [1]. Fig. 1 shows several possible DC-DC converters for wind turbines in a DC grid, including the basic full-bridge (FB) two-level converter, the basic half-bridge(HF) three-level converter, the basic FB three-level converter, and the FB three-level converter based on submodules (SMs). Although the required number of switches for the FB two-level converter are not so many among the four configurations, the switches in the two-level configurations will take the full dc-bus voltage. The rate of change of voltage dv/dt is high; therefore, it may cause electromagnetic interference (EMI) [4], [12], [13]. As the three-level converters with the advantages in the aspects of power quality, semiconductor electrical and thermal stresses, and EMI for high-power applications [7], [8], [14], [15] the switches in the basic HB three-level converter, FB three-level converter, and the SMs-based FB three-level converter only take half of the dc bus voltage, which effectively reduces dv/dt in comparison with the FB two-level converter.

For the N-level configuration, a total number of 8(N–1) switches are needed for the SMs-based FB converter, which is much more than 2(N–1) and 4(N–1) switches required in the basic HB and FB converters, respectively [16], [17]. Besides, the corresponding numbers of voltage sensors are normally required for the SMs, and the voltage balancing control would be complicated for the SMs-based Full Bridge converter [11].

The basic three-level full-bridge (TLFB) converter, with the advantages of the reduced voltage stress of the switches, reduced filter size, and improved dynamic
response, is becoming highly suitable for medium-voltage and high-power conversion applications [17]. Although both the basic TLFB and the SMs-based TLFB configurations can create five-level output voltage to minimize voltage steps and reduce $dv/dt$ in comparison with the HBTL configuration, particularly in the medium-voltage and high-power applications [3], [16], [18], the basic TLFB converter has simpler circuit structure and less number of switching devices than the SMs-based TLFB configuration, which leads to a high reliability and small footprint for the basic TLFB converter.

In this paper, an improved TLFB (TLIFB) dc-dc converter is presented for an offshore wind turbine connected to a dc grid as shown in Fig. 2, where the TLIFB converter is applied to boost the dc input voltage from a diode rectifier to a high voltage for the dc grid integration.

This paper is organized as follows. In Section II, the TLIFB

![Fig. 1(a) Basic FB two-level converter. (b) Basic three-level HB converter. (c) Basic three-level FB converter. (d) SMs based three-level FB converter.](image)

### TABLE I COMPARISON OF DIFFERENT CONVERTER TOPOLOGIES

<table>
<thead>
<tr>
<th>Converter topology</th>
<th>No. of switches required</th>
<th>Valve voltage</th>
<th>Produced voltage level</th>
<th>Voltage balance control complexity</th>
<th>Voltage sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 level</td>
<td>Basic FB converter</td>
<td>4</td>
<td>DC bus voltage</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>3 level</td>
<td>Basic HB converter</td>
<td>4</td>
<td>Half DC bus voltage</td>
<td>3</td>
<td>Easy</td>
</tr>
<tr>
<td>3 level</td>
<td>Basic FB converter</td>
<td>8</td>
<td>Half DC bus voltage</td>
<td>5</td>
<td>Easy</td>
</tr>
<tr>
<td>3 level</td>
<td>FB converter based on SMs</td>
<td>16</td>
<td>Half DC bus voltage</td>
<td>5</td>
<td>Calculation is proportional to the SMs number</td>
</tr>
</tbody>
</table>
DC-DC converter and the corresponding modulation strategy are proposed. The simulation results are given in Section III. The control circuit is made with 8051 microcontroller, IR2110 and tested. The description about the hardware setup of the control circuit of the proposed Three Level Improved Full Bridge (TLIMP) DC-DC converter is given in Section IV. The conclusions are drawn in Section V.

II. TLIFB DC-DC CONVERTER

A. Converter Description

Fig. 3 shows the circuit configuration of the TLIFB dc-dc converter, which is having eight switches (S₁–S₈), eight freewheeling diodes (D₁–D₈), four clamping diodes (D₉–D₁₂), an MFT, four rectifier diodes (Dᵣ₁–Dᵣ₄), a passive filter (Lₛ and Cₛ), an output filter inductor Lₒ, an output capacitor Cₒ between S₁–S₃ and S₈–S₆ is DₒTₛ/2, which is also for S₄–S₂ and S₅–S₇. Dₒ is the overlap duty ratio.

1) Operation Mode 1:
The PWM waveform for the pairs S₈–S₆, S₅–S₇, and S₄–S₂ lags behind the PWM waveform for pair S₁–S₃ by (D − D₉c)Tₛ/2, Ts/2, and (D − D₉c + 1)Tₛ/2 respectively as shown in Fig. 4(a). Tₛ is the switching cycle. The overlap time

B. Converter Operation

The switches S₁–S₈ are switched complementarily in pairs with a pulse width modulation (PWM), i.e., pairs S₁–S₃, S₄–S₂, S₅–S₇, and S₈–S₆, respectively. D is the duty cycle for S₁. The way of phase shifting the PWM for other switch pairs results in the different operation modes as follows.

1) Operation Mode 1:
The PWM waveform for the pairs S₈–S₆, S₅–S₇, and S₄–S₂ lags behind the PWM waveform for pair S₁–S₃ by (D − D₉c)Tₛ/2, Tₛ/2, and (D − D₉c + 1)Tₛ/2 respectively as shown in Fig. 4(a). Tₛ is the switching cycle. The overlap time
Fig. 3 Block diagram of the proposed TLIFB dc-dc converter.

Fig. 4 Key waveforms of the TLIFB dc-dc converter. (a) In operation mode I. (b) In operation mode II.
TABLE III Simulation parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage, $V_i$</td>
<td>100 V</td>
</tr>
<tr>
<td>Output voltage, $V_o$</td>
<td>300 V</td>
</tr>
<tr>
<td>Input capacitors, $C_{i1}$ and $C_{i2}$</td>
<td>3300 mF</td>
</tr>
<tr>
<td>Filter inductance, $L_S$</td>
<td>1.4 mH</td>
</tr>
<tr>
<td>Filter capacitor, $C_S$</td>
<td>300 μF</td>
</tr>
<tr>
<td>Transformer turns ratio, $N$</td>
<td>2.6</td>
</tr>
<tr>
<td>Inductance, $L_d$</td>
<td>100 mH</td>
</tr>
<tr>
<td>Capacitor, $C_o$</td>
<td>1000 μF</td>
</tr>
<tr>
<td>DC network resistance</td>
<td>100 Ω</td>
</tr>
</tbody>
</table>

III. SIMULATION RESULTS
To verify the theoretical analysis of the proposed topology, the simulation results are presented using PSIM 9.0 software. The parameters of various components used in the proposed TLIFB DC-DC converter are given in table II.

A comparator is used to generate the gating pulses. A triangular wave and a DC signal are compared to get the PWM signals for the switches $S_1$, $S_4$, $S_5$, $S_8$. The inverted signals of switches $S_1$, $S_4$, $S_5$, $S_8$ is given to $S_3$, $S_2$, $S_7$, $S_6$. The gating pulse waveforms are shown in Fig. 5. A DC voltage of 100V is applied as input. Fig. 6 shows the input voltage waveform. The output of three level is obtained at the multilevel converter with five voltage levels as shown in Fig. 7. Fig. 8 shows the pure sinusoidal AC output voltage which is obtained after the passive filter. Fig. 9 shows the DC output voltage. The input voltage of 100 volts is boosted to 302 volts.

IV. EXPERIMENTAL SETUP
To generate the gating pulses for the switches in the proposed TLIFB DC-DC converter, 8051 microcontroller is used with IR2110 driver IC. The control circuit is shown in Fig. 10. In the power circuit, the eight main switches and diodes are of standard MOSFET of IRFP250. The clamping diodes are STTH3006. The rectifier diodes are STTH3010.

To initialize the 8051 microcontroller and to generate the signals, a program is written using C coding and executed with the help of Keil software. Flash magic software is used to load the program into the microcontroller. The gating pulses are produced with this hardware setup. The waveforms of gating pulses to the switches $S_1$, $S_3$ is shown in Fig. 11.
Fig. 9 Output voltage waveform of the proposed TLIFB DC-DC Converter

Fig. 10 Photograph of the designed control circuit of the proposed TLIFB DC-DC Converter

Fig. 11 Waveforms of gating pulses to the switches $S_1, S_2$

Fig. 12 Waveforms of gating pulses to the switches $S_1, S_2$

V. CONCLUSION

This paper has presented the TLIFB DC-DC converter for the wind turbine system to facilitate the integration of wind turbines into a dc grid. The proposed two operation modes are discussed in detail where the alternation of the proposed two operation modes can keep the capacitor voltage balanced. The proposed TLIFB DC-DC converter reduces $dv/dt$ rating. It is highly suitable for medium-voltage and high-power conversion. The voltage stress of the power switches is reduced. It can create five-level output voltage to minimize voltage steps. With the usage of passive filter, the voltage stress of the transformer in the TLIFB DC-DC converter can be effectively reduced, which is very significant in the medium-voltage and high-power applications. The performance of the converter is also improved. Further by using the TLIFB, the voltage balancing of the converter can be effectively improved. In future, the TLIFB DC/DC converter prototype can be made with high efficiency and good voltage balancing control.

REFERENCES


