Application of Cascaded H-Bridge Multilevel Inverter in DFIG based Wind Energy Conversion System

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Abstract

The large-scale integration of wind power in today’s power system is increasing its proposition in total electricity generated. To improve the reliability of the power system a novel configuration for DFIG based wind energy conversion systems is developed. The PI based control for wind energy conversion systems is developed and the effectiveness of the Six switch Five level Cascaded multilevel inverter with reduced power devices are investigated using MATLAB on a 1.5-MW WECS.

Key Words - Cascaded MLI, Nearest Level Control, PI control, Reduced switches, Sine PWM, Phase Disposition.

1. Introduction

Wind energy is recently considered as an actual alternative to the conventional and pollutant energy sources such as oil, gas, and coal. Among the various techniques to obtain variable speed, the doubly fed induction generator (DFIG) is the most used. The basic configuration of a wind turbine based on a DFIG is shown in Fig 1.

![Fig 1 Proposed Five level Cascaded MLI Wind Energy Conversion System](image)

The stator of the machine is directly connected to the grid, and only the rotor power must be handled by converters.

Power conditioning devices are inexorable in our ever growing technological world. With this regard, Multilevel inverters (MLI) have obtained more significance in the high voltage and medium power applications as a new kind of power conversion approach. These are array of power semiconductor switching devices and lower dc voltage source/s, tactfully interconnected to provide a stepped high ac output voltage waveform. The resultant effects of this power circuit arrangement are: high power quality, better electromagnetic consistence, lower dv/dt, and lower switching losses. Due to these inherent features, MLI have been used for many applications such as micro-grid systems, distributed generation, power systems, adjustable-speed drives and static reactive power compensation. As the number of level in the MLI increases, the Total Harmonic Distortion in the
output voltage decreases. The major drawback of increasing the number of levels is that the number of devices are increased, hardware and the control circuit becomes very complicated. Hence, the objective of the present work is to improve the performance of the DFIG based Wind Energy System using the reduced number of switching devices as shown in Fig 2.

2. Methodology

**Cascaded H-bridge Multilevel Inverter Topology**

A cascaded multilevel inverter composed of a series of H-bridge inverter units. The prevalent function of the proposed multilevel inverter is to obtain a desired voltage from several separate dc sources (SDCS), which may be obtained from batteries, fuel cells, or solar cells. By adding each H-bridge module, the two levels in an output waveform is increased. Normally for a single phase cascaded H-bridge multilevel inverter, number of semiconductor switches required is \(2(n - 1)\), where \(n\) is the number of levels [2]. For a five level MLI eight power devices are required and for seven level four additional power devices are required. In proposed Topology as in Fig 2 for five level MLI only six power devices are required. In this topology at a time only three devices will conduct for any level except zero voltage level, where only two power devices will conduct. Fig 2 shows the power circuit of single phase five level cascaded H-bridge multilevel inverter CHB-MLI topology.

![Fig 2 Five level cascaded H-bridge Multilevel Inverter [2,3]](image)

**Modelling of DFIG**

For a static stator oriented reference frame, Equivalent model of DFIG is expressed as

\[
V_{st} = R_s i_{st} + \frac{d}{dt} \psi_{st} \tag{1}
\]

\[
V_{nt} = R_n i_{nt} + \frac{d}{dt} \psi_{nt} - j\omega \psi_{nt} \tag{2}
\]

In Proposed DFIG turbine, the stator is directly connected to the grid. The rotor voltage \(v_r\) is controlled by a converter and is used in machine control. The stator and rotor fluxes are given by

\[
p_{st} = L_{st} i_{st} + L_{mt} i_{nt} \tag{3}
\]

\[
p_{nt} = L_{nt} i_{nt} + L_{os} i_{nt} \tag{4}
\]

\[
p_{nt} = \frac{L_m}{L_s} \psi_{nt} - \sigma L_{nt} i_{nt} \tag{5}
\]

\[
V_{nt} = \frac{L_m}{L_s} \left( \frac{d}{dt} - j\omega \right) \psi_{nt} + (R_n + \sigma L_{nt} (\frac{d}{dt} - j\omega)) i_{nt} \tag{6}
\]

\[
V_{r0} = \frac{L_m}{L_s} \left( \frac{d}{dt} - j\omega \right) \psi_{st} \tag{7}
\]

\(V_{nt}\) - Rotor Voltage, \(V_{st}\) - Stator Voltage

\(V_{r0}\) - Rotor Voltage due to stator flux (Rotor voltage when rotor is in open circuit condition)

\(\psi_{st}\) - Stator Flux, \(\psi_{nt}\) - Rotor Flux, \(R_n\) - Rotor Resistance, \(\sigma L_{nt}\) - Rotor Transient Inductance

The stator voltage space phasor is a rotating vector of constant amplitude \(V_s\) that rotates at synchronous speed \(\omega_s\).

\[
v_s = V_s e^{j\omega_s t} \tag{8}
\]

Resistance \(R_s\) is neglected, Stator flux is obtained from (1) and (8)
\[
\psi_s = V_s e^{j\omega_s t} = \psi_{sf} e^{j\omega_s t}
\]

By substituting (9) in (7), rotor voltage due to stator flux is
\[
V_r = j\omega_r L_m L_s \psi_s = L_m \omega_r \omega_s V_s e^{j\omega_s t}
\]

The rotor voltage due to stator flux is proportional to the slip frequency. The rotor voltage depends on the difference between the synchronous and the rotor speed. Table 1 depicts the detailed specification of the DFIG.

### Table 1 Specifications of DFIG based WECS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal output power</td>
<td>1.5 MW</td>
</tr>
<tr>
<td>Rated Wind Speed</td>
<td>11 m/s</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>575 V</td>
</tr>
<tr>
<td>DC Link Voltage</td>
<td>1200 V</td>
</tr>
</tbody>
</table>

**SPWM-Phase Disposition with fixed carrier wave amplitude (Ac)**

The carrier wave magnitude from peak to peak are the very same for all carrier waves and the slope of the carrier wave is constant throughout the simulation time. The SIMULINK models for power circuit and control scheme for SPWM-PD are shown in Fig 3. The carrier signal and reference signals are designed using relational operators and OR logic gates to generate the desired Pulse signals. The carrier and modulation waves for five level MLI SPWM-PD control strategy with constant carrier wave amplitude (Ac) are shown in Fig 4 and the output shown in Fig 5. The output voltage and current waveforms for SPWM-PD control scheme with constant carrier wave amplitude (Ac) is shown in Fig 6 and Fig 7 respectively. In SPWM-PD with constant carrier wave amplitude (Ac), the THD has been reduced as compared to conventional control scheme.

**Switching Technique**

### Table 2 Switching table for Five Level Cascaded Multilevel Inverter

<table>
<thead>
<tr>
<th>S.No</th>
<th>Period (in Degrees)</th>
<th>Power Device Switching Topology</th>
<th>Voltage Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-30</td>
<td>1 1 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30-60</td>
<td>1 0 1 0 1 0</td>
<td>+Vdc/3</td>
</tr>
<tr>
<td>3</td>
<td>60-120</td>
<td>1 0 1 0 0 1</td>
<td>+Vdc</td>
</tr>
<tr>
<td>4</td>
<td>120-150</td>
<td>1 0 1 0 1 0</td>
<td>+Vdc/3</td>
</tr>
<tr>
<td>5</td>
<td>150-180</td>
<td>1 1 0 0 0 0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>180-210</td>
<td>1 1 0 0 0 0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>210-240</td>
<td>0 1 0 1 1 0</td>
<td>-Vdc/3</td>
</tr>
<tr>
<td>8</td>
<td>240-300</td>
<td>0 1 0 1 0 1</td>
<td>-Vdc</td>
</tr>
<tr>
<td>9</td>
<td>300-330</td>
<td>0 1 0 1 1 0</td>
<td>-Vdc/3</td>
</tr>
<tr>
<td>10</td>
<td>330-360</td>
<td>1 1 0 0 0 0</td>
<td>0</td>
</tr>
</tbody>
</table>
The control scheme shown in Table 2, in which the devices are switched on, for α period the output obtained is zero, for next α period the output is $V/3$ volts and for next $2\alpha$ period the output is $V$ volts and so on as shown in the above table. For single phase Five level MLI, the value of $\alpha$ is $30^\circ$.

3. Simulation and Results

![Fig 3 Proposed DFIG based wind turbine configuration.](image1)

![Fig 4 Carrier and modulation waves for SPWM-PD control strategy with constant $A_c$.](image2)

![Fig 5 Five Level Cascaded MLI output for SPWM-PD](image3)
The Five Level Cascaded MLI output for SPWM-PD is shown in Fig 5. The output voltage and current of B575 are 1 p.u, Real and Reactive power of 9 (1.5 X 6) MW, the DC link voltage is 1200V dc and the output voltage and current of B25 are 1 p.u as shown in Fig 6. The cascaded MLI output voltage and current of the DFIG system is shown in Fig 7.
THD spectrum of the Cascaded five level inverter with SPWM-PD control strategy is shown in Fig 8. From the THD spectrum, the Voltage THD is reduced to 3.86% and the Current THD is reduced to 4.62%.

4. Conclusion

Sinusoidal Pulse Width Modulation-Phase Disposition Technique has become the most popular technique for the control of WECS. The inherent advantages of the Multilevel inverter are its cost effectiveness and improved reliability. The simulation results reveal that the five-level inverter seamlessly controls DFIG. The advantages and benefits associated with the proposed configuration over other Conventional techniques are the lower order harmonics are reduced considerably and even harmonics are almost negligible and no additional output filter circuits are needed.

References


