A Comparison of Conventional and Multilevel Inverter for 2.3 kV Induction Motor Drives

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ABSTRACT- Conventional inverters have many limitations in high-voltage and high-power applications like poor power quality, high voltage stress, EMI/EMC issue etc. In recent years, multilevel inverters (MLI) are becoming alternatives for high-power applications due to their good power quality. Many attractive features of this modern power electronic converter topology have been told in the literature on multilevel inverters types, modulation techniques, and applications. In this paper three and seven level cascaded H-bridge multilevel inverter fed induction motor drive is simulated, analyzed and compared with conventional two level inverter drives. Speed of the motor is controlled by open loop v/f method. All inverters topologies are modulated by Sine pulse width modulation (SPWM) technique.

Keywords: Multilevel inverter, Cascaded H-bridge inverter, Sine PWM technique, Induction motor drives.

I. INTRODUCTION

In many industrial applications, large electrical drives require medium voltage and high power. Now-a-days, power semiconductor switches support around 6.5 kV and 2.5 kA high voltage and high current respectively [1]. There are many problems; like poor power quality, high dv/dt stresses, high common mode noise, stresses on motor bearing etc. with the use of conventional power converter topologies and high-voltage semiconductors. So, there is demand of new converter topologies using medium-voltage devices. Motor damage and failure have been noticed due to some conventional inverters, as high stress level rates produces a common mode voltage across the motor windings. The main problems are motor bearing and motor winding insulation breakdown [2].

Multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations such as laminators, mills, conveyors, pumps, fans, blowers, compressors etc. Multilevel inverters solve problem with the present two-level PWM inverter as their rating of semiconductor switches is much lower. Output of multilevel inverter has good power quality. Multilevel inverter can be modulated at fundamental frequency to reduce switching losses.

1.1 Concept of Multilevel Inverter

The concept of MLI has been introduced since 1975. The term multilevel began with the introduction of the three-level converter. The aim of a multilevel inverter is to achieve higher power using a series of power semiconductor switches with many lower voltage dc sources, as shown in fig 1. Multilevel inverters obtain DC-AC power conversion by synthesizing a staircase voltage waveform for harmonic reduction. Capacitors, batteries, and RES (renewable energy sources) can be used as the separate dc (SDC) sources. The switching of the switches adds these SDC sources in order to obtain high power high voltage at the output. The rating of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected [3-4].
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A multilevel converter has several advantages over a conventional two-level converter that uses high switching frequency pulse width modulation (PWM) [5-6]. The attractive features of a multilevel converter are as follows; staircase waveform quality, small common-mode (CM) voltage, and good power quality. Among this multilevel converters also have little disadvantage. One of that is the large number of power semiconductor switches required. Although lower voltage rated switches can be utilized in a multilevel converter, each switch requires its own gate pulse generation circuit. This may lead the whole system to be more complex and more costly.

1.2 Topologies of Multilevel Inverter

Several multilevel converter topologies have been developed and underdevelopment, among this the most important topologies of multilevel-inverter are, Diode-clamped (DDC) or Neutral Point clamped (NPC) multilevel inverter, Flying-capacitor (FC) multilevel inverter and Cascaded H-bridge (CHB) multilevel-inverter.

Cascaded H-bridge has been successfully implemented for very high-power and power-quality applications up to a range of 31 MVA, due to their series expansion capability. It requires the least number of components among all multilevel converters types to achieve the same number of voltage levels. Table 1 shows the suitable cascaded H-bridge inverter level for medium voltage drives.

<table>
<thead>
<tr>
<th>Level</th>
<th>Cell per phase</th>
<th>Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3</td>
<td>2.3 kV</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>3.3 kV</td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>4.16 kV</td>
</tr>
</tbody>
</table>

The NPC or DDC has advantage of back-to-back configuration for regenerative applications but experiences problem of a capacitor unbalance for certain operating conditions.

The FC capacitor voltages have to be recharged at start up, near to their normal values, also called as initialization. This can be done via additional and very simple control logic of the power switches of the converter.

1.3 Modulation Techniques for Multilevel Inverter

There are many modulation techniques for multi-level inverters. Carrier based modulation (SPWM) technique is easy and efficient. Phase-shifted multicarrier techniques for obtain multilevel output voltages are commonly used in real industrial applications. Another very interesting alternative is the space-vector modulation (SVM) strategy which has recently been proposed [6-9]. Space-vector PWM methods generally have the following features: good utilization of dc-link voltage, low current ripple, and easy hardware implementation by a digital signal processor (DSP). Due to all this advantages SVPWM is becoming popular choice for high-voltage high-power applications.
II. SPEED CONTROL OF MOTOR

The most common control principle for induction motors is the constant volts per hertz (V/Hz) principle. Scalar control of an AC motor drive is only due to the variation in the magnitude of the control variables. By contrast, vector control involves the variation of both the magnitude and phase of the control variables. Voltage can be used to control the air gap flux and frequency or slip can be used to control the torque. However, flux and torque are functions of frequency and voltage respectively but this coupling is disregarded in scalar control. Generally, an induction motor requires nearly constant amplitude of air gap flux for satisfactory working of the motor. Since the air gap flux is the integral of the voltage impressed across the magnetizing inductance, and assuming that the air gap voltage is sinusoidal, a constant volts/Hz ratio results in a constant air gap flux.

Figure 2: Open loop v/f control of IM

III. SIMULATION OF INDUCTION MOTOR DRIVE

3.1 Conventional - Two level Inverter fed Induction Motor Drive

The power circuit and pulse generation circuit of conventional-two level inverter fed induction motor drives is as shown in fig 3.1.

Figure 3.1: Power and control circuit of two level inverter fed induction motor drive

3.2 Multi-level Inverter fed Induction Motor Drive

The power circuit and control circuit of multi-level inverter (three level and seven level) fed induction motor drive is as shown in fig 3.2 and fig 3.3. A three level inverter requires single power cell (full bridge circuit) per phase while a seven level inverter has three cells per phase.
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Figure 3.1: Power and control circuit of seven level inverter fed induction motor drive

Figure 3.2: Power and control circuit of three level inverter fed induction motor drive

IV. SIMULATION RESULT ANALYSIS

The result analysis is based on the simulation results. Different speed-command is given and the performance of different level inverters is compared with the conventional inverter. The speed responses are observed under different operating conditions such as a sudden change in command speed, step change in load etc. Fig. 4.1 shows the line voltage waveforms and the power quality are found to be improved as level increases.

Figure 4.1: Line voltage waveform of two, three and seven level inverter

Initially, 1500 rpm speed command is applied; after one, two and three seconds 1000 rpm, 500 rpm and 1500 rpm speed commands respectively are applied to analyze the performance of the drive. Fig. 4.2 shows that the torque pulsation gets reduced with increase in the level of the inverter.
Figure 4.1: Torque and rotor speed of two, three and seven level inverter

Variation of THD (Total harmonic distortion) with different modulation indices (Fig 4.3 and Table 2) for conventional and multilevel inverter is analyzed.

**TABLE 2**

<table>
<thead>
<tr>
<th>modulation index</th>
<th>level 2</th>
<th>level 3</th>
<th>level 5</th>
<th>level 7</th>
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<tbody>
<tr>
<td>1.3</td>
<td>52%</td>
<td>27%</td>
<td>16%</td>
<td>10%</td>
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<td>70%</td>
<td>40%</td>
<td>24%</td>
<td>14%</td>
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<td>0.9</td>
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<td>54%</td>
<td>29%</td>
<td>18%</td>
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<tr>
<td>0.8</td>
<td>91%</td>
<td>67%</td>
<td>30%</td>
<td>19%</td>
</tr>
<tr>
<td>0.7</td>
<td>107%</td>
<td>79%</td>
<td>28%</td>
<td>22%</td>
</tr>
</tbody>
</table>

Figure 4.1: Variation of THD with modulation index
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V. CONCLUSION

A multilevel converter is emerging technology and an attractive solution for medium-voltage high power drives. MLI topologies have its own combination of advantages and disadvantages and for any one specific application; one MLI type will be more suitable than the others.

The cascaded multilevel inverters have developed from a theoretical concept to real world applications due to its many attractive features as high degree of modularity, the probability of connecting directly to medium voltage, low THD on input and output side, high availability, and the easy control of active power flow in the regenerative form.

Today, several commercial products are based on the multilevel inverter structure, and more and more research and development of multilevel power inverter-related technologies is occurring.

APPENDIX

The motor parameters considered are 2.3 kV, 50 Hz, 4pole Induction Motor:
Rated power– 500kW,
Rated speed (rpm) – 1493
Efficiency - 97.0,
Power factor - 0.87,
Rated current – 150A
Moment of inertia – 10kg-m²
Stator resistance (R_s) = 1.115Ω,
Inductance of stator winding (L_s) = 0.005974 H
Rotor resistance (R_r) = 1.085 Ω,
Inductance of rotor winding (L_r) = 0.005974 H
Magnetizing reactance L_m = 0.2037 H

References