Analysis and comparison of THD in Five Phase PWM Inverter drive using Resonant Filter

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Abstract—Power Converters and Power Inverters are widely used in distributive generation system, the problem of injected harmonics are critical, total harmonic distortion (THD) increases the rms current that flows from a source to a load. Most of the harmonic currents/voltages flows in the load are frequencies which are higher than the fundamental supply frequencies, it generates more heat and increase the possibility of equipment may break. Harmonics are the additional current and voltages doesn’t contribute any mechanical force to the motors, instead it is simply dissipated as heat in the load, this may cause premature equipment failure and can cause equipment malfunction. In order to mitigate these harmonic problems a LCL filter is proposed in this paper. Harmonics in five phase PWM Inverter is studied using simulation and results will be presented.

Index Terms— Harmonics, Five phase, LCL filter, Inverter output filter, THD

I. INTRODUCTION

Multi/poly phase drive offers immense advantages over their three-phase drive. The major advantages of using a multi/poly phase drive machine instead of a three-phase machine are high torque density, reduced torque pulsations, greater fault tolerance, reduction in the required rating per inverter leg, better noise characteristics, higher phase number gives smoother torque due to the simultaneous enhancement of the frequency of the torque pulsation and reduction of the torque ripple magnitude.

Multi/poly phase drives are unsuitable for general purpose drives application because of few drawbacks that is availability of phase voltages, and complexity of control at the out put of the power electronic system. Thus their application areas are restricted to some applications such as ship propulsion, electric aircraft, hybrid electric vehicles, electric traction, and battery-powered electric vehicles. A multiphase motor requires voltage source inverter (VSI) for their input supply. An inverter topology uses two switches connected in series as one inverter leg. The number of inverter leg depends on number of phases [1-10].

The term “harmonics” refers to the voltage and current harmonic distortion in a power electronic AC circuit. An electrical system will supply power to load by delivering current at the fundamental frequency. Only fundamental frequency current/voltage can provide main power. Current/voltage delivered at harmonic frequencies do not contribute any real power to the load, instead these harmonic voltage/current simply dissipated as heat, therefore the heat is the major factor in the power electronic systems, also the power converters and inverters are used to drive linear and non linear loads like motors and generators, the generation of harmonics at the output of the inverter system is very high, these harmonic content does not contribute any mechanical torque in the motor, instead it is deliberately dissipated as heat in the windings of the motors and generators, this leads to deterioration of life time of the systems and also adversely affect the other parameters like bearing current, and vibration, dv/dt effects, and EMI noise etc.

The percentage of harmonics in a AC circuit output waveform is called THD (total harmonic distortion) and can be further classified into total harmonic voltage distortion and total harmonic current distortion. Efficiently of the system is depends on Total harmonic distortion (THD),THD is normally expressed as a percentage with respect to the value of fundamental current or voltage. Harmonics are the odd integral multiples of fundamental frequency resulting in the distortion of supply waveform due to interference by superposition. Harmonic order or harmonic number is reference to the frequency of the harmonic component. The 3rd order harmonic content refers to a harmonic content having frequency 3 times that of fundamental i.e. for a 50 Hz supply 3rd order content is of 3x50=150Hz and magnitude of the harmonic is 33.33% of the fundamental voltage/current.

Many researchers working on non linear loads power electronic system, the current drawn from the supply will no longer remains sinusoidal. Thus the resultant waveform will have number of different waveforms of different frequencies. Harmonics deteriorates the power factor and gradual increasing electrical losses in the circuit and device. This results in equipment failure.
Harmonic distortion will reduce the power factor, causes efficiency of the system to suffer.

A harmonic filter is a circuit used to block the content of different harmonic orders from coupling source to the load. The harmonics will affect to the low impedance devices. Many of the harmonic filters designs are available today and it consists of parallel connected capacitor and inductor circuits to create a low impedance device. These filters will be considered as passive devices. The passive devices attract harmonic current from the sources connected to the system. Then it is dissipated as heat in the load and heat is dissipated by the harmonic filter, rather than being coupled to the load to be dissipated by any other passive devices.

In Five Phase PWM Inverter Drive 5th and its multiple harmonics are absent, the leading and dominant harmonic content in Five Phase PWM Inverter is 3rd harmonic, to reduce these harmonics an LCL filter is used in five phase PWM drive [11-18].

II. FIVE PHASE INDUCTION MOTOR DRIVE

The construction of five phase PWM drive is as shown in Fig.1. Five Phase Signals generated with 72° out of phase with each other. Five phase signals are connected to inverter drive circuit consists of ten IGBT’s (Insulated-Gate Bipolar Transistor) switches are employed to construct five phase inverter drive. All the switches are provided to conduct for a period of 180° as shown in Fig.2.

Fig.1. Construction of Five Phase PWM Inverter Drive

Fig 2. Switching sequences of 180° conduction mode

III. FIVE PHASE PWM INVERTER DRIVE WITH LCL FILTER

Fig.3 shows the constructional block diagram of five phase inverter with LCL filter at each phase connected with an RL load.

A. LCL Filter Design:

A simulation work has been carried out using LCL filter, it gives better attenuation of harmonics in the PWM inverter than the L, LC and π filters. Major advantages of the LCL-filter are that it gives low distortion in output current and low distortion in reactive output power. LCL filter’s attenuation will be of -60 dB/decade of the resonance frequency.

The resonant frequency of the LCL-filter is given by:

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{L_1+L_2}{L_1L_2C}}$$

To minimize or eliminate the third harmonics content the resonant frequency designed and used is $f_0 = 150$ Hz. The filter has been designed with L and C given in Equation 1. Therefore the values $L_1=L_2= 2.25$ mH and $C=1000\mu F$.

Fig 3. Constructional Block Diagram of Five Phase inverter with LCL filter

An LCL Filter is used between the inverter and the Five Phase load. The complete setup is shown in Fig 4. THD will be obtained to studying the presence of harmonics in five phase PWM Inverter Drive with and without LCL filter.

Where $L_1-L_{10}= 2.25$ mH and $C_1=C_2=C_3=C_4=C_5= 1000\mu F$.

Fig 4. Complete Setup in Simulink of Five Phase PWM Inverter Drive with LCL Filter
IV. SIMULATION RESULTS
Simulation work has been done for five phase PWM Inverter Drive with and without LCL filter at different frequencies. For the Variable Speed Drive applications low frequencies such as 5 Hz has been simulated and harmonics are studied, also THD at the five phase PWM inverter is also obtained. Then the study is extended to rated frequency of 50 Hz.

FFT analysis has been done to obtain voltage waveforms using simulink and the result used for comparison, with and without LCL filter of five phase PWM inverter Drive.

![Fig 5. Line Current and line voltage waveforms of a phase without filter](image)

![Fig 6. Line current and line voltage waveforms of a phase with filter](image)

A. At fundamental frequency \( f = 5 \text{ Hz} \), \( V_{dc} = 40 \text{ V} \), % of THD is as shown in Table I.

<table>
<thead>
<tr>
<th>Modes</th>
<th>THD %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without LCL Filter(Normal PWM drive)</td>
<td>42.88</td>
</tr>
<tr>
<td>With LCL Filter</td>
<td>28.74</td>
</tr>
</tbody>
</table>

**Table I. OVERALL THD COMPARISON WITHOUT AND WITH FILTER FOR F= 5 Hz**

![Figure 7. FFT analysis without LCL Filter for 5 Hz](image)

![Figure 8. FFT analysis with LCL Filter for 5 Hz](image)

The Harmonic content and % of THD is shown in Fig. 7 and Fig. 8, the harmonics and % of THD is drastic reduction with filter is obtained for the input frequency of 5 Hz. Table II shows the presence of various \( n^{th} \) harmonics content with and without LCL filter for \( f = 5 \) Hz.

<table>
<thead>
<tr>
<th>Harmonics</th>
<th>Without Filter THD</th>
<th>With Filter THD</th>
</tr>
</thead>
<tbody>
<tr>
<td>3(^{rd})</td>
<td>33.23</td>
<td>21.16</td>
</tr>
<tr>
<td>7(^{th})</td>
<td>14.24</td>
<td>0.13</td>
</tr>
<tr>
<td>9(^{th})</td>
<td>11.07</td>
<td>0.19</td>
</tr>
<tr>
<td>11(^{th})</td>
<td>9.07</td>
<td>0.04</td>
</tr>
<tr>
<td>13(^{th})</td>
<td>7.68</td>
<td>0.09</td>
</tr>
<tr>
<td>17(^{th})</td>
<td>5.88</td>
<td>0.05</td>
</tr>
<tr>
<td>19(^{th})</td>
<td>5.26</td>
<td>0.02</td>
</tr>
</tbody>
</table>

![Table II. THD COMPARISON OF N\(^{th}\) HARMONICS WITH AND WITHOUT FILTER FOR F= 5 Hz](image)

B. At fundamental frequency \( f = 50 \text{ Hz} \), \( V_{dc} = 390 \text{ V} \), THD % is as shown in table III.

**Table III. Overall THD comparison without AND WITH filter for F= 50 Hz**

<table>
<thead>
<tr>
<th>Modes</th>
<th>THD %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without LCL Filter</td>
<td>42.75</td>
</tr>
<tr>
<td>With LCL Filter</td>
<td>13.33</td>
</tr>
</tbody>
</table>

The comparison of harmonics with normal drive and with filter is as shown in Fig. 9 and Fig. 10 respectively.
Table IV shows the presence of various $n^{th}$ harmonics content with and without LCL filter for $f=50$Hz.

<table>
<thead>
<tr>
<th>Harmonics</th>
<th>Without Filter THD %</th>
<th>With Filter THD %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3$^{rd}$</td>
<td>33.50</td>
<td>4.13</td>
</tr>
<tr>
<td>7$^{th}$</td>
<td>14.75</td>
<td>2.31</td>
</tr>
<tr>
<td>9$^{th}$</td>
<td>11.72</td>
<td>2.14</td>
</tr>
<tr>
<td>11$^{th}$</td>
<td>9.85</td>
<td>1.41</td>
</tr>
<tr>
<td>13$^{th}$</td>
<td>8.61</td>
<td>1.37</td>
</tr>
<tr>
<td>17$^{th}$</td>
<td>7.16</td>
<td>1.20</td>
</tr>
<tr>
<td>19$^{th}$</td>
<td>6.75</td>
<td>1.12</td>
</tr>
</tbody>
</table>

V. CONCLUSION

A study of Harmonics and % of THD has been carried out using simulink model of five phase PWM inverter drive, to reduce the harmonics and its content at the output of a the PWM inverter, an LCL filter is designed and constructed with MATLAB. FFT analysis has been done without and with LCL filter. The Presence of THD at the output of the five phase Inverter drive is drastically minimized and compared with the normal PWM drive, the results are obtained for two different frequencies and presented.

The simulation work will be implemented experimentally for future work, to study the temperature of five phase Induction motor drive.

REFERENCES


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