THD Analysis of Output Voltage for VSI fed Induction Motor Drives

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ABSTRACT

The paper mainly focuses on the study of the comparison of harmonic analysis executed by voltage source inverter using Fast Fourier Transform in MATLAB/Simulink. Here the comparison analysis of THD obtained for line voltage through simulation as well as mathematical model has been performed. It investigates the effect of Total Harmonic Distortion on the adjustable ac drive system. If THD is minimized at the output terminal of the inverter than rotor current, rotor speed and torque performance is improved which results in smooth operation. Paper also include the comparison analysis of line and phase voltage with respect to THD. The performance comparisons are analyzed in term of Fast Fourier transform and THD. The proposed work for THD analysis for VSI fed induction motor drives is modeled in MATLAB/Simulink software.

Keywords: Voltage source inverter, Total harmonic distortion, Induction motor, MATLAB/Simulink.

I. INTRODUCTION

In industrial application, Power Electronic devices such as Inverter play a major role. It is commonly of two types Voltage Source Inverter (VSI) and Current Source Inverter (CSI) [1]. Recently AC motor drive system are predominantly founded on three phase VSI. Reduction of harmonic content in voltage source inverter is one of the major issues faced.

When motor starts with VSI fed drives system, then at the output terminal of the inverter large amount of harmonics introduces [2]. The voltage harmonics causes additional core losses depending on motor reactance’s, current harmonic causes stray and copper losses, due to these Total Harmonic Distortion the rotor current waveform is distorted. THD can be reduce in phase current and line voltages by varying the carrier wave frequency or by varying the modulation index from low to high value (i.e. 0.1 to 1.0) [13]. By minimizing the Total Harmonic Distortion response of induction machine is improved. The input voltage to the asynchronous machine operating on a voltage source inverter are periodic but non sinusoidal. Input wave which is non sinusoidal is resolved in Fourier series.

II. TOTAL HARMONIC DISTORTION

Total Harmonic distortion is the important method to calculate the order of harmonics present in the voltage or current waveform. It is also useful in analyzing the quality of ac output voltage or current. Non sinusoidal wave quality can also be observed through Total harmonic distortion (THD). The total harmonic distortion was a measurement of the harmonic distortion and is prescribed as the ratio of rms value of all harmonic components to the rms value of fundamental component [2].

\[ \text{THD}_{V\%} = \sqrt{\sum_{n=2}^{\infty} (V_{n\text{rms}})^2} \]

\[ \text{THD} = \frac{V_{h\text{rms}}}{V_{or\text{rms}}} \quad \text{(Voltage THD)} \]

\[ V_{h\text{rms}} = \text{rms value of all harmonic components present in the o/p voltage of inverter.} \]

\[ V_{or\text{rms}} = \text{rms value of fundamental component of o/p voltage.} \]

Total Harmonic distortion is defined as summation of all the harmonic content of current with respect to fundamental component of current [9].

\[ \text{THD}_{I\%} = \sqrt{\sum_{n=2}^{\infty} (I_{n\text{rms}})^2} \]

\[ \text{THD} = \frac{I_{h\text{rms}}}{I_{or\text{rms}}} \quad \text{(Current THD)} \]
\( I_h \) = rms value of all the harmonic components.

\( I_{sr} \) = rms value of fundamental component of supply current.

**THD Calculation for VSI fed Induction machine –**

RMS value of Phasor Voltage

\[
(V_p)_{rms} = \frac{\sqrt{2}}{3}V_s
\]

RMS value of line Voltage

\[
(V_l)_{rms} = \sqrt{3}V_p
\]

Fundamental content of phase voltage

\[
V_{p1} = \frac{\sqrt{2}}{\pi}V_s
\]

Fundamental component of line voltage

\[
V_{l1} = \sqrt{3}V_{p1}
\]

RMS value of all harmonic voltage

\[
V_{ob} = \sqrt{V^2_l - V^2_{l1}}
\]

**Total Harmonic Distortion:**

\[
\text{THD} = \frac{V_{ob}}{V_{sr}}
\]

**III. INVERTER FOURIER SERIES**

The high frequency component of current and voltages in electrical systems are defined as harmonics. Presence of harmonic in power supply creates many problems including power losses, overheating of motors, high current in neutral paths, mechanical resonances due to magnetic fields. The harmonic distortion is caused by the magnitude of the harmonic contents. Usually voltage and current waveform are non-sinusoidal. These waveform are yet periodic in nature. General expression of Fourier series for voltage applied to the machine is written as

\[
v(t) = \sqrt{2}\left[V1 \sin(\omega t) + V5 \sin(5\omega t) + V7 \sin(7\omega t) + \ldots \right]
\]

The Fourier series for a periodic function \( v_0(\omega t) \) can be expressed as

\[
v_0(\omega t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(n\omega t) + b_n \sin(n\omega t)
\]

Where \( a_0 \) is the average value of periodic wave,

\[
a_0 = \frac{1}{T} \int_0^T v_0(t) \, dt
\]

\( a_n \) is the amplitude of \( \cos \) not component of \( v_0(t) \)

\[
a_n = \frac{2}{T} \int_0^T v_0(t) \cos(n\omega t) \, dt
\]

\( b_n \) is the amplitude of \( \sin \) not component of \( v_0(t) \)

\[
b_n = \frac{2}{T} \int_0^T v_0(t) \sin(n\omega t) \, dt
\]

**IV. HARMONIC REDUCTION TECHNIQUE**

Harmonic available in DC-AC inverter is more than the harmonic available in AC-DC converter. For proper execution of any system, there is a need of reducing harmonics [6]. Harmonic distortion in DC-AC inverter can be solved by using Active filter while passive filter play a role in reducing harmonics in AC-DC converter. Frequency domain method operates on the basis of Fourier analysis. This method is so arranged that it provide fast result at minimum calculation so that real time implementation in DSP can be made.

On the basis of frequency domain, harmonics detection methods can be classified as:

1. Discrete Fourier Transform (DFT)
2. Fast Fourier Transform (FFT)
3. Recursive Discrete Fourier Transform (RDFT) [8]

**Discrete Fourier Transform (DFT) –**

DFT is a form of mathematical transformation used for discrete signal. It provides both the amplitude and phase information of the required harmonics. After the DFT calculation the harmonics are obtained and are isolated. The isolated harmonics are reconstructed back to time domain to create the compensation signal.

**Fast Fourier Transform (FFT) –**

FFT follows the mathematical operation same as DFT but in different method so as to minimize the number of calculation as well as the required DSP time. Decimal operation (can be either in frequency domain or time domain) is used for this algorithm that depend on the decomposition of N point transform into double point transform. This method is continuing until 1 point transform is obtained and calculated.

**Recursive Discrete Fourier Transform (RDFT) –**

RDFT calculation is performed on sliding window and the principle of this transform is same as the principal of DFT. The sliding window is moving and such windows are moving with a number of sample at every sampling time. Hence the DFT can be performed on New window. The main difference between new and old window is all the sample are same except the first and last sample. So the same calculation made in old window for DFT result can be avoid in new window by using Recursive expression.

From all the above three methods, this paper involves the Fast Fourier Transform technique of frequency domain. The FFT tool is a part of Power GUI which is used to display the frequency spectrum of current and voltage waveform. The FFT tool or Fast Fourier Transform tool is used when
simulation is running for a given time period, for computation of fundamental component of current and voltage. [2, 3].

V. MODELING & ANALYSIS OF THD FOR VSI FED IMD

FFT analysis of output voltage for VSI fed Induction motor is simulated in MATLAB. Figure 5.2 shows that the THD obtained for line voltage through simulation is 31.06%. As per the calculation for different order of harmonics, it is observed that the odd harmonics are the dominating harmonics which are 3rd, 5th, and 7th. 5th harmonic cause losses in output voltage but it also produce reversed torque in the motor and in case if the amplitude is very high than the motor get overloaded, while in case of 7th harmonics the losses is more. When the value of THD is lower, the core losses, peak current and heating reduces consequently in the motor [4].

THD and the fundamental component for the output voltage are shown in the spectrum window in Fig 5.1 and Fig 5.2.

Fig 5.1 FFT window of Output line voltage of VSI fed LM

In this paper the THD for line voltage is observed. In figure 5.3 and figure 5.4 shows that the effect of modulation index on line voltage and phase voltage has been carried out, which show that the Total Harmonic Distortion decreases with increase in modulation index. Here the graph is plotted between THD and line voltage and the observation were made [7].

Fig 5.2 Voltage THD-FFT Analysis for VSI fed LM

Fig 5.3 Simulation graph between line voltage and THD [7]

Fig 5.4 Simulation graph between phase voltage and THD [7]
VI. RESULTS & DISCUSSION

After minimizing the THD of line voltages in Voltage Source Inverter the response of the Induction machine and its efficiency get improved. Here, comparison is also made between the simulation model and mathematical model for THD calculation for output voltage. This paper shows that by improving the value of THD the line voltage waveform can be improve more and order of harmonics can be obtained reduce to a large extend.

The fundamental component and THD of the voltage is shown in spectrum window in figure 5.1. Percentage of fundamental component shows the harmonics. The harmonics are generally occurs at the multiple of carrier frequency (i.e. n*18 ± k). The maximum value of THD obtain is 31.06%. The performance in order to obtain the accurate value of THD, the observation is made for simulation model through FFT analysis and through mathematical calculation for the line voltage. The value of THD obtained through simulation model is 31.06% and when we compare our result through mathematical expression it is 31.08%. Here the % of error between simulation model and mathematical model is 0.02%.

<table>
<thead>
<tr>
<th>Output line voltage of VSI fed Induction motor</th>
<th>% THD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation value</td>
<td>31.06%</td>
</tr>
<tr>
<td>Experimental value</td>
<td>31.08%</td>
</tr>
</tbody>
</table>

Summary

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three phase 60 Hz, 50 hp, 460V</td>
<td></td>
</tr>
<tr>
<td>Stator Resistance</td>
<td>Rs = 1.115 ohm</td>
</tr>
<tr>
<td>Rotor resistance</td>
<td>Rs = 1.083 ohm</td>
</tr>
<tr>
<td>Stator leakage inductance</td>
<td>Ls = 0.005974 mH</td>
</tr>
<tr>
<td>Rotor leakage inductance</td>
<td>Lr = 0.005974 mH</td>
</tr>
<tr>
<td>Mutual Inductance</td>
<td>Lm = 0.2037 mH</td>
</tr>
<tr>
<td>Number of Poles</td>
<td>P = 4</td>
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<tr>
<td>Moment of inertia</td>
<td>J = 0.02 Kg·m²</td>
</tr>
<tr>
<td>Fiction factor</td>
<td>F = 0.005752 N·ms</td>
</tr>
<tr>
<td>Rotor Speed</td>
<td>Ns = 188.4 radian/second</td>
</tr>
<tr>
<td>Electromagnetic Torque</td>
<td>6 20.469</td>
</tr>
</tbody>
</table>

REFERENCES