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Harmonic Distortion Analysis of Multilevel Inverter Driven Induction Motor using Different Modulation Schemes

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***Abstract*—Induction motors experience losses due to hysteresis and due to eddy currents set up in the iron core of the motor. These are proportional to the frequency of the current. Since the harmonics are at higher frequencies, they produce higher core losses which results in increased heating of the motor core, which can shorten the life of the motor. Induction motors driven by advanced modulation schemes can be more efficient and can last for a longer duration of time. In this paper Induction motor driven by three level inverter using two modulation schemes, SPWM(Sine Pulse Width Modulation) and SVPWM (Space Vector Pulse Width Modulation) is used. The stator current of the motor is then analyzed using FFT (Fast Fourier Transform) and Wavelet transform for detecting the THD (Total Harmonic Distortion).**

Keywords—Multilevel Inverter, Sine Pulse Width Modulation (SPWM, Space Vector Pulse Width Modulation(SVPWM), Wavelet Transform.

I. INTRODUCTION

Induction motors are prime movers for an industrialized society. Around 40% of electricity produced is consumed by induction motors. So the performance and efficiency of induction motors are very important for the energy distribution systems and society as well. Induction motor drives basically enable induction motors to operate more efficiently and to perform a wider variety of tasks. Multilevel inverters can synthesize switched waveforms with lower levels of harmonic distortion than an equivalently rated two-level inverter. The multilevel concept is used to decrease the harmonic distortion in the output waveform without decreasing the inverter power output. Multilevel concept starts with basic three level inverter[1]. The switching pulses for the inverters can be produced by various modulation techniques. The two techniques are Sine PWM (SPWM) and Space Vector Pulse Width Modulation (SVPWM). In SPWM high frequency carrier wave is compared with the reference wave to generate the switching pulses. SVPWM is used for multi-phase AC generation, in which the reference signal is sampled regularly; after each sample, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are selected for the appropriate fraction of the sampling period in order to synthesize the reference signal as the average of the used vectors.

II. SINE PULSE WIDTH MODULATION (SPWM)

Pulse Width Modulation is a technique in which a fixed DC voltage is given to the inverter and a controlled output voltage is obtained by adjusting the on and off periods of the inverter components. Sinusoidal Pulse width modulation is also known as triangulation. Here high frequency triangular carrier wave is compared with sinusoidal reference wave to determine the switching instants [3].

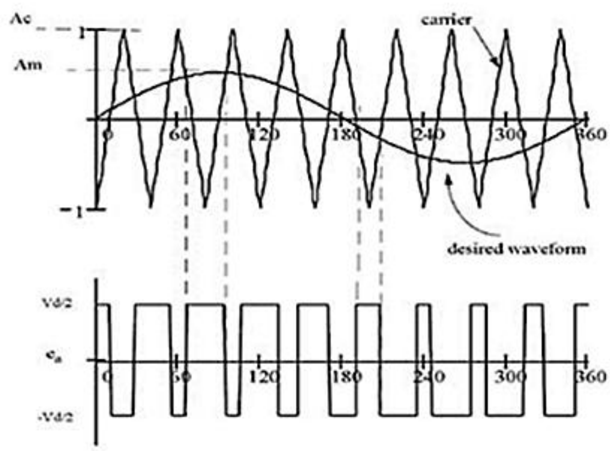

Figure2: PWM using triangular carrier wave and Sinusoidal reference wave.

III. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

Space Vector Pulse Width Modulation is a vector approach to pulse width modulation for three-phase inverters. In vector controlled application it is used for reference voltage generation. SVPWM is the best among all pulse width modulation techniques as it has efficient DC bus utilization and lower total harmonic distortion [4].

Three phase system is described by a co-planar vector space with three axes. Three phase inverters have three bridge arm and each arm represents an axis in the co-planar vector space. Therefore there are three vectors one for each arm of the bridge inverter that is uniformly distributed in the co-planarvector space at an angular distance of 120^0 with respect to each other [5]. Any vector in the co-planar vector space can be represented by a triple (a_1,b_1,c_1) .The co-planar vector space can be described by three primary vectors (0,0,1),(0,1,0)and (1,0,0) . The primary vectors of the co-planar vector space of the three phase system are shown in Figure 1.Using the *a*-axis as the reference axis, the primary vectors in the polar form are expressed as

$$(0,0,1) \Rightarrow 1\, e^{jo} = 1$$

$$(0,1,0) \Rightarrow 1\, e^{j(2*pi/3)} = e^{j(2*pi/3)}$$

$$(1,0,0) \Rightarrow 1\, e^{j4*pi/3)} = e^{j4*pi/3)}$$

Any vector in the co-planar vector space is called a space vector and is represented as

$$V = k_1.1 + k_2.e^{j(2*pi/3)} + k_3 e^{j4*pi/3)}$$

Where k_1 , k_2 , k_3 are scalar quantities along *a* ,*b* and *c* axes respectively.

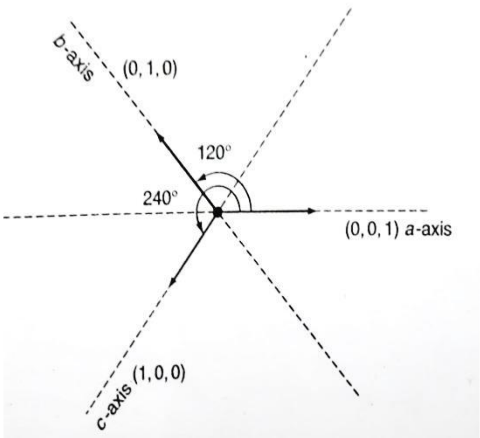

Fig1 Primary vectors defining the co-planar vector space[5]

Three phase Voltage Source Inverters have six power switches .When one of the switches in the upper half bridge is opened, the corresponding one in the lower bridge will be closed and vice-versa [5]. So there are 8 switching modes and the 8 voltage space vectors.V_1 – V_6 are called active or effective vectors and V_0 and V_7 are called null vectors or null vectors. The six space vectors and the two zero vectors form a hexagonal pattern as shown in figure 3

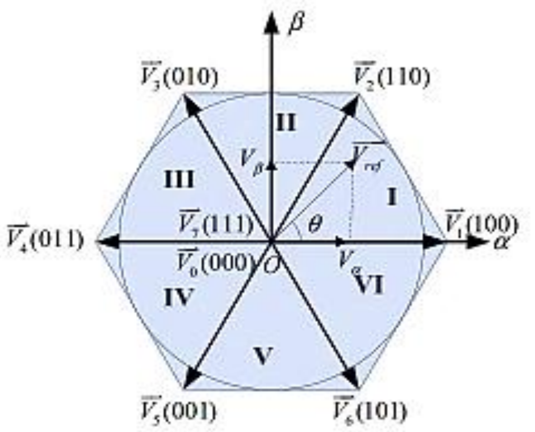

Figure 3 Representation of space vectors in complex plane [2]

The switching pulses for the inverter using space vector modulation is implemented using SVPWM algorithm as in [2].

IV. HARMONIC ANALYSIS

Induction motors experiences losses due to hysteresis and due to eddy currents set up in the iron core of motor. These losses are proportional to the frequency of current. Since the harmonics are present at higher frequencies, they produce higher core losses in a motor which results in increased heating of the motor core and can shorten the life of the motor. Therefore proper analysis of stator current of induction motor is necessary.

Harmonic analysis is done by calculating the Total Harmonic Distortion (THD).A harmonic is a signal or wave whose frequency is an integral multiple of the frequency of some reference signal or wave. Harmonics are multiples of the fundamental frequency. Total harmonic distortion is the contribution of all the harmonic components to the fundamental. The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the Fundamental frequency [6].

In this paper THD of the stator current of the induction motor is calculated using FFT and Wavelet transform. Here 3 HP,350V, 50Hz squirrel Cage induction motor is fed by SPWM modulated and SVPWM modulated inverter in Simulink. The resulting stator current is accessed and THD is calculated using FFT and wavelet transform (Haar and Daubechies wavelets are used).

A) HARMONIC ANALYSIS BY FFT

THD is the summation of all harmonic components of the current waveform compared against the fundamental component of the current wave.

$$THD = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2}}{I_1} \times 100$$

Where, I_n is the n^{th} harmonic component of the stator current and I_1 is the fundamental component.

B) HARMONIC ANALYSIS BY WAVELET TRANSFORM

Wavelet transform algorithm produces DWT coefficients starting from separating the original signal 'S' of length N to 2 set of coefficients: approximate coefficients CA1 by low pass filter and detail coefficients CD1 by high pass filter. The length of each filter is equal to half of original's length by down sampling function. The next step splits the approximate coefficients cA1 in two parts again by the same process but replace 'S' by cA1 and producing cA2 and cD2 and so on. Process for producing wavelet coefficient is shown in Figure 4. The approximation and detail coefficients at scale j are written as CAj and CDj[8]

In this paper the fundamental frequency is 50 Hz and used 8 levels of decomposition and detail and approximation coefficients are obtained. THD is calculated by including each sub-band contribution as in [10]

$$THD = \frac{\sqrt{\frac{1}{N_j}\sum CD_j\ (n)^\wedge 2}}{\sqrt{\frac{1}{N_8}\sum CA8\ (n)^\wedge 2}} \times 100$$

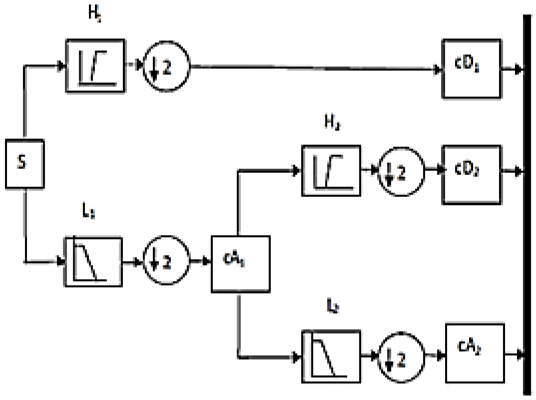

Figure 4: The process of Wavelet Transform which include low pass and high pass filter and down sampling produces DWT coefficients [9].

V. SIMULATION RESULTS

Here three level inverter using IGBT is used and is fed to 3 HP, 350V, 50Hz induction motor in Simulink / Matlab. Two modulation techniques are used, Sine PWM and Space Vector PWM. The stator current of induction motor using the above two techniques is accessed and harmonic analysis is done by calculating THD of the stator current using FFT and Wavelet transform (Haar, db4 and db6 wavelets are used). Figure5 shows the Simulink model. THD values for SPWM and SVPWM using different transforms are given in Table 1.

Table 1 Percentage THD for SPWM and SVPWM

Modulation Technique	Percentage THD				
	FFT	Haar	Db2	Db4	Db6
SPWM	12.53	11.83	11.77	6.67	6.63
SVPWM	8.20	8.49	7.86	3.55	3.00

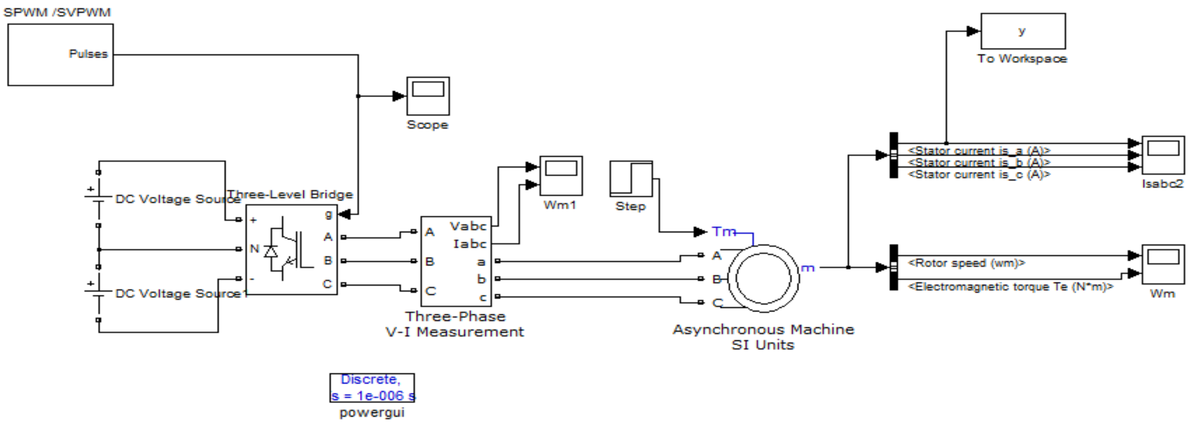

Figure 5 Simulink model

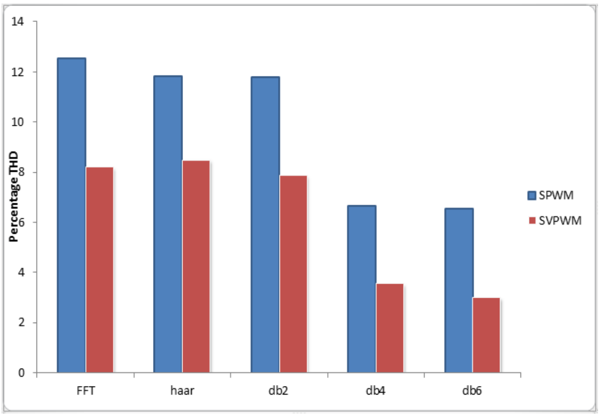

Figure 6 Percentage THD for SPWM and SVPWM

VI. CONCLUSION

In this paper, stator current of three level inverter driven Induction Motor using two modulation schemes (SPWM and SVPWM) was investigated. From table 1 and Figure 6 it can be seen that the stator current of Induction Motor driven by SVPWM inverter has lower THD compared to the stator current of induction motor driven by SPWM inverter. While Haar and db2 have close results to FFT. Db4 and Db6 have slight variations.

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