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Performance of Variable Delay Randomization PWM Algorithm based Vector Controlled Induction Motor Drive with reduced acoustical noise

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Abstract— *This paper presents Performance of Variable Delay Randomization pulse width modulation (VDRPWM) Algorithm based Vector Controlled Induction Motor Drive with reduced acoustical noise. A simplified SVPWM algorithm for vector controlled induction motor drive with the concept of imaginary switching times (IST) to reduce the computational burden involved in the conventional approach. In order to reduce the acoustical noise, VDRPWM algorithm based on imaginary switching times is proposed and numerical simulations have been carried for various operating conditions of the drive. From the simulation results, it can be observed that the proposed VDRPWM algorithm reduces the THD and acoustical noise by giving spread spectra.*

Index Terms—*SVPWM, VDRPWM, IST, Induction motor, vector control, THD, acoustical noise.*

1 Introduction

THE high performance speed control of induction motor is based on the vector control, which is also known as field oriented control (FOC). The invention of field oriented control or vector control brought a renaissance in high performance induction motor drives. With the vector control algorithm [1], the decoupling of torque and flux control commands of the induction motor is guaranteed, and the induction motor can be controlled as a separately excited dc motor. However, the vector control algorithm uses hysteresis type current controllers for the generation of gating signals, which results in variable switching frequency operation of the inverter. To achieve constant switching frequency operation of the inverter, the conventional space vector PWM (SVPWM) algorithm [2] has been used for vector controlled induction motor drive. The SVPWM algorithm divides the zero state time equally among the two zero voltage vectors. The hysteresis controllers based FOC schemes suffer from high ripples in torque and current since none of the inverter state is able to generate exact stator voltage vector required to produce desired changes in torque. To achieve a substantial reduction of ripple in current at each sampling period, it is necessary to calculate the stator voltage space vector to exactly compensate the torque errors. In order to apply this principle, the control system should be able to generate the desired voltage vector, using the SVPWM technique [3].

Acoustic noise has been a major problem since the invention of the induction motor drive. Basically, it is caused by flux space harmonics. The flux space harmonics are dependent upon certain factors, such as winding layout, fluctuation in air-gap permeance due to slots of stator and rotor, eccentricity [4], local saturation etc. The acoustic noise radiated by induction machines increases when they are operated from non sinusoidal power supplies, such as pulsewidth modulated inverters[5]. Electromagnetic noise due to PWM switching is generated at narrow band high frequencies, which cause communication obstacles and unpleasant high-frequency audible noise. Several studies related to techniques to reduce this audible switching noise have been reported [6-8]. Recently, new PWM methods for noise reduction called random pulse width modulation (RPWM) methods have been investigated extensively. These use broad-band switching frequencies to spread the noise spectrum instead of using a specific fixed switching frequency. RPWM strategies are attracting interest as excellent methods for noise reduction because of their simple algorithm [9].

To reduce audible noise, VDRPWM algorithm based on imaginary switching times is proposed for FOC based induction motor drives. The proposed algorithm reduces acoustical noise and also avoids burden in calculations. Further, the switching frequency of the inverter is maintained constant.

2 SVPWM Algorithm

Voltage source inverters (VSI) are utilized in many applications. The three-phase, two-level VSI has a simple structure and generates a low-frequency output voltage with controllable amplitude and frequency by programming high-frequency gating pulses. For a 3-phase, two-level

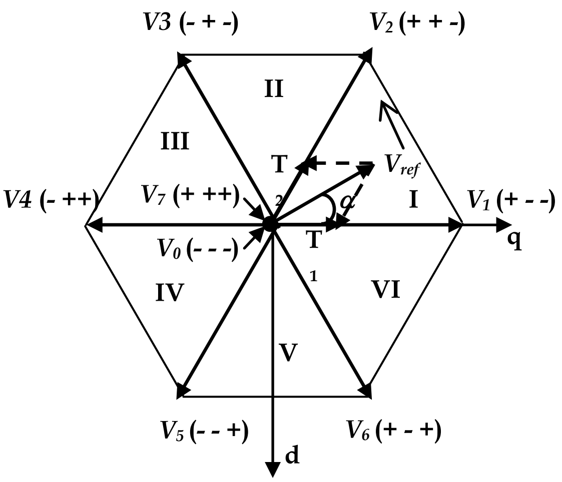

Fig. 1 Voltage space vectors produced by an inverter

VSI, there are eight possible voltage vectors, which can be represented as shown in Fig. 1. Among these voltage vectors, V_1 to V_6 vectors are known as active voltage vectors or active states and the remaining two vectors are known as zero states or zero voltage vectors. The reference voltage space vector represents the corresponding to the desired value of the fundamental components for the output phase voltages. In the space vector approach this can be constructed in an average sense. The reference voltage vector (V_{ref}) is sampled at equal intervals of time, T_s referred to as sampling time period. Different voltage vectors that can be produced by the inverter are applied over different time durations with in a sampling time period such that the average vector produced over the sampling time period is equal to the sampled value of the V_{ref}, both in terms of magnitude and angle. It has been established that the vectors to be used to generate any sample are the zero voltage vectors and the two active voltage vectors forming the boundary of the sector in which the sample lies. As all six sectors are symmetrical, the discussion is limited to the first sector only.

For the required reference voltage vector, the active and zero voltage vectors times can be calculated as in (1), (2) and (3).

$$T_1 = \frac{2\sqrt{3}}{\pi} M_i \sin(60^o - \alpha) T_s \quad (1)$$

$$T_2 = \frac{2\sqrt{3}}{\pi} M_i \sin(\alpha) T_s \quad (2)$$

$$T_z = T_s - T_1 - T_2 \quad (3)$$

where M_i is the modulation index and defined as in [1]. In the SVPWM algorithm, the total zero voltage vector time is equally divided between V_0 and V_7 and distributed symmetrically at the start and end of the each sampling time period. Thus, SVPWM uses 0127-7210 in sector-I, 0327-7230 in sector-II and so on.

3 Simplified SVPWM Algorithm:

To reduce the complexity involved in the conventional SVPWM algorithm and memory size, in this section, SVPWM algorithm has been developed using the concept of imaginary switching times. In this approach, the actual switching times for each inverter leg are deduced directly as a simple form. The proposed approach is based on the instantaneous values of the reference voltages of a, b and c phases only. This method does not depend on the magnitude of the reference voltage space vector and its relative angle with respect to the reference axis. By the d-q transformation theory, the transformation from two-phase voltages to three-phase voltages can be obtained from the stationary frame reference voltages as given in (4)

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & +\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_q \\ V_d \end{bmatrix} \quad (4)$$

If the reference voltage vector lies in the first sector as shown in Fig.1, then the actual switching times can be deduced as

$$\begin{aligned} T_1 &= \frac{3V_{ref}}{2V_{dc}} \frac{Sin(60^o - \alpha)}{Sin60^o} * T_s \\ &= \frac{\sqrt{3}}{V_{dc}} \left(\frac{\sqrt{3}}{2} V_{ref} \cos\alpha - \frac{1}{2} V_{ref} \sin\alpha \right) * T_s \end{aligned} \quad (5)$$

$$\begin{aligned} T_2 &= \frac{3V_{ref}}{2V_{dc}} \frac{Sin\alpha}{Sin60^o} * T_s \\ &= \frac{\sqrt{3}}{V_{dc}} \left(V_{ref} \cos\alpha \right) * T_s \end{aligned} \quad (6)$$

But from Fig. 1 it can be observed that $V_q = V_{ref} \cos\alpha$ and $V_d = -V_{ref} \sin\alpha$. Hence, the active vector times can be simplified as

$$\begin{aligned} T_1 &= \frac{\sqrt{3}}{V_{dc}} \left(\frac{\sqrt{3}}{2} V_q + \frac{1}{2} V_d \right) * T_s \\ &= \frac{T_s}{V_{dc}} \left(V_q + \left(\frac{1}{2} V_q + \frac{\sqrt{3}}{2} V_d \right) \right) \\ &= \frac{T_s}{V_{dc}} V_{an} - \frac{T_s}{V_{dc}} V_{bn} \equiv T_{an} - T_{bn} \end{aligned} \quad (7)$$

and

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$$\begin{aligned} T_2 &= \frac{\sqrt{3}}{V_{dc}}\left(-V_d\right) * T_s \\ &= \frac{T_s}{V_{dc}}\left(-\sqrt{3} * V_d\right) \\ &= \frac{T_s}{V_{dc}}\left[\left(\frac{-1}{2}V_q - \frac{\sqrt{3}}{2}V_d\right) - \left(\frac{-1}{2}V_q + \frac{\sqrt{3}}{2}V_d\right)\right] \\ &= \frac{T_s}{V_{dc}}V_{bn} - \frac{T_s}{V_{dc}}V_{cn} \equiv T_{bn} - T_{cn} \end{aligned} \tag{8}$$

From the above equations, the imaginary switching time periods proportional to the instantaneous values of the reference phase voltages are defined as

$$T_{an} \equiv \left(\frac{T_s}{V_{dc}}\right)V_{an}\ ; \quad T_{bn} \equiv \left(\frac{T_s}{V_{dc}}\right)V_{bn}\ ; \quad T_{cn} \equiv \left(\frac{T_s}{V_{dc}}\right)V_{cn} \tag{9}$$

Hence, the active vector switching times T_1 and T_2, if the reference voltage vector falls in sector-1 may be expressed as

$$T_1 = T_{an} - T_{bn}\ ; \qquad T_2 = T_{bn} - T_{cn} \tag{10}$$

Thus, the active voltage vector switching times can be represented by the time difference between the imaginary switching time periods. In the SVPWM algorithm, when the reference voltage vector falls in the first sector, the imaginary switching time which is proportional to the a-phase (T_{an}) has a maximum value, the imaginary switching time which is proportional to the c-phase (T_{cn}) has a minimum value and the imaginary switching time which is proportional to the b-phase (T_{bn}) is neither minimum nor maximum switching time. Thus, in general to calculate the active vector switching times, the maximum and minimum values of imaginary switching times are calculated in every sampling time as given in (11) – (14).

$$T_{\max} = Max(T_{an}, T_{bn}, T_{cn}) \tag{11}$$

$$T_{\min} = Min(T_{an}, T_{bn}, T_{cn}) \tag{12}$$

Then the active vector switching times T_1 and T_2 may be expressed as

$$T_1 = T_{\max} - T_X\ ; T_2 = T_X - T_{\min} \tag{13}$$

where $T_X \in (T_{an}, T_{bn}, T_{cn})$ and is neither minimum nor maximum imaginary switching time.

The zero voltage vectors switching time is calculated as

$$T_z = T_s - T_1 - T_2 \tag{14}$$

By using the active vector times and zero vector times can be calculated. Thus, the active state times and zero states times can be calculated without determining the angle and sector information with the help of imaginary switching times.

4 Proposed VDRPWM Algorithm

The proposed approach dithering the switching periods, subsequently referred to as a variable delay randomization PWM (VDRPWM) algorithm, is characterized by a constant sampling frequency. In VDRPWM algorithm, the individual switching periods are varied in a random manner by randomizing the delays of switching cycles with respect to the corresponding sampling cycles. The variable delay acquires values between zero and the sampling time period. A flow-chart of proposed VDRPWM algorithm for the generation of random delay process in a switching period is shown in Fig. 2, from which, it can be observed that the number of switching cycles is the same as that of sampling cycles, that is, the average switching frequency equals the fixed sampling frequency. If the variable delay equals to zero, then the proposed VDRPWM algorithm becomes the standard SVPWM algorithm.

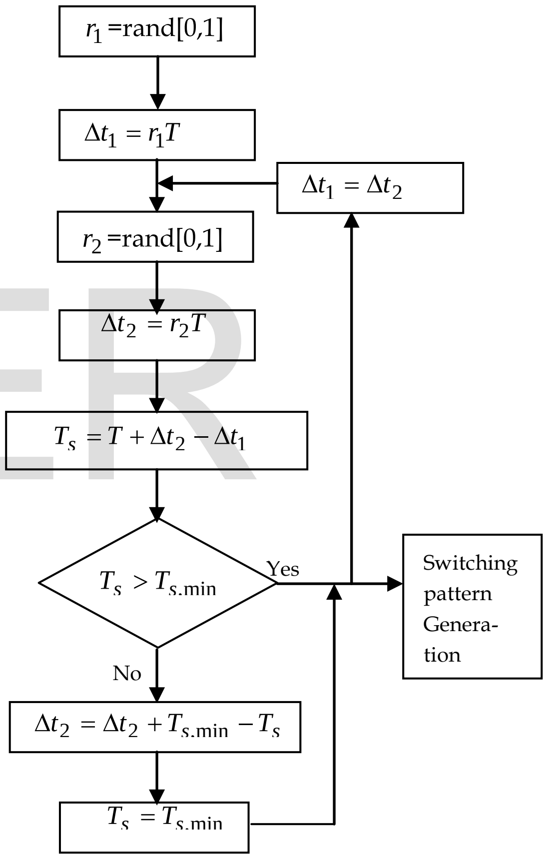

Fig. 2 Flowchart of the proposed VDRPWM algorithm for the generation of random delay process in a switching period

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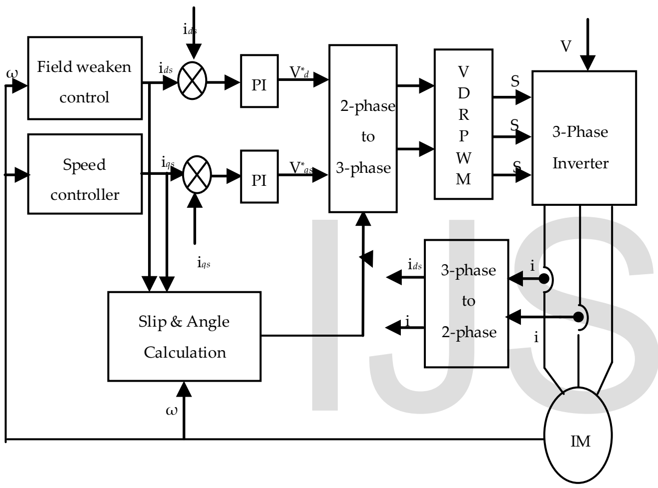
5. Proposed VDRPWM Algorithm Based Vector Controlled Induction Motor Drive

The block diagram of proposed PWM algorithms based indirect vector controlled induction motor drive can be shown as in Fig. 3. This shows how the rotor flux linkage position can be obtained by integrating the sum of rotor speed and actual speed. In the indirect vector control scheme, to regulate λ_r and rotor speed to desired values are the two objectives. Apparently the stator voltages that are required to generate the desired rotor flux linkage and rotor speed are not directly related to these variables. So the alternative way is to regulate the rotor flux linkage and rotor speed through PI controllers and the outputs of



these two controllers give out the reference values for the q- and d-axis stator currents in synchronous reference frame. Then the actual q- and d-axis stator currents are regulated to these two reference currents to get the stator voltages. The obtained two-phase voltages will be converted into three-phase voltages and given in VDRPWM block

Fig. 3 block diagram of VDRPWM based indirect vector controlled induction motor

6 Simulation Results and Discussions

To validate the SVPWM and proposed VDRPWM algorithms based vector controlled induction motor drive, several numerical simulation studies have been carried out at various conditions by using Matlab/Simulink. For the simulation studies, the switching frequency is taken as 5 kHz and dc link voltage is taken as 540V. The induction motor used in this paper is a 4 kW, 400V, 1470 rpm, 4-pole, 50 Hz, 3-phase induction motor having the following parameters:R_s= 1.57Ω, R_r = 1.21Ω, L_s = 0.17H, L_r = 0.17H, L_m = 0.165 H and J = 0.089 Kg.m². The simulation results of SVPWM and VDRPWM based vector controlled induction motor drive are shown in from Fig 4 to Fig.11.

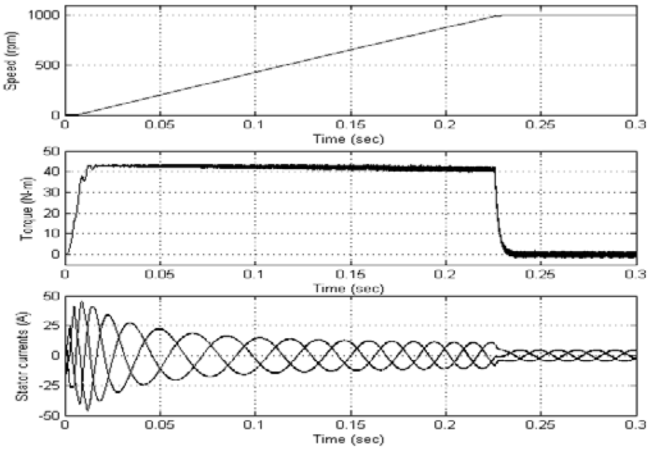


Fig. 4 Starting transient of vector controlled induction motor drive with SVPWM algorithm

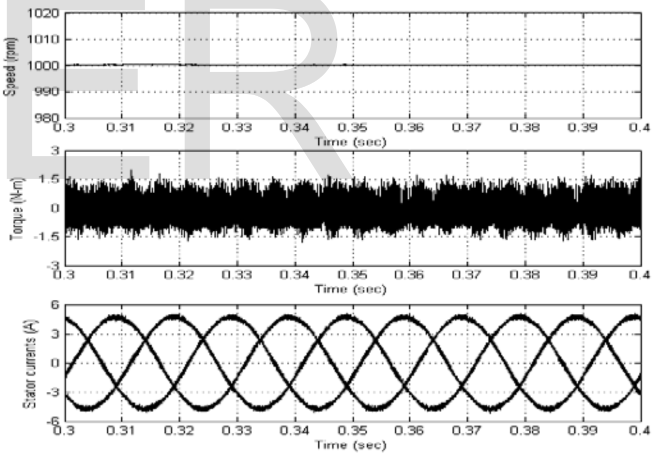


Fig. 5 Steady state plots of vector controlled induction motor drive with SVPWM algorithm

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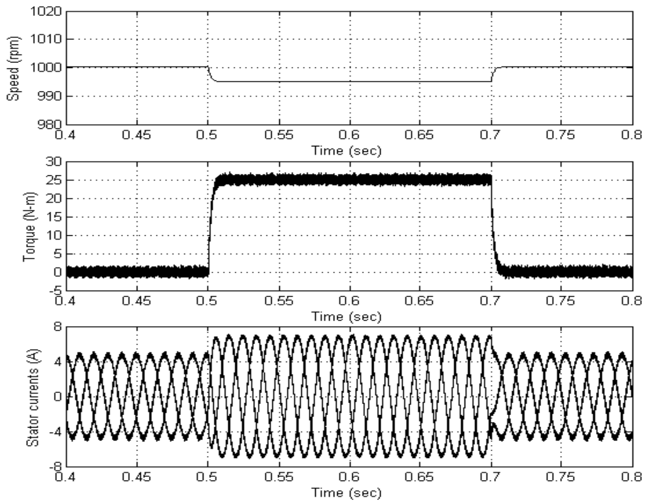

Fig. 6 Transients of vector controlled induction motor drive with SVPWM algorithm during step change in load

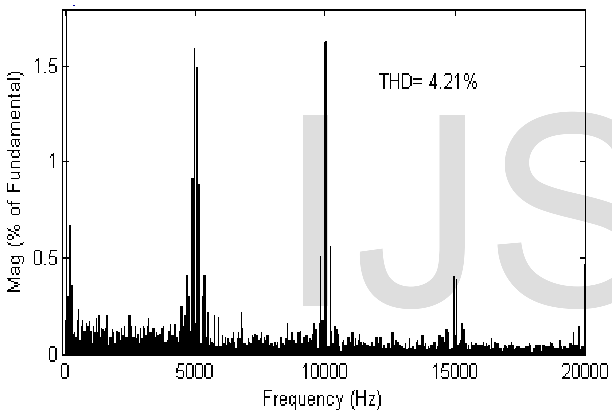

Fig. 7 Harmonic spectra of line current with the SVPWM algorithm based vector controlled induction motor drive

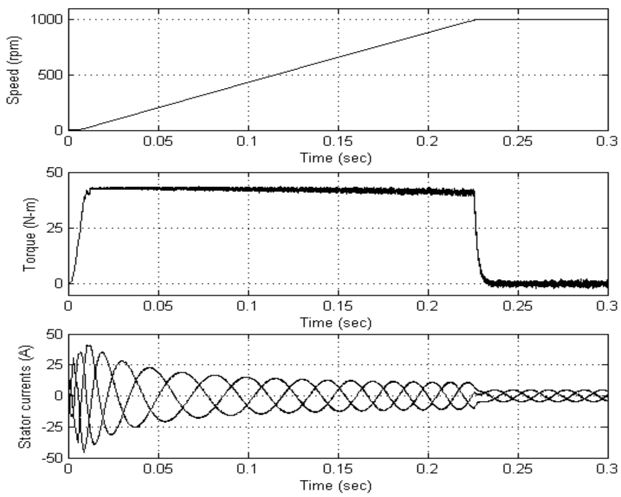

Fig. 8 Starting transients in proposed VDRPWM algorithm based vector controlled induction motor drive

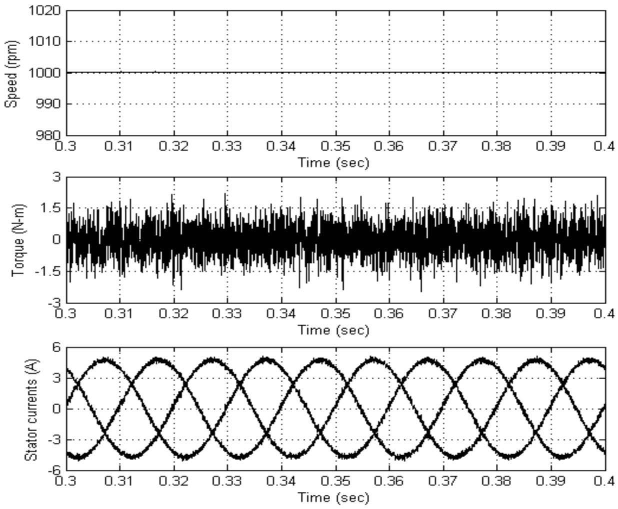

Fig 9 Steady state plots of proposed VDRPWM algorithm based vector controlled induction motor drive

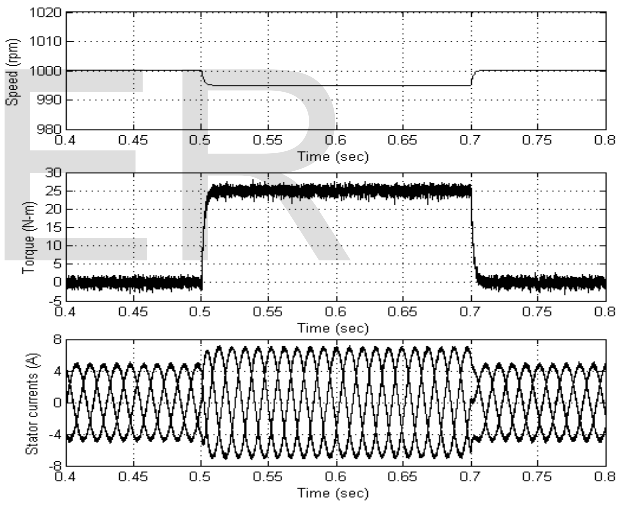

Fig 10. Transients of vector controlled induction motor drive with VDRPWM algorithm during step change in load

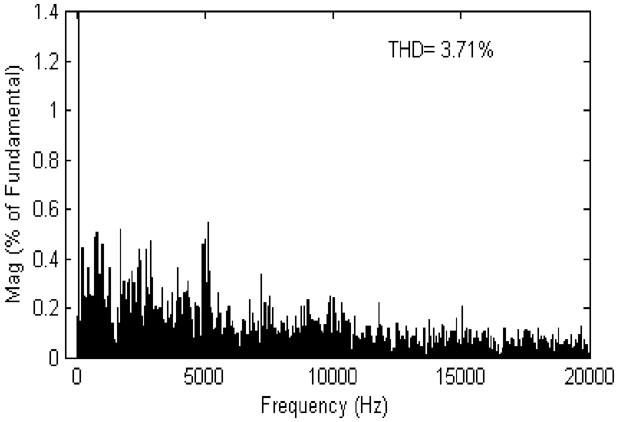

Fig 11 Harmonic spectrum of line current of proposed VDRPWM algorithm based vector controlled induction motor drive

Thus, the proposed VDRPWM algorithm reduces the steady state current ripple and acoustical noise of the induction motor when compared with the SVPWM algorithm.

7 CONCLUSIONS

Here, A simplified SVPWM algorithm for vector controlled induction motor drive with the concept of imaginary switching times is analyzed in order to reduce the computational burden involved in the conventional approach. To reduce THD and the acoustical noise, VDRPWM algorithm based on imaginary switching times is proposed and numerical simulations have been carried for various operating conditions of the drive. From the simulation results, it can be observed that the proposed VDRPWM algorithm reduces the THD and acoustical noise by giving spread spectra. The simulation results validate the proposed method.

REFERENCES

[1] F. Blaschke "The principle of field orientation as applied to the new transvector closed loop control system for rotating-field machines," *Siemens Review*, 1972, pp 217-220.

[2] Heinz Willi Vander Broeck, Hnas-Christoph Skudelny and Georg Viktor Stanke, "Analysis and realization of a pulsewidth modulator based on voltage space vectors" *IEEE Trans. Ind. Applicat.*, vol. 24, no. 1, Jan/Feb 1988, pp. 142-150.

[3] Michael M.Bech, Frede Blaabjerg, and John K. Pedersen, "Random modulation techniques with fixed switching frequency for three-phase power converters" IEEE Trans. Power Electron., vol.15, no.4, pp. 753-761, Jul, 2000.

[4] S-H Na, Y-G Jung, Y-C. Lim, and S-H. Yang, "Reduction of audible switching noise in induction motor drives using random position space vector PWM" IEE. Proc. Electr. Power Appl., vol.149, no.3, pp. 195-200, May, 2002.

[5] Andzrej M. trzynadlowski, Konstantin, Yuin Li, and Ling Qin, "A novel random PWM technique with low computational overhead and constant sampling frequency for high-volume, low-cost applications" IEEE Trans. Power Electron., vol. 20, no.1, pp.116-122, Jan, 2005.

[6] Dae-Woong Chung, Joohn-Sheok Kim and Seung-Ki Sul, "Unified voltage modulation technique for real-time three-phase power conversion" *IEEE Trans. Ind. Applicat.*, vol. 34, no. 2, Mar/Apr 1998, pp. 374-380.

[7] T. Brahmananda Reddy, J. Amarnath and D. Subbarayudu, "Improvement of DTC performance by using hybrid space vector Pulsewidth modulation algorithm" International Review of Electrical Engineering, Vol.4, no.2, pp. 593-600, Jul-Aug, 2007.

[8] K. Satyanarayana1, J. Amarnath2, and A. Kailasa Rao1, "Hybrid PWM Algorithm with Low Computational Overhead for Induction Motor Drives for Reduced Current Ripple" ICGST-ACSE journal, vol.10, isuue.1, pp. 29-37, Dec, 2010.

[9] K. Satyanarayana, Dr.J.Amarnath and Dr.A.Kailasa Rao "Random PWM Algorithms for VSI fed Induction Motor Drives with fixed switching frequency" International Journal of Engineering Science and Technology, Vol. 2(12), 2010,pp.6968-6975