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A New PWM Strategy for three phase Inverters applied for Induction motor

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Abstract: *Pulse width modulation is the process of modifying the width of the pulses in a pulse train in direct proportion to a small control. In the PWM technique reference is commonly taken depended on the output waveform. Depending on the frequency there are two types of switching frequencies; constant switching frequency and variable switching frequency. Compared with constant switching frequency pulse width modulation method, variable switching frequency PWM can benefit more because of the extra freedom. Two methods are discussed in this concept. The first method is designed to arrange the current ripple peak value within a certain value and can reduce the equivalent switching frequency and electromagnetic interference (EMI) noise, the second method is designed to keep ripple current RMS value constant and reduce the EMI noise. Simulation results should be validating by showing the variable switching frequency applied with induction motor drive could improve the performance of EMI and efficiency of converter by using Mat lab / Simulink.*
Keywords: *current ripple, three phase inverter, pulse width modulation, variable switching frequency, induction motor.*

I. Introduction

A THREE-PHASE inverter is an electronic device or circuitry that changes direct current(DC) to alternating current(AC).The three- phase inverters are widely used in various applications, such as grid connected photo voltaic (PV) inverters[1]-[5], uninterruptible power supplies[6], AC motor drives[2], PWM rectifiers[3],[4] and active filters. There are many types of PWM methods can be used for three phase converters, discontinuous PWM and space vectors PWM (SVPWM) are the typical two methods. Generally the switching frequency is constant for PWM methods in three phase converters. But because of this constant switching frequency the system losing its freedom and making the EMI problem very serious. Hence instead of CSFPWM, variable switching frequency is developed to reduce the disadvantage of CSFPWM.

Random PWM is one of the VSFPWM method, which has taken place over the last 20 years, the principle of RPWM is “Randomly spreading the switching period”. By using this method the results are without calculation and converter losses, current ripple of RPWM are not controllable therefore a controllable VSFPWM is preferred. This paper addresses the design and implementation of VSFPWM with induction motor drive.

II. Literature Survey

Current ripple is an important factor for design and control in converters. Hava et.al [7] introduced the harmonic flux and harmonic distortion function to determine the current ripple but there is no clear explanation at current ripple in time domain. Wei et.al [8] discussed methods that double the switching frequency in the area where the ripple current is maximum. This method can reduce the switching losses but it is only a rough determination and it could only reduce ripple current in some areas without theoretical arrangement. Mao et.al [9] proposed VSF method for single phase converters. In this method the current ripple is reduced with switching period Ts, duty cycle d, dc voltage Vdc and output inductance. Including peak current ripple and RMS ripple current, switching frequency could be arranged to control current ripple to satisfy certain requirements. Dujic et.al [10] introduced five phase voltage source inverter and studied about THD without closely studying the current ripple distribution.

Now-a-days there phase converters are mostly used in many applications compared to single phase converters. Hence this paper addresses a new PWM strategy applied to three phase converters with induction motor drive to control ripple current an achieve better efficiency. In section III of this paper introduces the principle operation of current ripple prediction ;In section IV, Architecture of VSFPWM addressed; In section V, the method 1 of VSFPWM to control peak value of ripple current and method 2 of VSFPWM to control RMS value of ripple current in converter system. In section VI, VSFPWM with induction motor drive circuit diagram and simulation results are mentioned. Then in section VII, conclusions are made.

III. Principle Operation Of Durrent Ripple Prediction

The most common meaning of ripple in electrical science is the small unwanted residual periodic variation of the direct current (dc) output of a power supply which has been derived from an alternating current (ac) source. This ripple is due to incomplete suppression of the alternating waveform within the power supply. As well as this time-varying phenomenon, there is a frequency domain ripple that arises in some classes of filter and other signal processing networks. In this case the periodic variation is a variation in the insertion loss of the network against increasing frequency. The variation may not be strictly linearly periodic. In this meaning also, ripple is usually to be considered an unwanted effect, its existence being a compromise between the amount of ripple and other design parameters. In this section, based on VSFPWM method current ripple analytical expression is given. In the modulator da, db and dc are the three duty cycles for three phase converters are varying from 0 to 1.

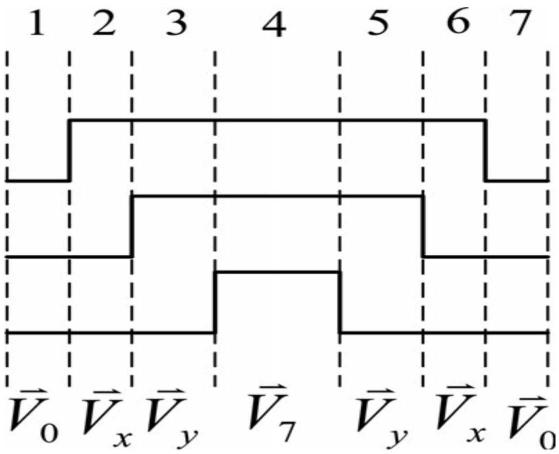

Fig.1. Seven zones in one switching cycle in SVPWM

The inverter output fundamental voltages in steady state are given as follows-

$$V_a = d_a^{'} \frac{V_{dc}}{2}$$

$$V_b = d_b^{'} \frac{V_{dc}}{2}$$

$$V_c = d_c^{'} \frac{V_{dc}}{2} \qquad (1)$$

Fig.1. Shows seven zones of switch state with SVPWM. From 1 to 7 are the zones with V_0 (000) and V_7 (111) zero vectors and V_X and V_Y are the non-zero vectors.

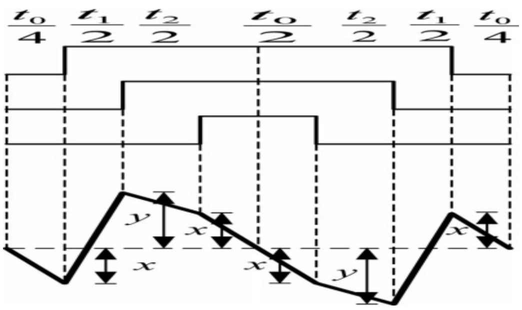

Fig.2. Ripple current variation in one switching cycle in SVPWM

In each zone, combination of voltage is added to output of inductor, the inductor current will linearly increase or decrease in this zone, so that one switching cycle will also have seven zones which is shown in fig.2. t_0 is called zero vector and t_1, t_2 are called non zero auction times and x, y are the values of ripple current turning point. There are 8 different switching combinations for three phase converters. These switching combinations have 8 voltage vectors and equivalent the venin's circuits are shown in fig.3.

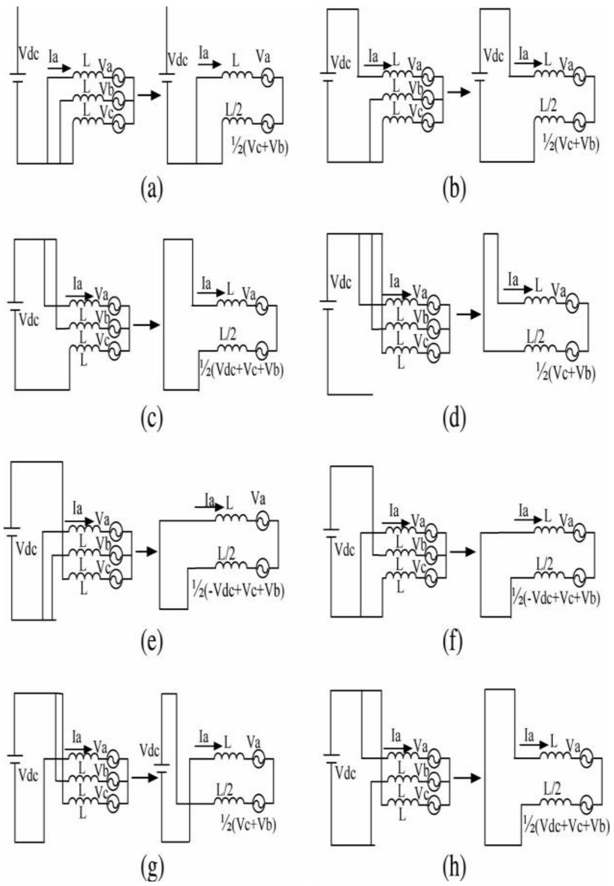

Fig.3. Switch combinations of 8 different voltage vectors and their the venin equivalent circuits

Consider the first voltage vector V_0(000) from fig.1.The equivalent the venin circuit is shown in fig.3(a).Take phase A to be our phase ,then phase B and phase C are parallel to each other, slope of ripple current, average value of phase voltage to be derived and given in equation (2) and (3) below.

$$\frac{di_a}{dt} = \frac{2}{3L}\left(\frac{V_b + V_c}{2} - V_a\right) \qquad (2)$$

$$\frac{di_a}{dt} = \frac{V_{dc}}{3L}\left(\frac{d_b^{'} + d_c^{'}}{2} - d_a^{'}\right) \qquad (3)$$

Similarly for remaining zones, the ripple current slopes are derived and shown in table 1

Table1: Ripple Current Slope with Different Voltage Vectors.

Vector	**Ripple Current Slope**
100	$\frac{di_a}{dt} = \frac{2V_{dc}}{3L}\left(1 + \frac{d_b^{'} + d_c^{'}}{4} - \frac{d_a^{'}}{2}\right)$
110	$\frac{di_a}{dt} = \frac{2V_{dc}}{3L}\left(\frac{1}{2} + \frac{d_b^{'} + d_c^{'}}{4} - \frac{d_a^{'}}{2}\right)$
111	$\frac{di_a}{dt} = \frac{V_{dc}}{3L}\left(\frac{d_b^{'} + d_c^{'}}{2} - d_a^{'}\right)$

001	$\frac{di_a}{dt} = \frac{V_{dc}}{3L}\left(\frac{d_b^{'} + d_c^{'}}{2} - 1 - d_a^{'}\right)$
010	$\frac{di_a}{dt} = \frac{V_{dc}}{3L}\left(\frac{d_b^{'} + d_c^{'}}{2} - 1 - d_a^{'}\right)$
011	$\frac{di_a}{dt} = \frac{2V_{dc}}{3L}\left(\frac{d_b^{'} + d_c^{'}}{4} - 1 - \frac{d_a^{'}}{2}\right)$
101	$\frac{di_a}{dt} = \frac{2V_{dc}}{3L}\left(\frac{1}{2} + \frac{d_b^{'} + d_c^{'}}{4} - \frac{d_a^{'}}{2}\right)$

IV. Architecture Of Variable Switching Frequency Method (VSFPWM)

Based on theoretical analysis of ripple current, before the generation of pulses to converter, it could be predicted. In controller the duty cycles d_a, d_b and d_c are calculated and sent to comparator then generates pulses to gate driver is shown in fig.4.

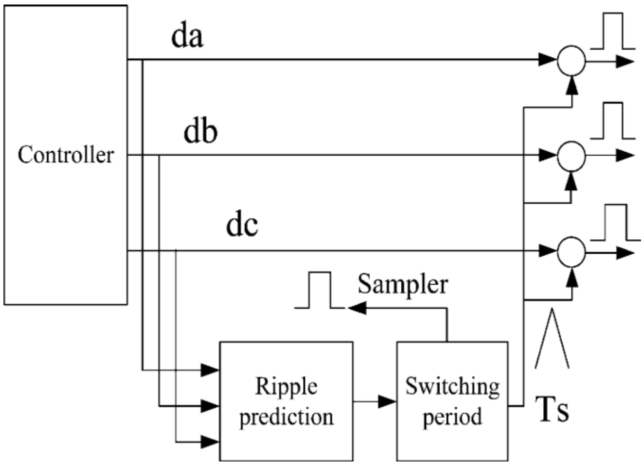

Fig.4. Structure of VSFPWM generation

From fig. 4.In comparator, the switching time period Ts is constant, duty cycles are updated in each switching cycle. When the duty cycles (da ,db, dc)are calculated with nominal switching period(T_{SN}) current ripple could be predicted. This process is shown in fig.5.

The current ripple in each switching cycle is linearly updated to Ts.

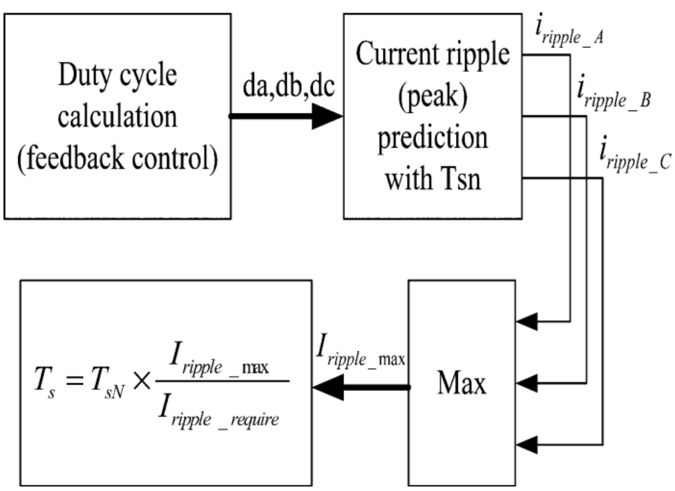

Fig.5. Switching period update process

If the updated current is fixed to the required current $I_{ripple\text{-}require}$, the updated switching period is derived in equation (6).

$$I_{ripple\_update} = I_{ripple\_predicted} \times \frac{T_s}{T_{sN}} \quad (6)$$

V. Vsfpwm Methods

With different ripple requirements, two kinds of VSFPWM methods are introduced: Method 1 is to control peak value of ripple current and method 2 is to control RMS value of ripple current. Based on fig.5.Updating switching process for VSFPWM 1 is achieved and shown in fig.6.

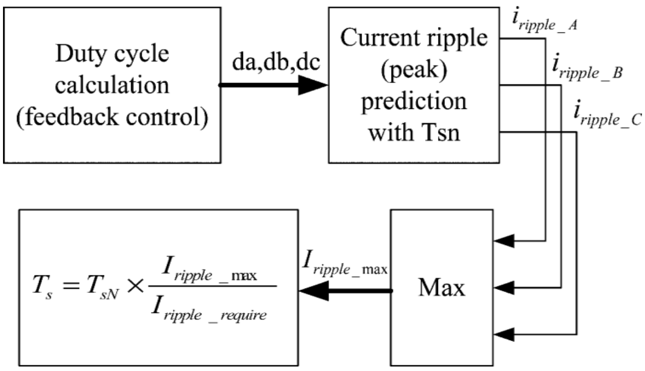

Fig.6. Switching frequency update diagram for VSFPWM 1

The principle of VSFPWM 1 is "by using switching period Ts current ripple peak value is controlled with certain range. From fig.6. The predicted ripple current values of three phases $i_{ripple\text{-}A,B,C}$ are compared with maximum ripple current and then sent to switching period calculation block(Ts). Hence by using this kind of control block diagram the maximum peak value of ripple can be obtained the THD lavel of VSFPWM 1 is given in fig.7. Which is maintained as 6.17% when compared with CSFPWM.

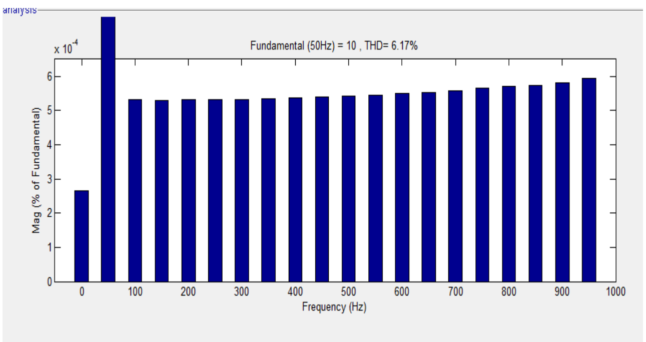

Fig.7. THD level with VSFPWM1

Similarly VSFPWM 2 is another method which is used to control the RMS value of current ripple compared with CSFPWM to be same with reduction of EMI.

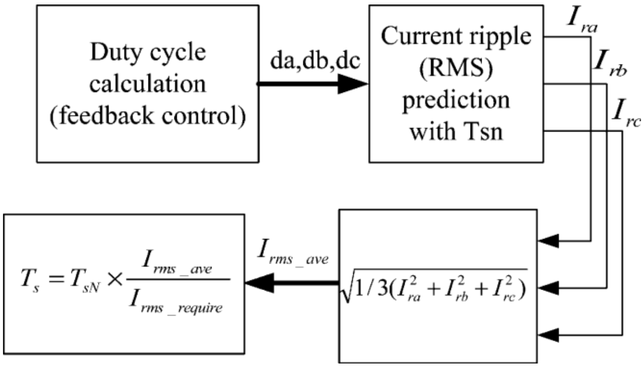

Fig.9. Switching frequency update diagram of VSFPWM 2

From fig.9. Duty cycles are calculated sent to RMS ripple prediction block and these RMS values (I_{ra}, I_{rb}, I_{rc}) are sent to make the three phase square root average and getting $I_{rms\text{-}avg}$. The THD level is same as CSFPWM which is 9.18% but EMI is reduced.

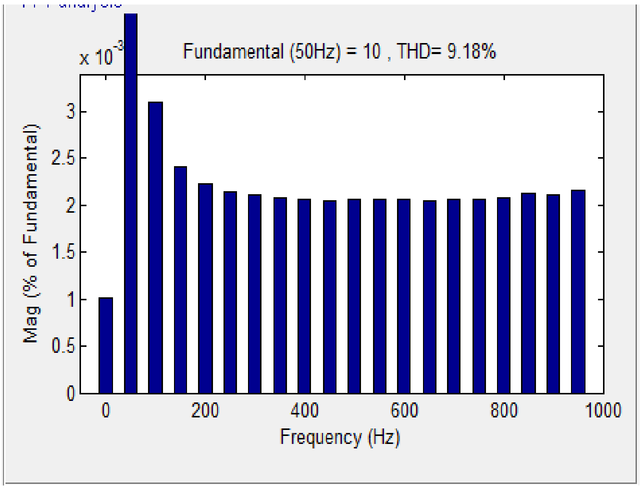

Fig.10. THD level with VSFPWM 2

VI. VSFPWM Method Applied For Induction Motor Drive

Current ripple is an important requirement for design and control of three phase inverters the percentage of THD is reduced by using VSFPWM method compared to CSFPWM with distribution of switching frequency. For this proposed method induction motor drive is connected and its stator current and rotor speed is shown in the simulation results below.

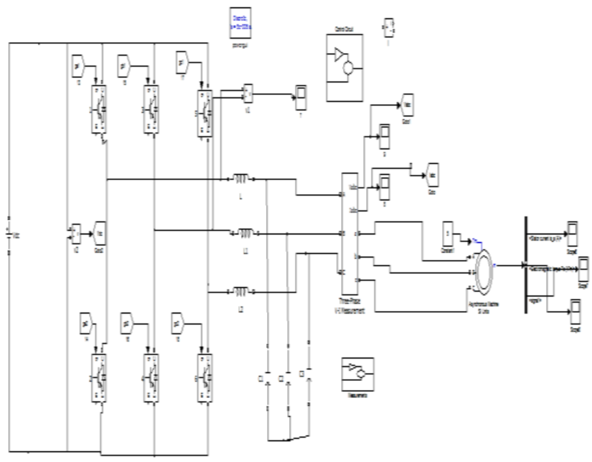

Fig.11. Circuit diagram of VSFPWM with induction motor drive

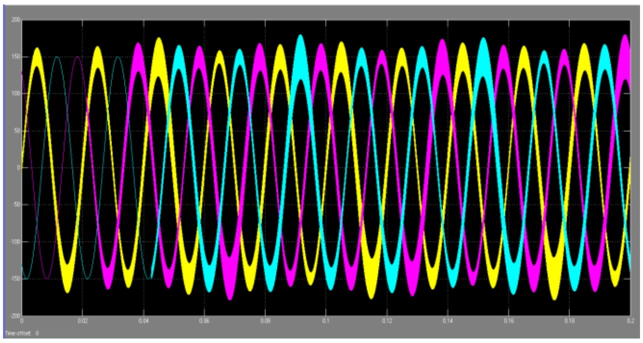

Fig.12.Phase voltage with VSFPWM

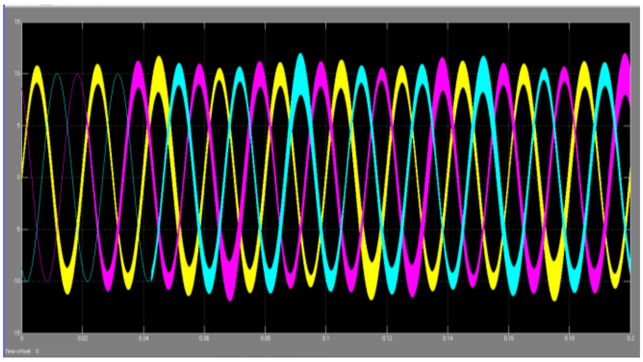

Fig.13. Phase current with VSFPWM

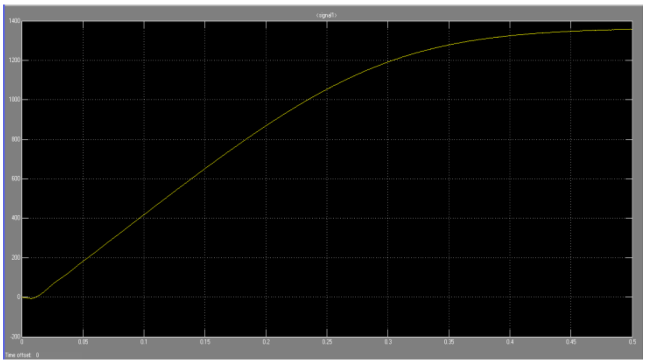

Fig.14.speed of induction motor drive with VSFPWM

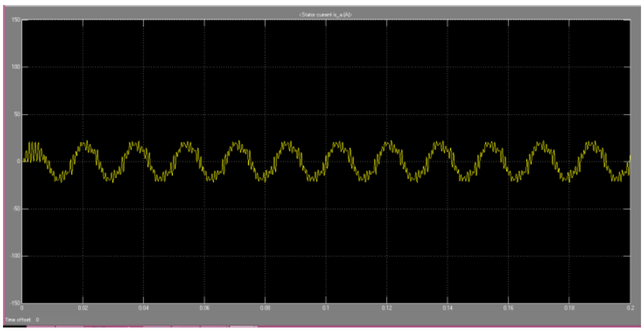

Fig.15. Stator current of induction motor drive with VSFPWM

Fig.11. shows the circuit diagram of induction motor drive with VSFPWM method, the dc supply is given to power electronic devices (IGBTs)and with LC filters the pure sinusoidal voltage and currents is obtained which is shown in the fig 12 and 13.Also the stator current and rotor speed of induction motor are obtained without disturbing the THD level of VSFPWM by using mat lab / Simulink.

VII. Conclusion

Thus with the help of different switching frequency variation loss ,the efficiency of three phase converters is improved and the level of THD also reduced with satisfying the ripple current requirement .The ripple currents are controlled to have the maximum value equal with the current limit in every switching period

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