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Space Vector Based Centric and Non-Centric PWM Techniques for VSI Fed Asynchronous Motor Drive

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***Abstract*—In this paper, scalar based SVPWM techniques are proposed for a two level three phase Voltage Source Inverter (VSI) fed Induction Motor (IM) drive. To reduce the complexity involved in lookup tables and sector identification in conventional or centric PWM, scalar based SVPWM techniques are proposed. Scalar based SVPWM techniques are obtained by adding a common mode signal to the reference phase voltages. To generate the different discontinuous or non-centric PWM techniques, a unique zero sequence voltage is derived, in which, by varying the constant 'a' value from 0 to 1, various non-centric pulse width modulation techniques are generated along with the centric SVPWM technique. The proposed non-centric PWM techniques provides less THD in both motor phase voltage and current when compared with centric SVPWM technique. To validate the proposed work numerical simulations have been carried out on three phase Voltage Source Inverter fed Induction Motor drive in MATLAB/SIMULINK, and the results have been presented and compared for the proposed model.**

***Index Terms*—Centric PWM (CPWM), Induction Motor, Non-Centric PWM (NCPWM), SVPWM, Voltage Source Inverter.**

I. INTRODUCTION

Three-phase voltage source inverter (VSI) converts dc power into ac power in order to achieve desired output voltage and frequency. The output of three-phase VSI can be controlled by various Pulse Width Modulation Techniques. In applications like variable speed motor drives, VSI are commonly used. Out of several PWM Techniques, Space Vector PWM technique [1] is more efficient in view of THD, Harmonics and dc bus utilization. Due to these superior performance characteristics SVPWM technique can be easily implemented by using scalar approach. SVPWM techniques using scalar approach are further classified as Centric PWM and Non-Centric or Discontinuous PWM techniques. Centric PWM uses the concept of revolving voltage reference vector and it is approximated by considering the average time over a sub cycle of two adjacent active states and two zero states [1] – [2]. Then the time lengths of the each state of the inverter are determined for each carrier cycle. Moreover it requires lookup tables and sector identification which leads to increase the complexity of the system. In order to decrease the complexity in Centric PWM technique, Non-Centric PWM techniques have been proposed [3]. NCPWM techniques use the concept of imaginary switching times. To generate various NCPWM techniques it needs different offset expressions. In the scalar approach, a triangular carrier signal is compared with three reference modulation signals and the intersections determines the switching times for the inverter leg switches. In implementation point of view the scalar approach is simple when compared to space vector approach [2]. In three-phase VSI, no neutral current path exists as the neutral point of the load is isolated, So there exists a potential between the neutral point and the dc midpoint, known as common mode voltage and it can be varied easily. In those cases, by amplifying the modulating signals (reference voltages) with a common mode signal, results the inverter average value of output line voltage per carrier cycle is remains unchanged. When the revised common mode signal is continuous, the centric PWM technique is produced. It result the increase of switching losses. Similarly, when amplifying common mode signal is discontinuous, Non-Centric PWM techniques are generated with phase segments clamped either to the positive or negative DC bus [5-8]. In case of Non-Centric PWM techniques, the modulating signal of each phase is clamped to 120 degrees either positive or negative link voltage. By this technique, when compared with conventional SVPWM there will be reduction of switching losses about 33.3% [6-8].

This paper presents a scalar based SVPWM techniques on VSI fed induction motor drive. In this proposed technique, by changing the value of constant called zero vector parameter of common mode signal various NCPWM techniques are generated. This paper is organized as follows, Section-II introduces VSI and its importance where as Section-III explains in detail about various SVPWM Techniques and Section-IV is provided with simulation results for the proposed model.

II. VOLTAGE SOURCE INVERTER

Voltage source inverters can be categorized according to different criteria. They can be classified on the basis of number of phases depending upon utility of output. Accordingly they are single-phase and three-phase inverters. The output of single phase inverter which is a non-sinusoidal waveform consists of harmonic component and it is suitable for low power industrial applications. To reduce the harmonic content in the output waveform and for high power applications, three phase inverters are more suitable when compared with single phase inverters. Now a days, PWM controlled inverters are suitable for controlling the variable speed drives. Three-phase, two-level VSI is shown fig.1.From this figure it can be observed that for a 3-phase, two-level VSI, there are six switching devices and this devices can be triggered in two modes of operation and they are 180 degrees mode of operation and 120 degree mode of operation. In above two modes 180 degrees conduction mode is preferred here. In this mode each switch conducts for duration of 180 degrees per each cycle. In this switching pattern, conduction of three switches from three different legs of the inverter is selected. Two switches from the same leg cannot be operated at once. The complete one cycle of switching can be operated in six modes and duration of each mode is 60 degrees, this gives the detailed information about the operation of inverter in 180 degrees conduction mode.

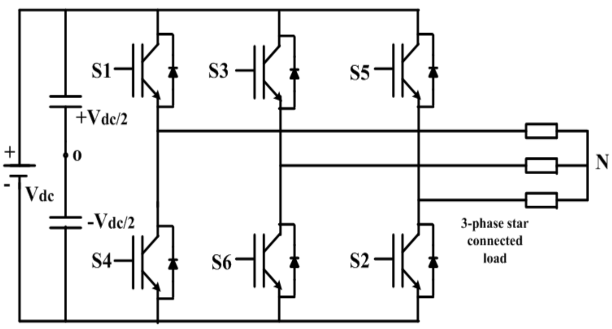


Fig.1. Voltage Source Inverter

III. SVPWM TECHNIQUE USING SCALAR APPROACH

Space Vector PWM technique provides low harmonic distortion and 15% higher ac voltage than SPWM technique. SVPWM is explained by considering the two level VSI fed to three phase balanced load. For a 3-phase, two-level VSI, eight switching combinations are possible. Among these six switching combinations are known as active state voltage vectors and the remaining two vectors are known as zero voltage vectors that is no voltage is applied to the load. SVPWM Technique uses the concept of revolving reference voltage vector (V_{ref}) represented in Fig.2. The active voltage vectors V_1 to V_6 and the zero voltage vectors V_0, V_7 forms the voltage space-vector plane which is represented by a regular hexagon shown in Fig.2.The voltage space vector plane is divided into six sectors. The reference voltage vector is approximated by sampling at regular intervals of time in each sector and it is calculated by using adjacent vectors and zero vectors for a sampling time period T_s using principle of volt-second balance rule.

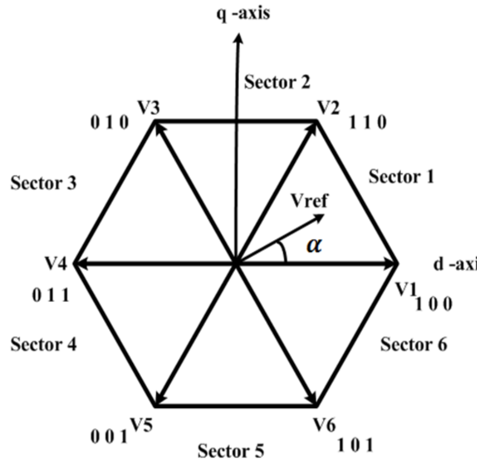


Fig.2.Space Vector Diagram for two level inverter

The generalized expression defined for sector 'K' is given by

$$V_{ref}\, T_s = V_k T_k + V_{k+1} T_{k+1} + V_0 T_0 + V_7 T_7 \quad (1)$$

$$\text{Where } T_s = T_k + T_{k+1} + T_z \quad (2)$$

$$T_0 = (1-a)T_z \text{ and } T_7 = aT_z \quad (3)$$

The duration of active and zero voltage vectors can be obtained for each sector 'k' is given in (4),(5) and (6).

$$T_k = \frac{2\sqrt{3}}{\pi} M_i [\sin[\, k\frac{\pi}{3} - \alpha]] T_s \quad (4)$$

$$T_{k+1} = \frac{2\sqrt{3}}{\pi} M_i [\sin[\alpha - (k-1)\frac{\pi}{3}]] T_s \quad (5)$$

$$T_z = T_s - T_k - T_{k-1} \quad (6)$$

In Centric PWM, active vectors are located at the middle of sampling period. In order to develop various Non-Centric PWM techniques, it uses the concept of zero state distribution.Fig.3 relates the space vector (SV) and scalar approach (SA) based PWM techniques, it shows the duration of both gating pulses of SA method and the voltage space vectors in the first sector. From Fig.3, the durations of gating pulses for switches S_a, S_b, S_c are expressed as

$$T_{ga} = T_7 + T_2 + T_1 = aT_z + T_1 + T_2 \quad (7)$$

$$T_{gb} = T_7 + T_2 = aT_z + T_2 \quad (8)$$

$$T_{gc} = T_7 = aT_z \quad (9)$$

The durations of active and zero state can be obtained from the equations(10),(11) and represented as[5-8].

$$T_1 = \frac{T_s}{V_{dc}}(V_{Max} - V_{Mid}) \quad (10)$$

$$T_2 = \frac{T_s}{V_{dc}}(V_{Mid} - V_{Min}) \quad (11)$$

Where V_{Max} denotes the maximum value of V_{in} , V_{Min} is the minimum value of V_{in} and V_{Mid} middle value of V_{in}, and it is given by [6-7]

$$V_{in} = V_{ref}\cos(\theta - \frac{2(r-1)\pi}{3}) \quad (12)$$

For i=a,b,c and r=1,2,3

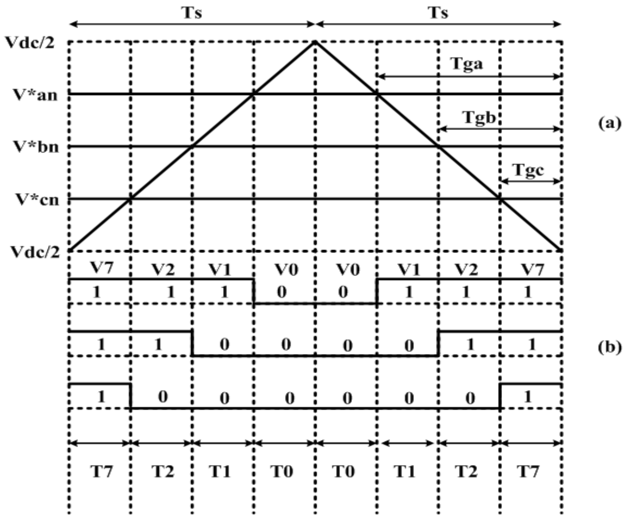


Fig. 3.Co-relation between Scalar and SVPWM (a) duration of control signals using scalar approach (b) Duration of voltage space vectors in SVPWM

To associate the above two techniques input reference voltages has to be calculated same as SVPWM in comparison with triangular carrier PWM. The equations are represented as

$$V_t = [\frac{2t}{T_s} - 1]\frac{V_{dc}}{2} \quad (13)$$

Where V_t represents the instantaneous voltage value of triangular wave. Modulating waveform V_{in}^* is generated by addition of zero sequence signal to the old set of reference phase voltages V_{in}, as follows:

$$V_{in}^* = V_{in} + V_{zs} \quad (14)$$

Where V_{zs} denotes zero sequence voltage and it can be calculated as shown below :[6-7]

$$V_{zs} = \frac{V_a+V_b+V_c}{3} = \frac{[2[\frac{T_a+T_b+T_c}{T_s}]-1]\frac{V_{dc}}{2}}{3} \quad (15)$$

$$V_{zs} = \frac{V_{dc}}{2}(2a-1) - a * V_{Max} + (a-1) * V_{Min} \quad (16)$$

To generate the various PWM Techniques, consider the set of three-phase voltages are given in equation (17)

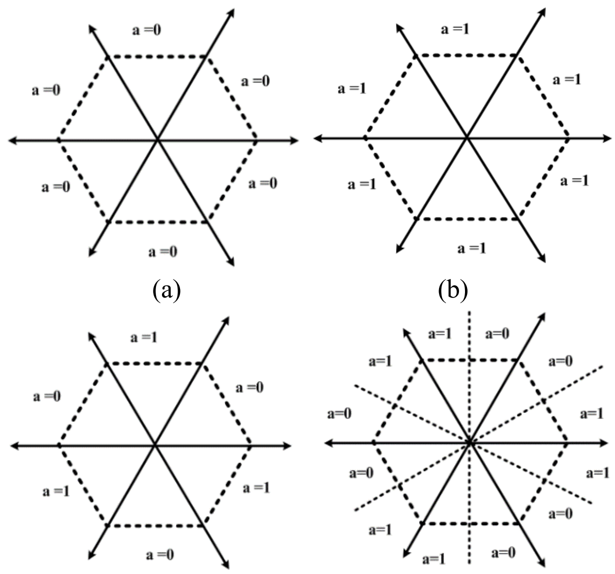
$$V_{ix} = V_{ref}\cos(\theta - 2(r-1)\frac{\pi}{3} - \frac{\pi}{6}) \quad (17)$$

From the above equation the maximum value is $V_{Max,x}$=max(V_{ix}),and the minimum value is $V_{Min,x}$ =min(V_{ix}).Table 1 shows the various PWM techniques with the variations of ‘a’ value in above equations.

TABLE I. Realization of different PWM Techniques by changing a constant ‘a’ value.[7]

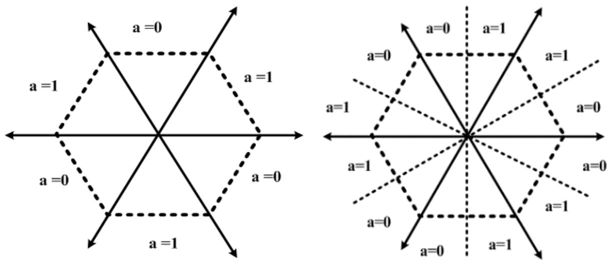
PWM Technique	Value of ‘a’
Centric PWM	0.5
Non-Centric PWM MIN	0
Non-Centric PWM MAX	1
Non-Centric PWM0	If $V_{Max,x}$+ $V_{Min,x}$<0 => a=1 If $V_{Max,x}$+ $V_{Min,x}$ >=0 => a=0
Non-Centric PWM1	If V_{Max}+ V_{Min} < 0 => a=0 If V_{Max}+ V_{Min} >= 0 => a=1
Non-Centric PWM2	If $V_{Max,x}$+ $V_{Min,x}$<0 => a=0 If $V_{Max,x}$+ $V_{Min,x}$ >= 0 => a=1
Non-Centric PWM3	If V_{Max}+ V_{Min} < 0 => a=1 If V_{Max}+ V_{Min} >= 0 => a=0

The generation of this Non-Centric (or) Discontinuous PWM techniques and the duration of zero state in each sector is diagramatically shown below



(a) (b)

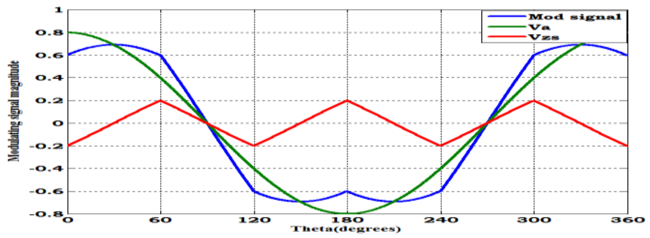
(c) (d)



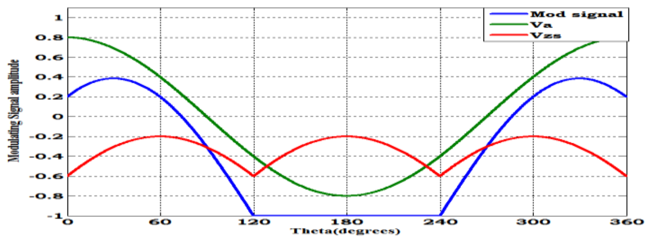
(e) (f)

Fig.4. Generation of scalar based Non-Centric PWM techniques. (a)Centric PWM(b)Non-Centric PWMMIN (c) Non-Centric PWMMAX(d) Non-Centric PWM0 (e) Non-Centric PWM1(f) Non-Centric PWM2(g) Non-Centric PWM3

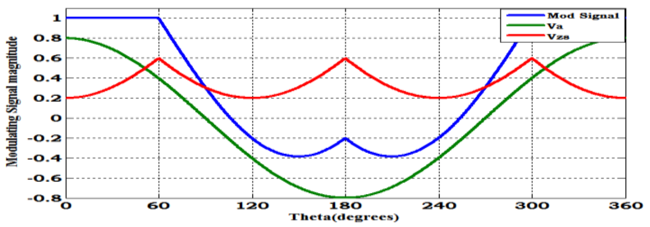
The reference phase voltage, zero sequence voltage and modulating wave form of different PWM techniques are shown in Fig.5 at a modulation index of 1.



(a)



(b)



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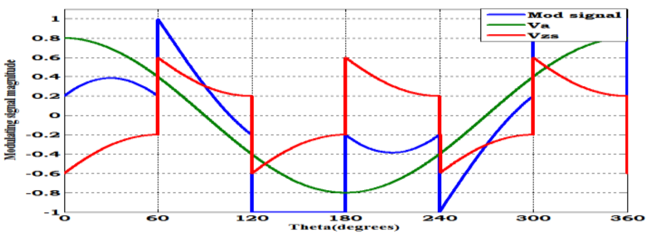
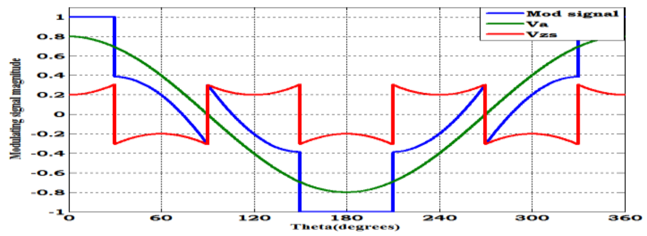
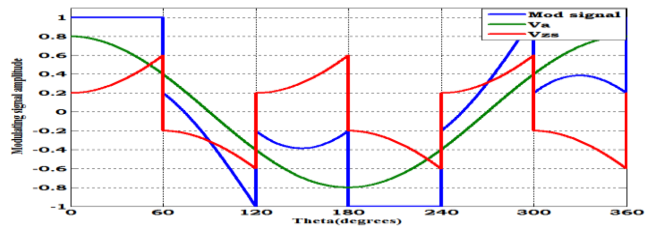


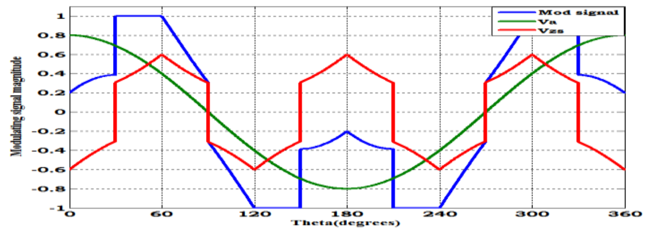
(d)



(e)



(f)



(g)

Fig. 5.Reference phase voltage,zero sequence voltage and modulated wave form for different PWM techniques(a)Centric PWM(b)Non-Centric PWMMIN (c) Non-Centric PWMMAX(d) Non-Centric PWM0 (e) Non-Centric PWM1(f) Non-Centric PWM2(g) Non-Centric PWM3

The magnitude of reference voltage vector is within the hexagon region in linear modulation region. From Fig.5 it can be observed that various continuous and discontinuous modulating signals are generated with variations in zero voltage signal.In NCPWMMAX and NCPWMMIN technique, the clamping of 120^0 takes place for every 360^o of fundamental voltage cycle. In NCPWM0 and NCPWM2 techniques, 60° of clamping takes place from 0°−180° for NCPWM0 and 180°-360^o for NCPWM2 of fundamental voltage cycle.In NCPWM1 technique, clamping of 60° takes place at the middle of fundamental voltage cycle. In NCPWM3 sequence, clamps every phase between 0° to 180° and from 180^0 to 360° of fundamental voltage cycle.

IV. Results and Discussion

To verify the proposed model, various simulations have been performed using MATLAB/SIMULINK environment. The switching frequency is considered as 3 kHz and dc link voltage is considered as 600V. The simulation traces of various PWM techniques are shown in Fig.6(6.1-6.7).

Simulation traces shows that centric SVPWM technique is having continuous pulse pattern, with a pole voltage of magnitude +Vdc/2 and –Vdc/2, phase voltage of magnitude 2Vdc/3, Vdc/3 and 0, a common mode voltage of magnitude +Vdc/2 and –Vdc/2, and stator current of magnitude 20 amperes are shown in fig.6.1 and it has more THD and switching losses when compared with NCPWM techniques. In NCPWM techniques maximum clamping of 120 degrees takes place in every fundamental voltage cycle shown in fig.6.2-6.7. Similarly in NCPWM techniques there is no change in magnitude of common mode voltage but in view of THD there is a gradual decrement when compared with CPWM technique.

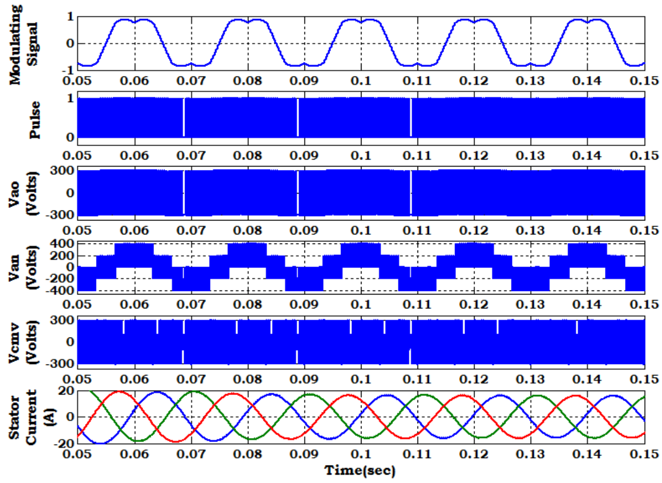


Fig. 6.1. Simulation traces of Centric PWM technique (modulating wave, pulse pattern, pole voltage, phase voltage and stator current) at M=1.

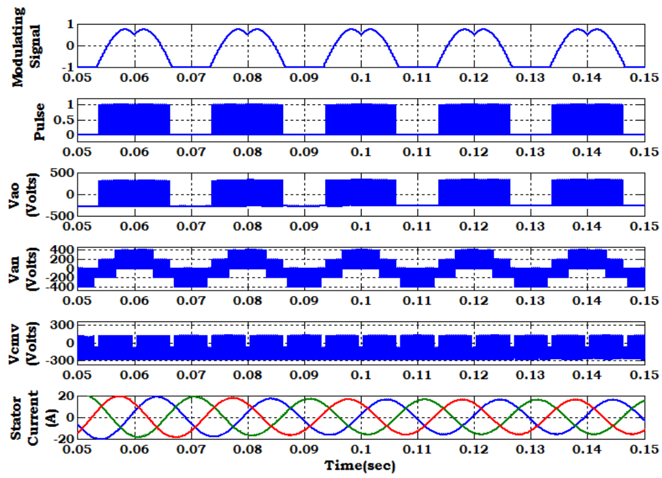


Fig. 6.2. Simulation traces of Non-Centric PWM MINIMUM technique (modulating wave, pulse pattern, pole voltage, phase voltage and stator current) at M=1

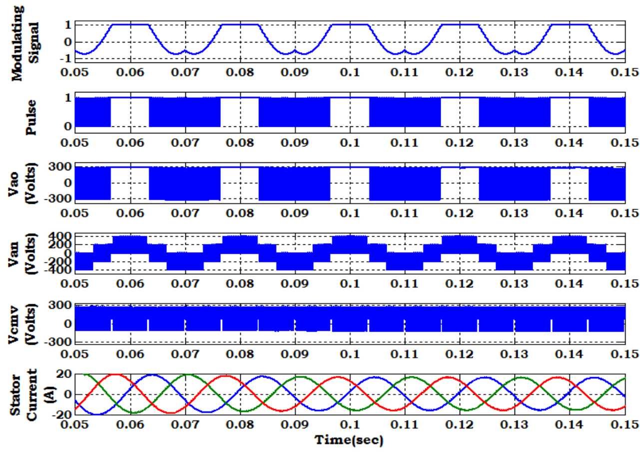


Fig. 6.3. Simulation traces of Non-Centric PWM MAXIMUM technique (modulating wave, pulse pattern, pole voltage, phase voltage and stator current) at M=1.

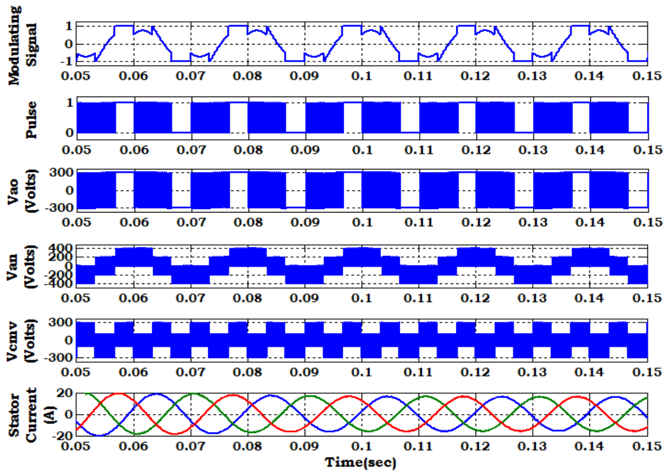


Fig. 6.4.Simulation traces of Non-Centric PWM0 technique (modulating wave, pulse pattern, pole voltage, phase voltage and stator current) at M=1.

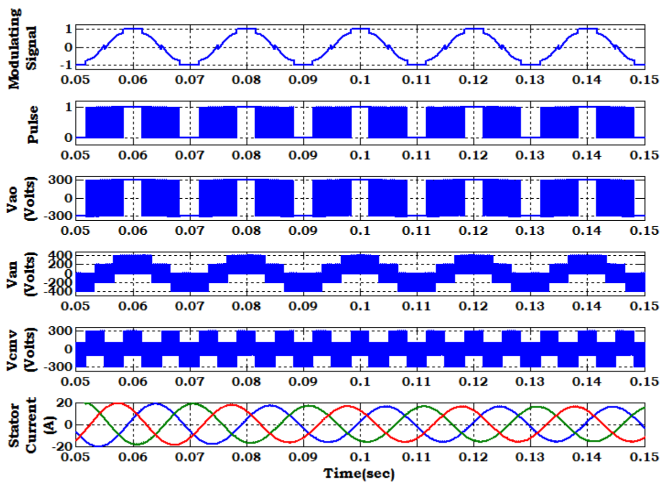


Fig. 6.5. Simulation traces of Non-Centric PWM1 technique (modulating wave, pulse pattern, pole voltage, phase voltage and stator current) at M=1.

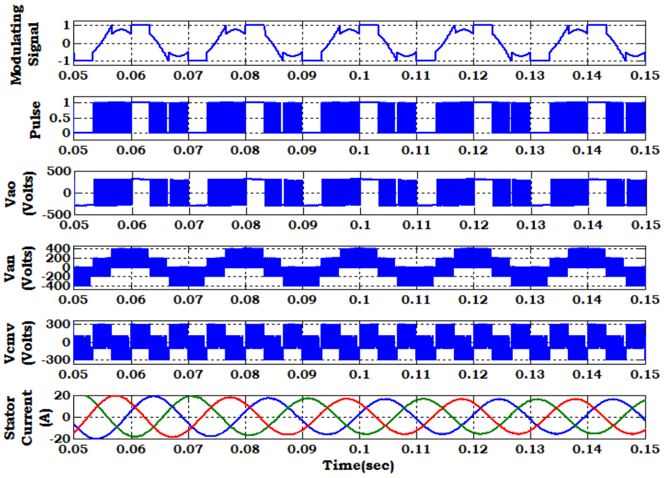


Fig.6.6. Simulation traces of Non-Centric PWM2 technique (modulating wave, pulse pattern ,pole voltage, phase voltage and stator current) at M=1.

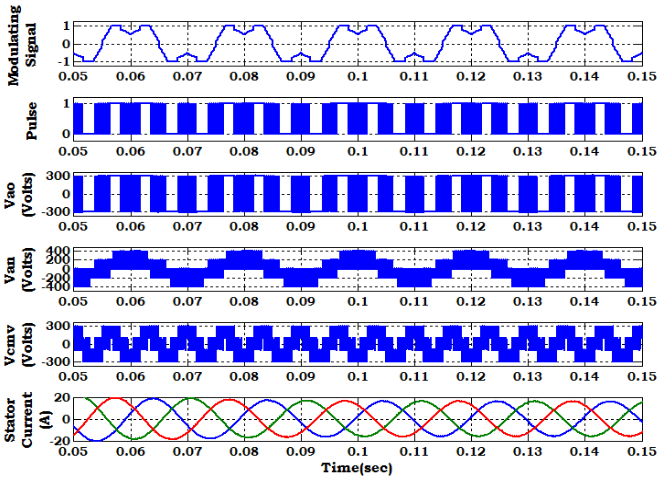


Fig.6.7. Simulation traces of Non-Centric PWM3 technique (modulating wave, pulse pattern, pole voltage, phase voltage and stator current) at M=1.

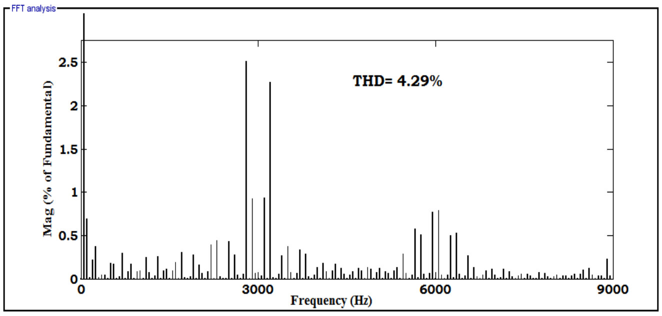


Fig.6.8.Harmonic analysis of stator current at M=0.8

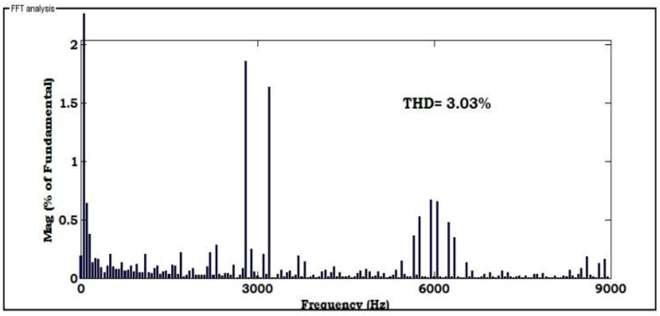


Fig.6.9.Harmonic analysis of stator current at M=1

Table II. Comparison of %THD of different PWM Techniques.

S.NO	PWM Technique	%THD of Vph(V) at M=0.8	%THD of Stator Current(A) at M=0.8	%THD of Vph(V) at M=1	%THD of Stator Current(A) at M=1
1	CPWM	53.21	5.85	42.15	4.97
2	NCPWM MAX	46.01	4.38	31.10	3.29
3	NCPWM MIN	46.12	4.43	31.49	3.20
4	NCPWM0	42.96	4.31	30.09	3.28
5	NCPWM1	44.02	4.56	34.22	3.47
6	NCPWM2	43.53	4.42	30.14	3.36
7	**NCPWM3**	**41.06**	**4.29**	**28.05**	**3.01**

V. CONCLUSION

The proposed Scalar based SVPWM techniques produces different Non-Centric PWM techniques along with the Centric PWM Technique. In Non-Centric PWM Techniques each phase is clamped to either positive or negative DC bus for 120 degrees in every fundamental voltage cycle. Hence it results in reduction of switching loss by 33.33% when compared with the Centric PWM Technique. The THD of stator current and phase voltage of the motor in Centric PWM is more compared to the Non-centric or discontinuous PWM techniques. Out of all Non-Centric PWM techniques, Non-Centric PWM3 gives superior performance over remaining PWM techniques.

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