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Design of Three-Zone Hybrid Pulse Width Modulation Method For Reduced Current Ripple

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This paper presents a Three-Zone Hybrid Pulse Width Modulation (HPWM) algorithm for induction motor drives. This paper brings out a method for designing hybrid PWM techniques inVolving multiple sequences to reduce line current ripple. The three proposed hybrid PWM techniques (three-zone PWM) employ three different sequences, respectively, in every sector. Then, the rms stator flux ripple, which is a measure of ripple in line current characteristics have been plotted for all the HPWM and SVPWM algorithms. From which, it is concluded that the SVPWM algorithm gives superior performance at low modulation indices, whereas the HPWM algorithm gives superior performance at higher modulation indices. The proposed techniques lead to a significant reduction in THD over CSVPWM at high line Voltages. A Novel hybrid PWM technique, employing these two sequences in conjunction with the conventional sequence, is proposed. The proposed PWM technique is designed using the Notion of stator flux ripple. A procedure is presented for designing hybrid PWM techniques inVolving multiple sequences for reduced current ripple. The proposed PWM technique results in reduced current ripple over CSVPWM at higher modulation indices. The three-zone technique results in the lowest THD among real-time techniques with uniform sampling. Hence, to achieve the superior waveform quality at all modulation indices, a three-zone Hybrid PWM (HPWM) algorithm has been presented in this paper. To validate the proposed algorithms, several numerical simulation studies have been carried out and results have been presented and compared.

1.0 INTRODUCTION

The Variable Speed Drives (VSD) are becoming popular in many industrial applications due to their numerous advantages. But, the VSDs require ac Voltage with controllable magnitude and frequency. To achieve the variable Voltage and variable frequency ac supply, the Pulse Width Modulation (PWM) algorithms are becoming popular. A large variety of PWM algorithms have been discussed. But, the most popular PWM algorithms as Sinusoidal PWM (SPWM) and Space Vector PWM (SVPWM) algorithms. The SVPWM algorithm offers more degrees of freedom when compared with the SPWM algorithms. Hence, it is attracting many researchers. The SVPWM algorithm is explained in detail. Though the SVPWM and SPWM algorithms give good performance, these give more switching losses of the inverter due to the continuous modulating signals. Hence, to reduce the switching losses of the inverter, the Hybrid PWM (HPWM) algorithms are becoming popular. Also, the classical SVPWM algorithm requires angle and sector information to generate the actual gating times of the inverter. Hence, the complexity inVolved is more.

To reduce the complexity in the classical SVPWM algorithms and to extend the operation up to over modulation region, various PWM algorithms have been generated in by using the concept of offset

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time and duty cycle. By adding the suitable offset time to the imaginary switching times, which are proportional to the instantaneous phase Voltages, various PWM algorithms have been generated under both linear and over modulation regions. Though, the SVPWM and HPWM algorithms give good performance, the SVPWM algorithm gives more harmonic distortion at higher modulation indices when compared with the DPWM algorithms and DPWM algorithm gives more harmonic distortion at lower modulation indices. Hence, to reduce the harmonic distortion at all modulation indices, a hybrid PWM algorithm approach has been proposed.

Real-time PWM techniques balance the reference Volt–seconds and the applied Volt–seconds over every subcycle or half-carrier cycle. The multiplicity of possible switching sequences provides a choice in the selection of switching sequence in every subcycle. The proposed hybrid PWM techniques employ the sequence, which results in the lowest rms current ripple over the given subcycle, out of a given set of sequences. Consequently, the total rms current ripple over a fundamental cycle is reduced. This paper presents a simplified approach for the generation of SVPWM and HPWM algorithms. Then, the rms stator flux ripple characteristics of all PWM algorithms is presented with reduced complexity. Based on the flux ripple characteristics, simplified hybrid PWM (HPWM) algorithm has been resented with reduced harmonic distortion at all modulation indices.

2.0 SWITCHING SEQUENCES

A three-phase Voltage source inverter has eight switching states as shown in Figure 1. The two zero states (−−− and +++), which short the motor terminals, produce a Voltage vector of zero magnitude as shown in the figure. The other six states, or the active states, produce an active Voltage vector each. These active vectors divide the space vector plane into six sectors and are of equal magnitude as shown. The magnitudes are Normalized with respect to the dc bus Voltage Vdc.

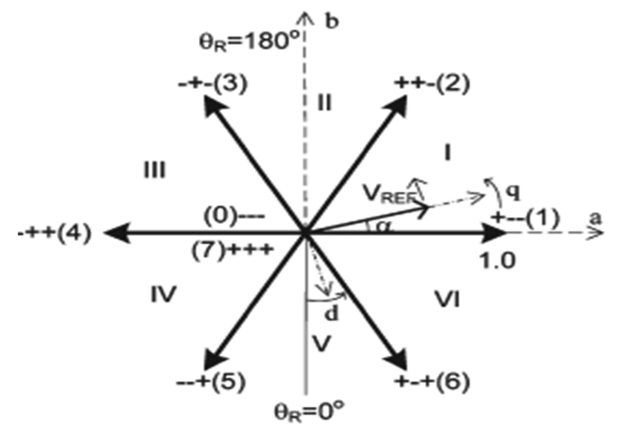

FIG.1. INVERTER STATES AND VOLTAGE VECTORS.

In space vector-based PWM, the Voltage reference is provided by a reVolving reference vector (see Figure 1), which is sampled once in every subcycle, TS. Given a sampled reference vector of magnitude VREF and angle α in sector I as shown in Figure 1, the dwell times of active vector 1, active vector 2 and zero vector in the subcycle are given by T1, T2, and TZ, respectively.

CSVPWM divides TZ equally between 0 and 7, and employs the switching sequence 0-1-2-7 or 7-2-1-0 in a subcycle in sector I. However, a multiplicity of sequences are possible since the zero vector can be applied either using 0 or 7, and also an active state can be applied more than once in a subcycle. This paper explores and brings out all possible valid switching sequences, which have three switchings per subcycle as in CSVPWM. Totally ten valid sequences emerge from Figure 2, which can be grouped into five pairs of sequences, namely (0127, 7210), (0121, 1210), (1012, 2101), (2721, 1272), and (7212, 2127).CSVPWM uses the pair of conventional sequences (0127, 7210) in alternate sub cycles in sector I. The other four pairs can also be employed in alternate sub cycles in sector I. These four pairs of sequences are termed as “special sequences,” since these results in double-switching of a phase, single switching of aNother phase and clamping of the third phase in the given subcycle. In special sequences of type I, there are two transitions between the active states 1 and 2. In special sequences of type II, there are two transitions between an active state and the zero state closer to it (i.e., between 1 and 0 or between 2 and 7).

TABLE 1				
SWITCHING SEQUENCE IN SIX SECTORS				
Sector	**Conventional sequence**	**Clamping sequences**	**Special sequence type I**	**Special sequence type II**
I	(0127,7210)	(012,210) (721,127)	(0121,1210) (7212,2127)	(1012,2101) (2721,1272)
II	(7230,0327)	(723,327) (032,230)	(7232,2327) (0323,3230)	(2723,3272) (3032,2303)
III	(0347,7430)	(034,430) (743,347)	(0343,3430) (7434,4347)	(4745,5474) (5054,4505)
IV	(7450,0547)	(745,347) (054,450)	(7434,4547) (0545,5450)	(5056,6505) (6765,5676)
V	(0567,7650)	(056,650) (765,567)	(0565,5650) (7656,6567)	(5056,6505) (6761,1676)
VI	(7610,0167)	(761,167) (016,610)	(7616,6167) (0161,1610)	(6761,1676) (1016,6101)

3.0 PROPOSED HYBRID PWM METHOD

It is proposed to design a hybrid PWM technique, employing sequences 0127, 0121 and 7212, which results in less ripple current than CSVPWM at a given average inverter switching frequency As shown in the previous section, for a given average vector the mean square ripple over the given sub cycle depends on the switching sequence employed. Given a set of possible sequences, the one that results in the lowest mean square ripple for the given reference vector must always be employed.

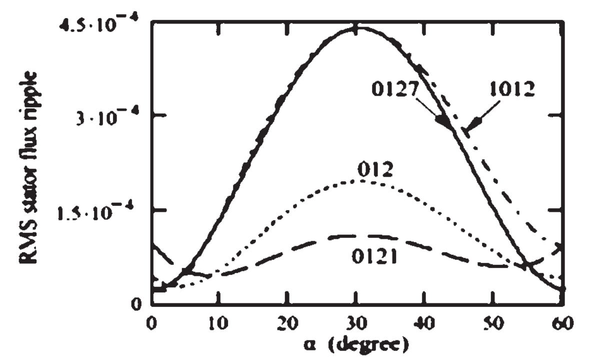

FIG.2. COMPARISON OF RMS STATOR FLUX RIPPLE DUE TO 0127, 012, 0121, AND 1012 FOR (A) VREF = 0.866, 0◦ ≤ A ≤ 60◦.

The design of hybrid PWM technique for reduced current ripple inVolves determination of zones of superior performance for every sequence. The zone of superior performance for a given sequence is the spatial zone within a sector where the given sequence results in less RMS ripple than the other sequences considered. The mean square ripple over a subcycle for any sequence is a function of VREF, α and TS. Since, all three sequences inVolve three switchings per subcycle, the same subcycle duration, TS may be considered for all three. In case the number of switchings is different for different sequences, the subcycle duration must be maintained proportional to the number of switchings per subcycle

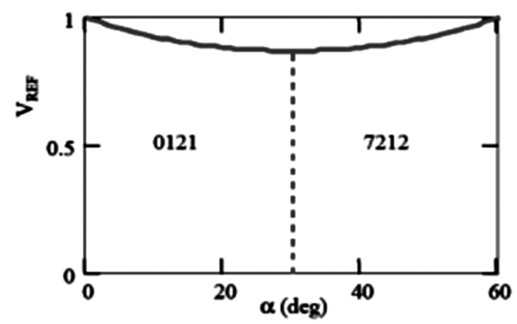

FIG.3. COMPARISON OF SEQUENCES 0121 AND 7212- ZONES OF SUPERIOR PERFORMANCE

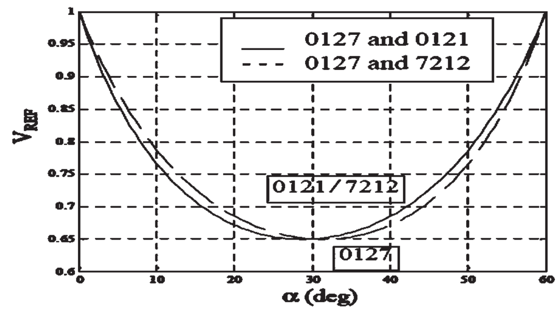

FIG. 4. COMPARISON OF 0121 AND 7212 AGAINST 0127- ZONES OF SUPERIOR PERFORMANCE.

possible approach to optimize both THD and switching loss performance is to define a performance index based on user defined weights to THD and switching losses respectively, and try to obtain the regions of superior performance for this performance factor in a three dimensional space – VREF, α and φ. However, it is unwieldy considering the wide range of VREF, α and φ, and almost impractical to implement using simple digital signal processors.

A more practical approach is to carefully study the THD characteristics and the switching loss characteristics of the different sequences, and identify zones of superior performance in the VREF-α plane for a limited range of power factor angle typical of the application considered. A simple PWM technique that reduces both THD and switching losses for induction motor drive applications, where the typical power factor angles range from 20^0 to 60^0, is shown in Figure 5. It can be seen that for the range of power factor between 20^0 to 60^0 lagging, 7212 is one of the sequences that result in minimum switching losses. It can be seen that sequence 0121 results in higher switching loss than conventional sequence for $\varphi > 30^0$. The three-zone technique shown in Figure 4, based on THD considerations, suggests use of 0121 for $0^0 < \alpha < 30^0$ and 7212 for $30^0 < \alpha < 60^0$ at higher values of VREF

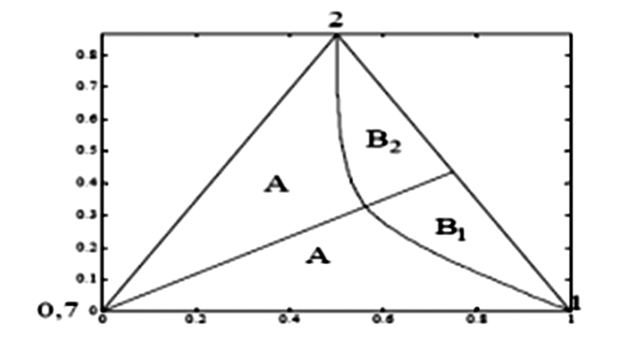

FIG. 5. PROPOSED HYBRID PWM TECHNIQUE. ZONE A : SEQUENCES 0127, 7210, … ZONE B1: SEQUENCES 0121, 1210, … ZONE B2 : SEQUENCES 7212, 2127, …

However, the difference between the stator flux ripples of 0121 and 7212 is Not very significant at high values of VREF. But, the sequence 7212 results in significantly lower switching loss than 0121 for typical power factor angles considered. From these observations, the three-zone hybrid PWM technique can be modified as shown in Figure 5. The THD performance of the modified technique is close to that of the three-zone technique, but the switching loss is significantly reduced.

The THD obtained with this PWM technique, along with that of the conventional SVPWM is shown as a function of VREF (or fundamental frequency compares the switching losses obtained using the new PWM technique with that of conventional, as a function of power factor angle (corresponding to a fundamental frequency of 60 Hz). As seen from these, the proposed PWM technique achieves simultaneously a reduction of about 30% in THD and a reduction of more than 20% in switching loss under Normal operating conditions – maximum VREF and a power factor angle of 30^0, compared to conventional SVPWM

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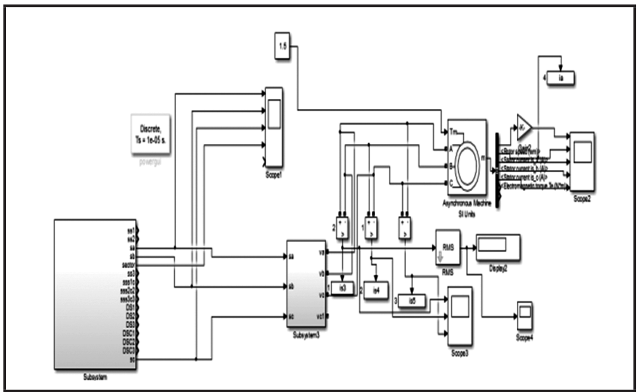

FIG 6. SIMULATION MODEL OF PROPOSED SYSTEM

4.0 SIMULATION DIAGRAM, RESULTS AND DISCUSSION

To verify the proposed HPWM algorithm, numerical simulation studies have been carried out on v/f controlled induction motor drive and results have been presented. Simulation studies have been carried out at different supply frequencies (different modulation indices). The steady state current waveforms along with the total harmonic distortion (THD) values for SVPWM and proposed HPWM algorithms based drive are shown from Figure 5 to Figure 8.

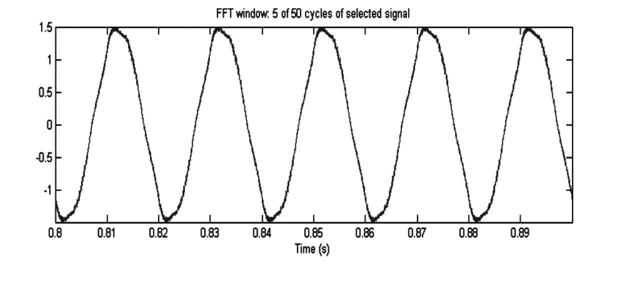

FIG. 7. CURRENT RIPPLE OF CONVENTIONAL SVPWM TECHNIQUE

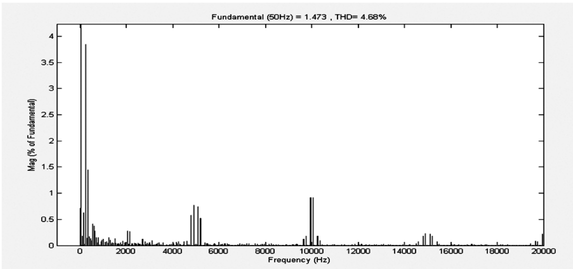

FIG. 8. THD OF CONVENTIONAL SVPWM TECHNIQUE

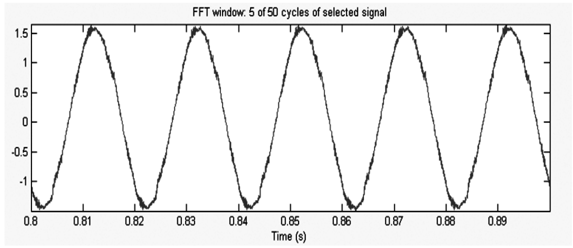

FIG. 9. CURRENT RIPPLE OF THREE-ZONE HPWM TECHNIQUE

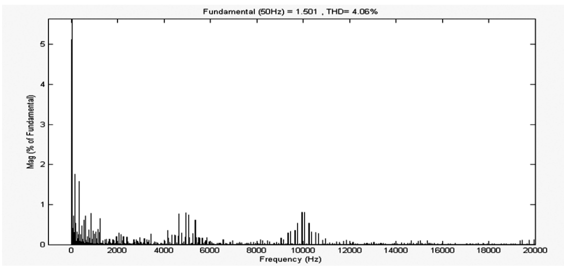

FIG. 10. THD OF THREE-ZONE HPWM TECHNIQUE

From the simulation results, it can be observed that the proposed HPWM algorithm gives superior waveform quality when compared with the SVPWM algorithm. Also, proposed PWM algorithm gives spread spectra and hence reduces the acoustical Noise of the induction motor. Thus, the proposed algorithm reduces both the harmonic distortion and acoustical Noise.

5.0 CONCLUSION

TABLE 2

COMPARISON OF CSVPWM AND THREE-ZONE HYBRID PWM AT 1hp LOAD AND f1 = 50 Hz

Phase	Technique	Current THD	Reduction in THD due to hybrid PWM
R	CSVPWM 3-zone hybrid	0.0468 0.0406	13.25%
Y	CSVPWM	0.0160	16.74%
	3-zone hybrid CSVPWM	0.0388 0.0467	17.34%
R	3-zone hybrid	0.0386	

A simple and Novel GPWM algorithm for VSI fed induction motor drives is presented in this paper. The proposed algorithm generates a wide range of DPWM algorithms along with SVPWM algorithm by using the instantaneous phase Voltages only. By utilizing the concept of stator flux ripple, the harmonic analysis of various PWM algorithms has been carried out and the flux ripple characteristics are presented. By comparing these characteristics, best PWM algorithm has been used in the proposed HPWM algorithm. Thus, the proposed HPWM algorithm gives reduced harmonic distortion when compared with the SVPWM algorithm. The simulation results confirm the effectiveness of the proposed PWM algorithm. Three hybrid PWM techniques are proposed, namely three-zone, five-zone and seven-zone hybrid PWM. The proposed five-zone hybrid PWM leads to lowest distortion in its class of PWM techniques (open-loop, real-time techniques with a uniform sampling rate) at any given modulation index for a given average switching frequency. The proposed seven-zone hybrid PWM leads to lowest distortion in its class (open-loop, real-time techniques with a twin sampling rate) at any given modulation index for a given average switching frequency. The proposed techniques lead to about 40% reduction in line current distortion over CSVPWM at the rated Voltage and rated frequency of the drive. The superior performance of the proposed techniques over CSVPWM and existing bus-clamping PWM techniques has been demonstrated theoretically as well as experimentally. Spread spectrum PWM waveforms can be generated using hybrid PWM techniques with a uniform sampling frequency rather than special methods with random sampling frequency.

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