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Space Vector Based Generalized Dpwm Algorithms for Vsi Fed Induction Motor Drive

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Abstract:
This paper presents Space Vector based Generalized DiscontinuousPulse width modulation (GDPWM) algorithms for VSI fed Induction motor drive. To avoid the complexity due to angle calculation and sector identification involved in Conventional space vector pulse width modulation (CSVPWM). The Proposed algorithms use the concept of Imaginary Switching times and a constant variable μ and modulation phase angle δ are used to generate modulating waveforms.The proposed algorithms results in reduced current ripple over CSVPWM. To validate the proposed methods, simulation is carried on V/f controlled Induction Motor drive in MATLAB/SIMULINK environment and the results are discussed.
Keywords-CSVPWM, GDPWM, Imaginary Switching times, Induction motor, *V/f* control

I. INTRODUCTION

Improvements in fast switching power devices have led to an increased interest in voltage source inverters (VSI) with pulse width modulation (PWM) control. Out of several approaches, triangular comparison (TC) approach and space vector (SV) approach are main implementation techniques. The space vector approach offers additional degrees of freedom indesigning PWM techniques over the triangle-comparison methods. The conventional SVPWM algorithm employs equal division of zero voltage vector times within a sampling period or sub cycle [1, 2]. In this method the reference voltage vector is synthesized by time averaging two active states and two zero states in every sampling period [3]. However, the CSVPWM is known as continuous PWM (CPWM)method in this switching loss is high. Hence to reduce the switching losses and to improve the performance several discontinuous PWM (DPWM)methods have been reported [3-9]. If the zero sequence signals are continuous it produces CPWM scheme and if it is discontinuous it results in DPWM schemes. A carrier based generalized PWM method comprising of all DPWM methods is considered as generalized discontinuous PWM scheme (GDPWM)[3][4][5].

The conventional space vector pulse width modulation sector identification and switching sequences are discussed in [10].CSVPWM suffers from the drawbacks like computational burden and it takes more time to execute. Hence the complexity involved in CSVPWM is more. To reduce the complexity involved in CSVPWM algorithm, a simplified approach is developed in [6-9] by using the concept of imaginary switching times.

This paper presents Space Vector based Generalized Discontinuous Pulse width modulation (GDPWM) algorithms for VSI fed Induction motor drive using the concept of imaginary switching times.

II. PROPOSED SPACE VECTOR BASED GENERALIZED DISCONTINUOUS PWM ALGORITHMS

SVPWM is a continuous PWM (CPWM) method where Discontinuous SVPWM results when one of the two zero vector is not used in the implementation of the SVPWM. One leg of the inverter does not switch during the whole switching period and remains tied to either the positive or negative DC bus .This is known as Discontinuous SVPWM, since the switching is not continuous. Due to the manipulation of the Zero Space vector application in a Switching period one branch of the inverter remains un-modulated during one Switching interval. Switching takes place in two branches: one branch either to the positive DC bus or the negative DC bus, [when zero voltage [000] is eliminated the leg voltage is tied to the positive DC bus $0.5V_{dc}$ or when zero voltage [111] is eliminated the leg voltage is tied to the negative bus voltage $0.5V_{dc}$]. The number of switching's thus reduced to two- thirds compared to the continuous SVPWM and hence switching losses are reduced significantly. Moreover, complexity involved in conventional SVPWM is more. To avoid the complexity due to angle calculation and sector identification involved in CSVPWM. The Proposed GDPWM algorithms use the concept of Imaginary Switching times. The imaginary switching time periods are proportional to the instantaneous values of the reference phase voltages are defined as

$$T_{as} = \frac{T_s}{V_{dc}} V_a \quad (5)$$

$$T_{bs} = \frac{T_s}{V_{dc}} V_b \quad (6)$$

$$T_{cs} = \frac{T_s}{V_{dc}} V_c \quad (7)$$

Where T_s is the sampling time
V_{dc} is the dc link voltage
V_a, V_b, V_c are the Phase voltage

To calculate the active vector switching times, the maximum and minimum values of imaginary switching times are calculated in every sampling time

$$T_{max} = max(T_{as}, T_{bs}, T_{cs}) \quad (8)$$

$$T_{min} = min(T_{as}, T_{bs}, T_{cs}) \quad (9)$$

To generate the actual gating signals for inverter, the actual switching times for each inverter leg can be obtained by the time shifting operation as follows:

$$T_{ga} = T_{as} + t_{offset} \quad (10)$$

$$T_{gb} = T_{bs} + t_{offset} \quad (11)$$

$$T_{gc} = T_{cs} + t_{offset} \quad (12)$$

Where

$$t_{offset} = T_s(1-\mu) + (\mu - 1)T_{max} - \mu T_{min} \quad (13)$$

In the proposed method μ can be defined as

$$\mu = 1 - 0.5\left[1 + sgn\big(cos3(\omega t + \delta)\big)\right] \quad (14)$$

Where $'\omega'$ is the angular frequency of the reference voltage.

'$sgn(y)$'is the sign function, where

$$sgn(y) = \begin{cases} +1 \; if \; y > 0 \\ 0 \; if \; y = 0 \\ -1 \; if \; y < 0 \end{cases}$$

'δ' is the modulation phase angle

When μ=0.5, μ=0 andμ= 1 the CSVPWM, DPWMMAX and DPWMMIN algorithms can be obtained. Similarly, the variation of modulation phase angle δ yields to infinite number of DPWM methods. If δ = -π/3, π/6, 0, - π/6 then DPWM0, DPWM1, DPWM2 and DPWM3 can be obtained respectively. Thus by varying μ and δ the switching time periods of zero voltage vectors can be changed and so thatdifferent DPWM sequences can be obtained.

The modulating waveforms of different DPWM sequences and CSVPWM are as shown in Fig 1. DPWM sequences are obtained based on their clamping sequences. In DPWMMAX method, the clamping of 120° takes place at the middle of 0°-180° for every 360° of fundamental voltage. In DPWMMIN method, the clamping of 120° takes place at the middle of 180°– 360°for every 360° of fundamental voltage.

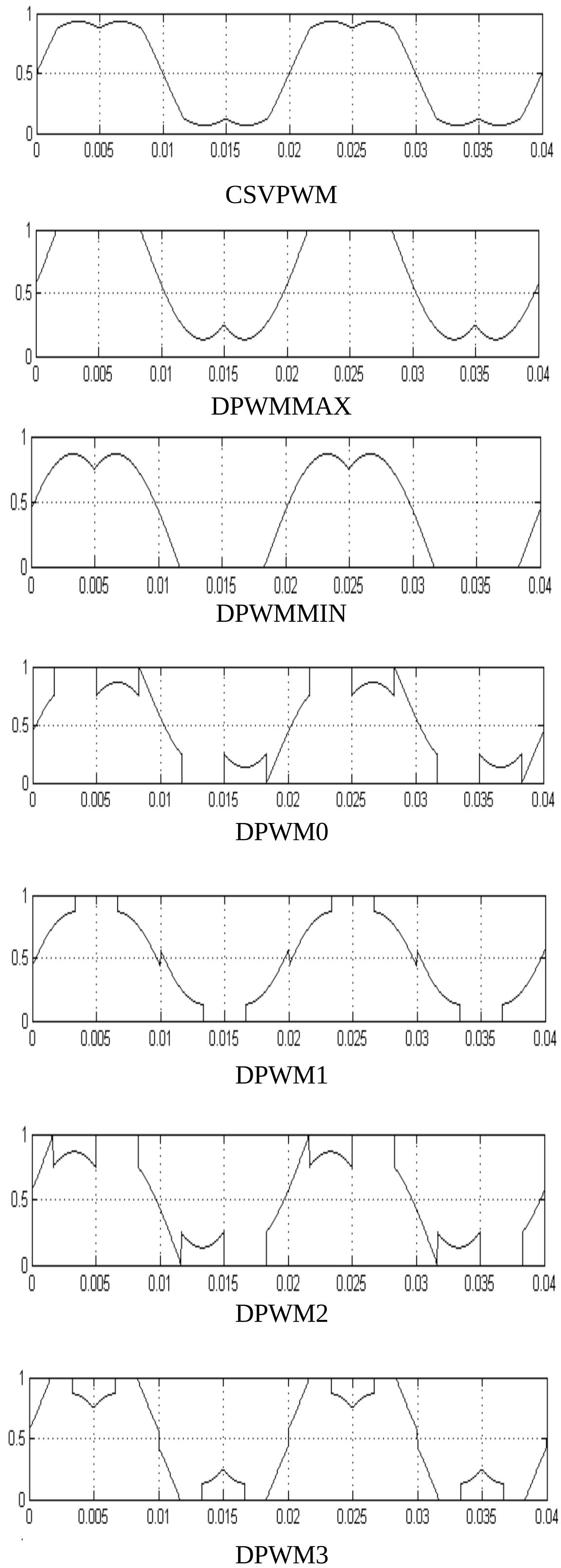

Figure-1 Modulating waveforms of different sequences

In DPWM0 method, the clamping of 60° takes place at the end of $0° - 90°$for every 180° of fundamental voltage. Another well known method DPWM1, the clamping of 60° takes place at the middle 0° −180° for every 180° of fundamental voltage. InDPWM2 method, the clamping of 60° takes place at the start of 90°-180° for every 180° of fundamental voltage. Another acceptedmethod DPWM3 clamps every phase during the middle 30° for every 90° of its fundamental voltage.

Block diagram representation of Generalized DPWM sequences for V/f control induction motor drive

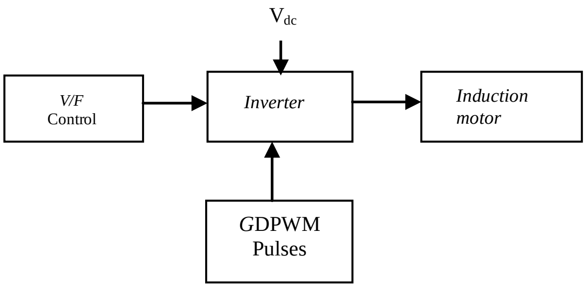

Figure-2 Block diagram of GDPWM sequences for*V/f* control induction motor drive

III. MODELING OF INDUCTION MOTOR

The most popular method of Speed control is *V/f* control method. The Flux and Torque are also function of frequency and voltage respectively.Speed is varied by varying the frequency; maintain *V/f* constant to avoid saturation of flux. With constant *V/f* ratio, motor develops a constant maximum torque. Among the various reference frames, *V/f* control method uses the stationary reference frame. Hence, the induction motor model is developed in the stationary reference frame, which is also known as Stanley reference frame.

The stator and rotor voltage and flux linkages in the stator reference frame are defined as

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \quad (15)$$

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \quad (16)$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \quad (17)$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \quad (18)$$

$$V_{ds} = R_s i_{ds} + \frac{d\lambda_{ds}}{dt} \quad (19)$$

$$V_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} \quad (20)$$

$$0 = R_r i_{dr} + \omega_r \lambda_{qr} + \frac{d\lambda_{dr}}{dt} \quad (21)$$

$$0 = R_r i_{qr} + \omega_r \lambda_{dr} + \frac{d\lambda_{qr}}{dt} \quad (22)$$

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \quad (23)$$

The electro-mechanical equation of the induction motor drive is given by

$$T_e = T_L + J\frac{d\omega_m}{dt} = T_L + \frac{2}{p}J\frac{d\omega_r}{dt} \quad (24)$$

IV. SIMULATION RESULTS

To validate Space Vector Based GDPWM Algorithms for Inverter fed Induction Motor Drive. Simulation test can be done using Matlab/Simulink model. The parameters used for simulation and output results will be given below

The induction motor used in this case study is a 4 KW, 1470 rpm, 4-pole, 3-phase induction motor having the following parameters:

Parameter	value
Stator Resistance (R_s)	7.83 Ω
Rotor Resistance (R_r)	7.55 Ω
Magnetizing Inductance (L_m)	0.4535 H
Stator Self Inductance (L_s)	0.475 H
Rotor Self Inductance (L_r)	0.475 H
Moment of inertia (J)	0.06 Kg-m^2

Table-1 parameters of Induction motor

The total harmonic distortion (THD) of the no-load current is used as the performance indices for proposed PWM Techniques. The line current waveforms at no-load and harmonic spectra for CSVPWM and some popular DPWM methods for supply frequency 50Hz are as shown.

4.1 STARTING TRANSIENT RESULTS

The simulation results of starting transients of proposed drive are shown in Fig 3 (3.1-3.7).The output voltage waveform is similar to all sequences. The dc voltage considered for inverter is 600V and the output voltage obtained at the inverter is $\frac{2}{3}V_{dc}$=400V as shown in fig.3.

Initially when the motor is started due to large inertia in the rotor it posses large amount of torque so it takes large amount of current which is observed from Fig 3.

From Fig 3 (3.1-3.7) it can be observed that upto 0.8sec the starting transients are shown during this period the speed starts from 0 rpm and reaches nearly 1500rpm, that means at the time of steady state it satisfies $T\alpha\frac{1}{N}$ and before reaches to the steady state the current waveform gradually reduce and reaches to the min value of the current less than 4 amps in steady state.

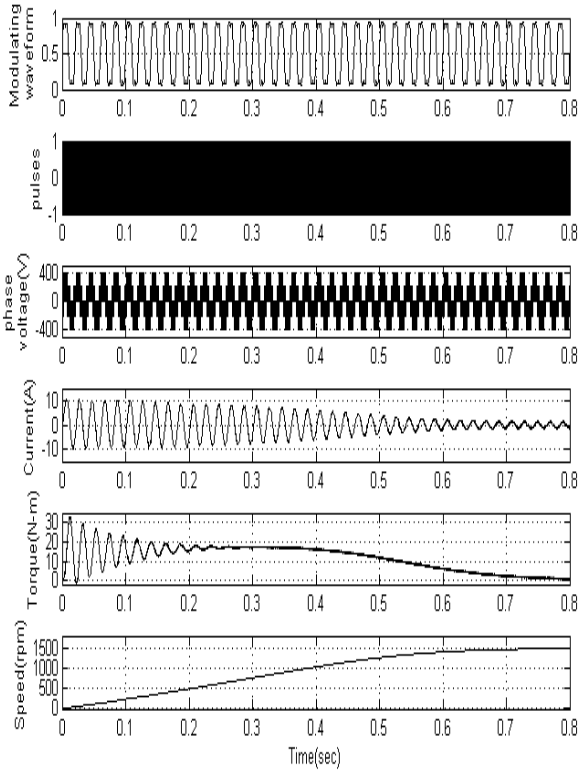

Figure3.1 Starting transients of continuous SVPWM

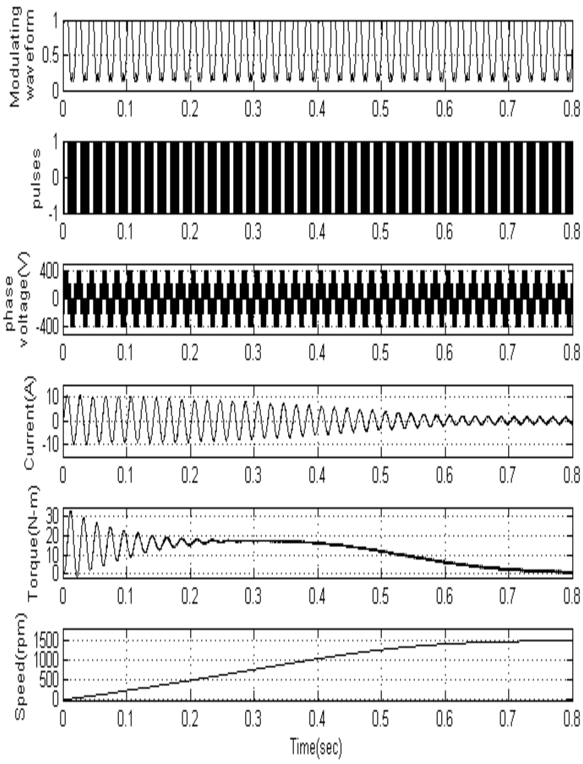

Figure3.3 Starting transients of DPWMMAX

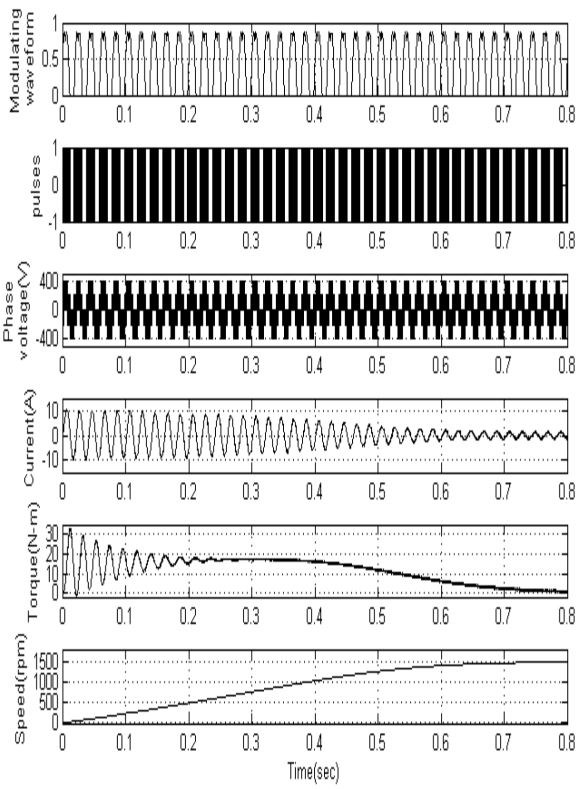

Figure3.2 Starting transients of DPWMMIN

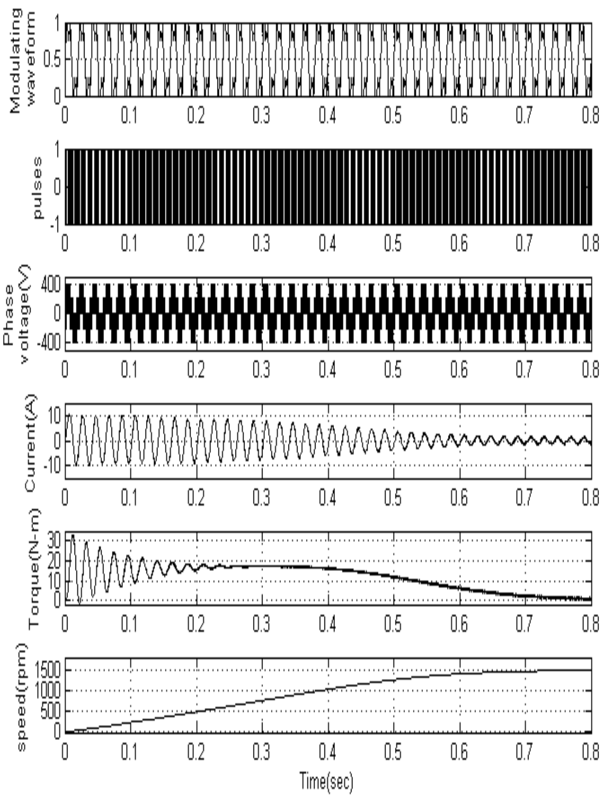

Figure3.4 Starting transients of DPWM0

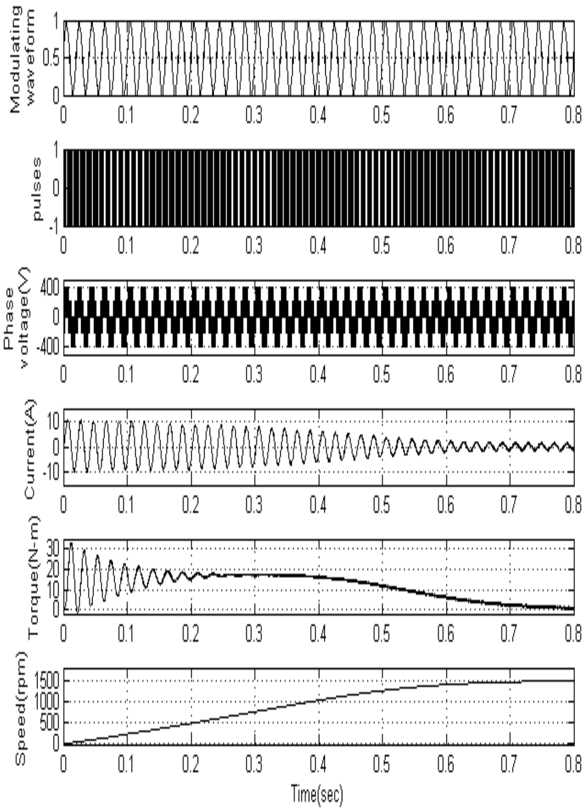

Figure3.5 Starting transients of DPWM1

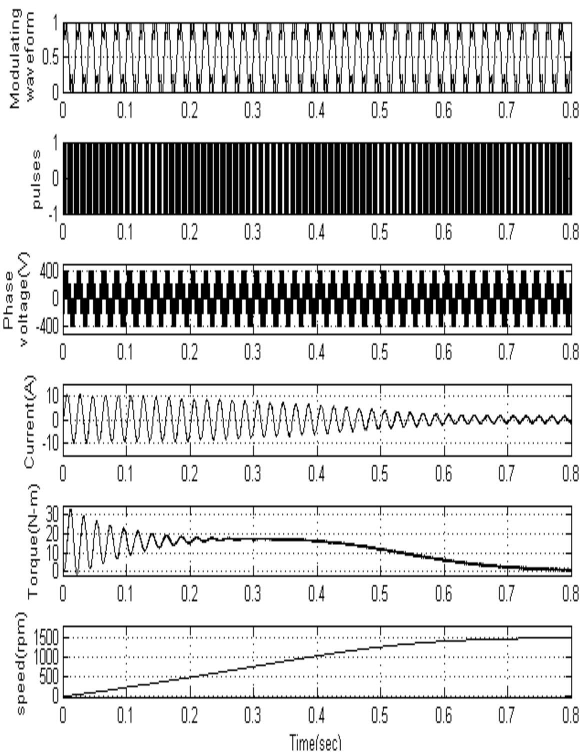

Figure3.6 Starting transients of DPWM2

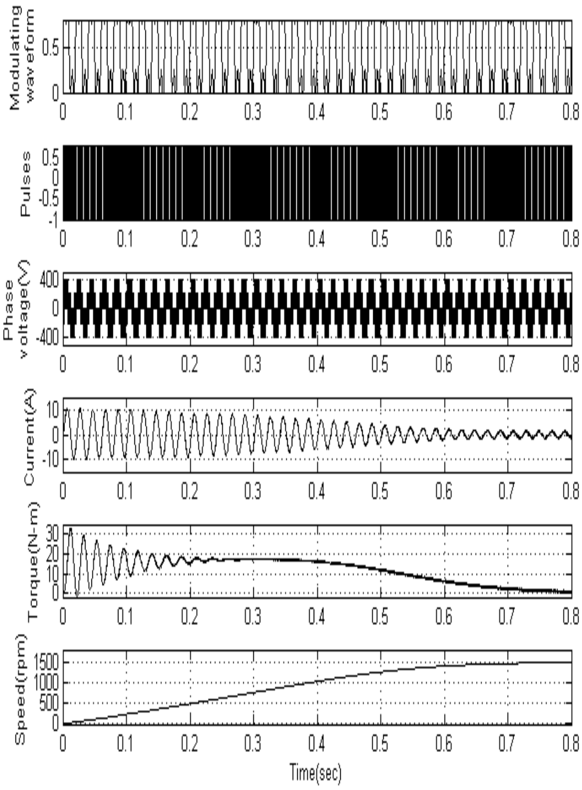

Figure3.7 Starting transients of DPWM3

Figure-3(3.1-3.7) are results of starting transients of proposed GDPWM drive

4.2 STEADY STATE RESULTS

The simulation results of steady state transients of proposed drive are shown in Fig 4 (4.1-4.7). In steady state period the speed reaches 1500rpm. After 0.8 sec the torque reaches zero and current reaches minimum value this minimum value current appears because of steady state/no load effect.

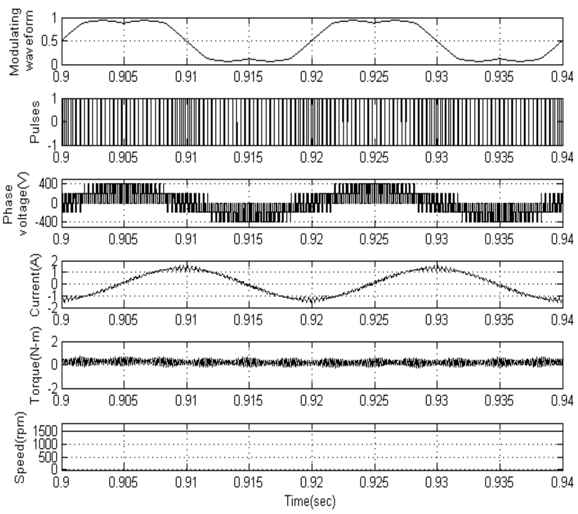

Figure4.1 Steady state transients of continuous SVPWM

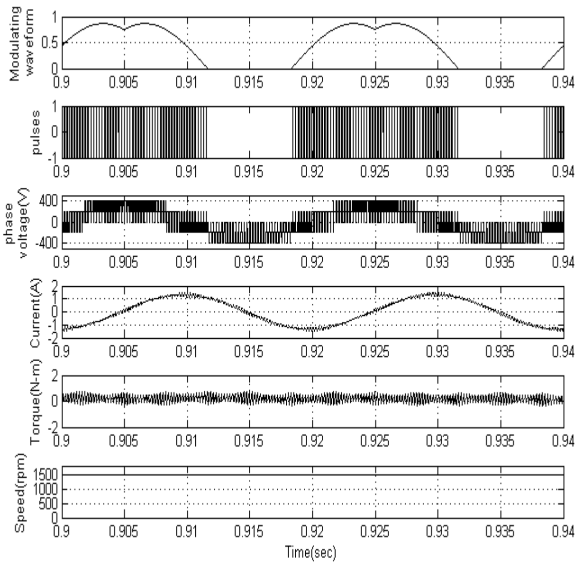

Figure4.2 Steady state results of DPWMMIN

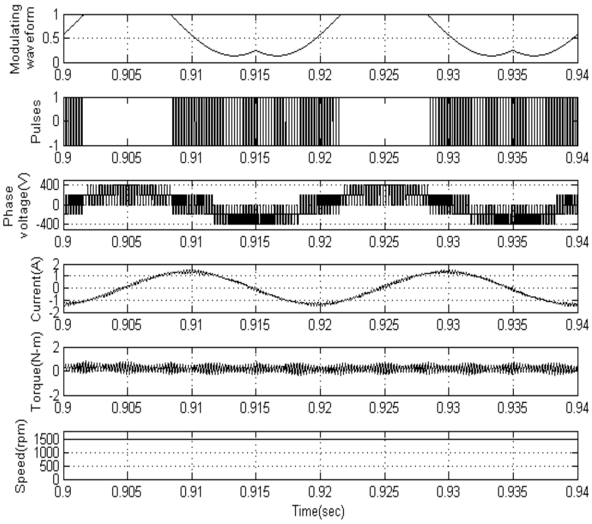

Figure4.3 Steady state transients of DPWMMAX

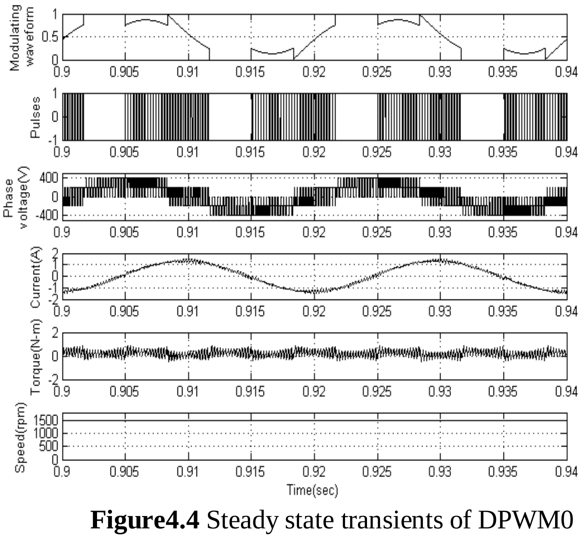

Figure4.4 Steady state transients of DPWM0

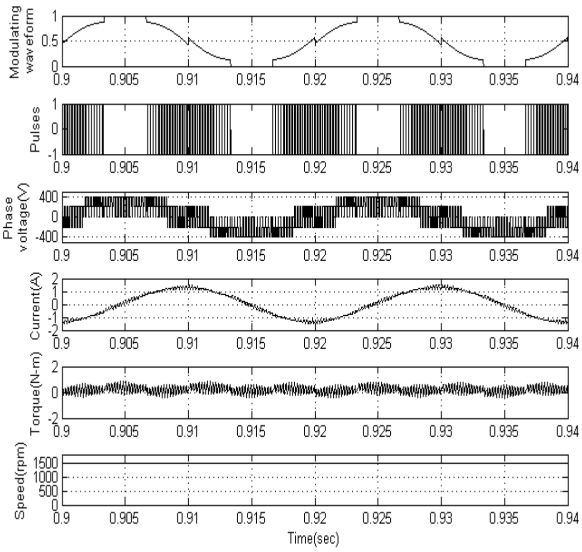

Figure4.5 Steady state transients of DPWM1

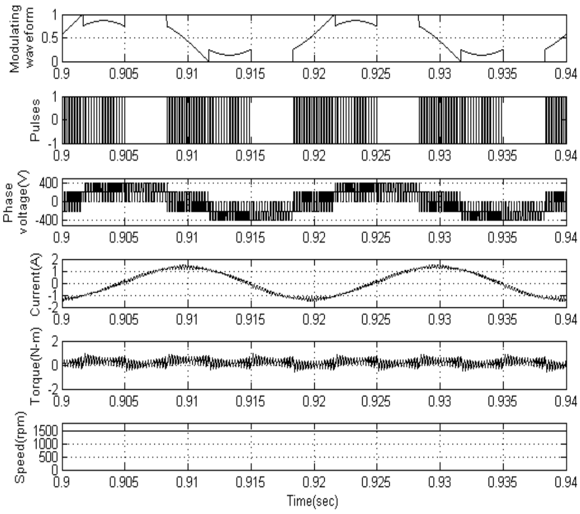

Figure4.6 Steady state transients of DPWM2

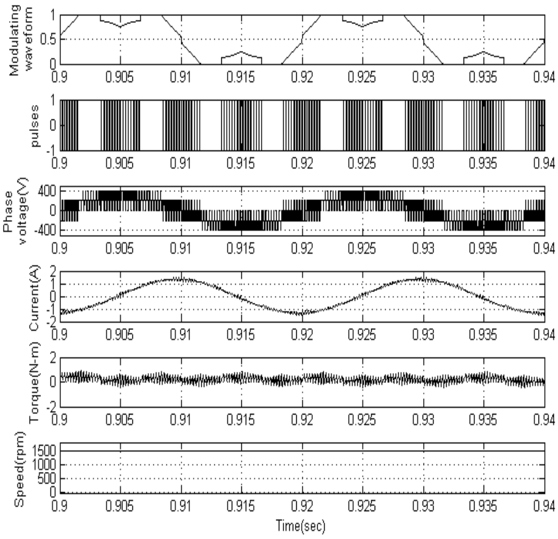

Figure4.7 Steady state transients of DPWM3

Figure-4(4.1-4.7) are steady state results of proposed GDPWM drive

4.3 TOTAL HARMONIC DISTORTION OF NO-LOAD CURRENT FOR INVERTER FED INDUCTION MOTOR

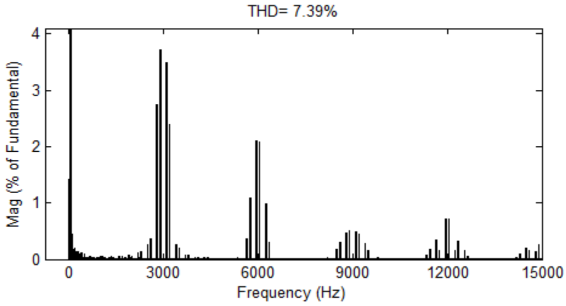

Figure5.1 THD of Continuous SVPWM

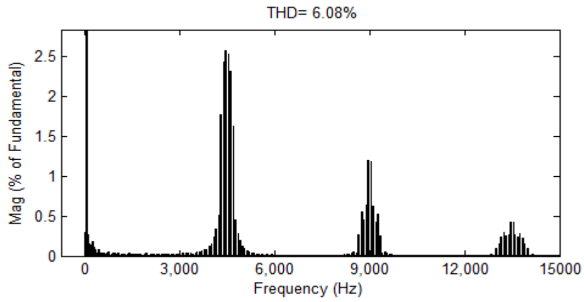

Figure5.2 THD of DPWMMIN

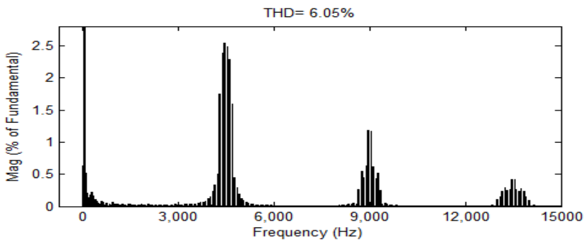

Figure5.3 THD of DPWMMAX

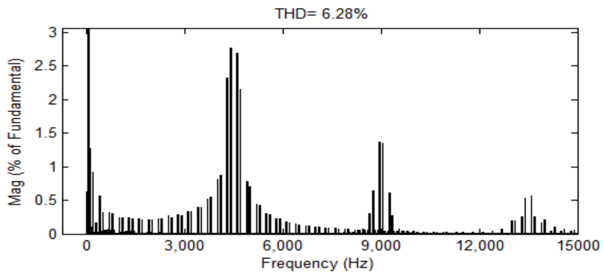

Figure5.4 THD of DPWM0

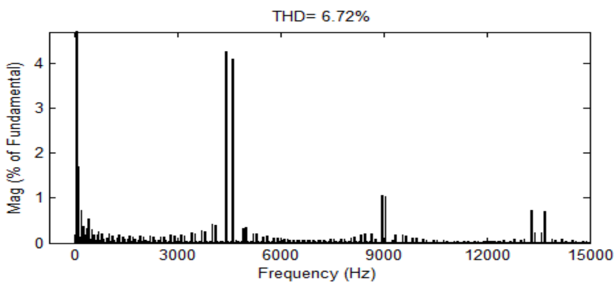

Figure5.5 THD of DPWM1

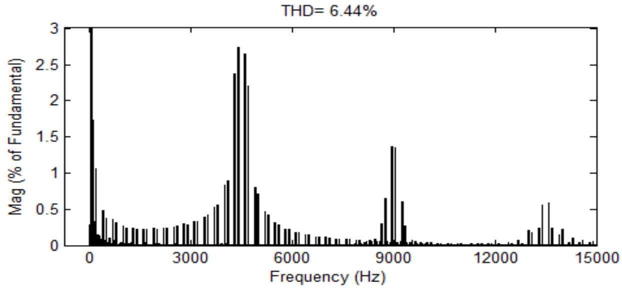

Figure5.6 THD of DPWM2

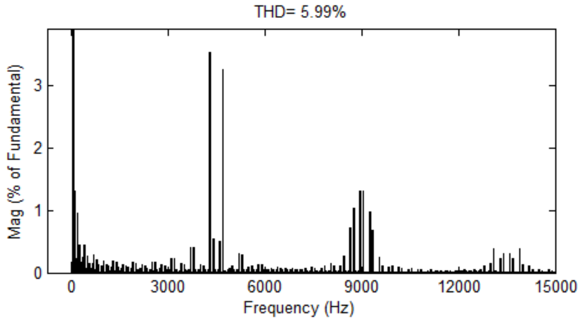

Figure5.7 THD of DPWM3

Figure 5 (5.1-5.7) are the total harmonic distortion of different sequences

The total harmonic distortion of current in CSVPWM is more compared to the DPWM sequences. These THDs are calculated during the steady state period.

Table-2 comparison of %THD of different PWM sequences

S.NO	SEQUENCES	%THD
1	CSVPWM	7.39
2	DPWMMIN	6.08
3	DPWMMAX	6.05
4	DPWM0	6.28
5	DPWM1	6.72
6	DPWM2	6.44
7	DPWM3	5.99

V. CONCLUSIONS

The proposed space vector based generalized discontinuous PWM algorithms uses the concept of imaginary switching times.To avoid the complexity due to angle calculation and sector identification involved in Conventional SVPWM.Also the execution time and memory required is reduced by eliminating the angle and sector estimation.

From the simulation results of*V/f* control of induction motor drive are discussed here. The total harmonic distortions of the motor phase current in Continuous SVPWM are more compared to the generalized DPWM sequences. The Total THD values for the proposed GDPWM algorithms are listed. It is observed that there is a gradual decrement of the %THD in motor phase currents. Hence DPWM sequences give better performance.The simulation results show the validity of the proposed algorithm.

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