IMPLEMENTATION OF dSPACE CONTROLLED DPWM BASED INDUCTION MOTOR DRIVE

J.Jona[1], Y.Chintu Sagar[2], K. Sri Gowri[3], G.Kumaraswamy[4]

[1, 2]PG Student, [3]Professor, [4]Assistant Professor, Electrical and Electronics, RGMCET NANDYAL, A.P, India
jona_jana@yahoo.co.in**, **chintu215@gmail.com**, **gowrivasu.3@gmail.com, kumar1718@gmail.com

Abstract

The paper presents dSPACE controlled Induction motor drive fed through Discontinuous pulse width modulation (DPWM) algorithm based voltage source inverter. Two important performance measuring factors harmonic distortion in line current and dc bus utilization of the inverter can be improved with Discontinuous PWM approach in comparison with the popular conventional space vector (CSVPWM) approach; the paper contemplates on the implementation of DPWM algorithm for pulse generation which in turn are fed to intelligent power module that feeds the motor drive through DS1104 PPC603e / 250 MHz control desk. The results conclude the successful implementation of dSPACE Controlled induction motor drive. To validate the proposed work, numerical simulation including the experimental results is presented.

***Keywords:**-DPWM, dSPACE, RTI*

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1. INTRODUCTION

With the inventions of fast switching power semiconductor devices and motor control algorithms, emerging interest instituted among researchers in the area of PWM techniques. During the past decade several PWM algorithms have been studied extensively. Various PWM methods have been developed to achieve wide modulation range, less switching loss, improved total harmonic distortion (THD) with ease in digital implementation with less computation burden on the controller. A large variety of algorithms for PWM exist, and a survey of these was done in [1]. There are two popular approaches for the implementation of PWM algorithms, namely triangular comparison (TC) approach and space vector (SV) approach. For a long period, TC approach based PWM methods were widely used in most applications. The earliest modulation signals for TC approach are sinusoidal. But, the addition of the zero sequence signals to the sinusoidal signals results in several non-sinusoidal signals. Compared with sinusoidal PWM (SPWM) algorithm, non-sinusoidal PWM algorithms can extend the linear modulation range for line-to-line voltages. Different zero-sequence signals lead to different non sinusoidal PWM modulators [2]. In this paper pulse generation through dSPACE control desk is done for DPWM algorithm, which in turn generates the required ac voltage by means of intelligent inverter module (PEC16DSM01). The performance of the motor is tested at different modulation indices ranging from low, medium to high. Simulation and experimental results of pulse pattern for a-phase, modulating waves of phase a, b are also presented.

With the development of digital signal processors, SVPWM has become one of the most popular PWM methods for three-phase inverters [3]-[4]. It uses the space vector approach to compute the duty cycle of the switches. The main features of this PWM algorithm are easy digital implementation and wide linear modulation range for output line-to-line voltages. The equivalence between TC and SV approaches were elaborated in [5] and concluded that SV approach offers more degrees of freedom compared to TC approach.

While, SVPWM gives superior performance, switching losses in the inverter are more as it generates continuous pulses (modulating signal). Hence, to reduce the switching losses of the inverter, discontinuous PWM (DPWM) methods are considered. The generation of these DPWM algorithms [6]-[8] can also be considered. However, this paper presents the results of CSVPWM along with few Discontinuous PWM algorithms for induction motor using the conventional notion of sector selection.

2. CONVENTIONAL SVPWM ALGORITHM

The main purpose of the voltage source inverter (VSI) is to generate a three-phase voltage with controllable amplitude, and frequency. A conventional 2-level, 3-phase VSI feeding a three-phase induction motor is shown in Fig 1.

From Fig.1, it can be observed that the two switching devices on the same leg cannot be turned on and cannot be turned off at the same time, as this condition will result in short circuit/open circuit to the connected phase. Thus the nature of the two switches on the same leg is complementary. The switching-on and switching-off sequences of a switching device are represented by an existence function, which has a value of unity when it is turned on and becomes zero when it is turned off. The existence function of a VSI comprising of switching devices T_i is represented by S_i, i = 1, 2, . . . 6. Hence, S_1, S_4 which take values of zero or unity respectively, are the existence functions of the top device (T_1) and bottom device (T_4) of the inverter leg connected to phase 'a'.

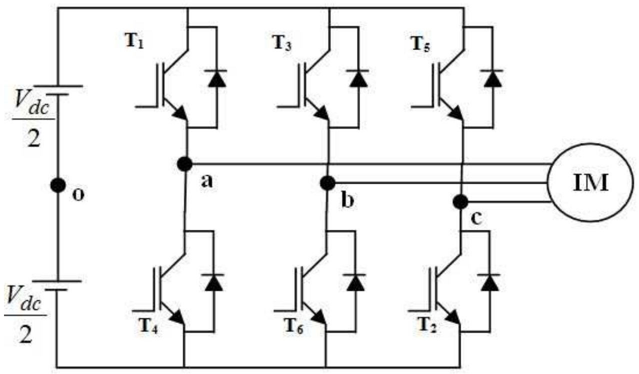

Fig -1 2-level, 3-phase voltage source inverter feeding induction motor

$$S_1 + S_4 = 1;\ S_3 + S_6 = 1;\ S_5 + S_2 = 1 \qquad (1)$$

As seen from Fig 1, there are totally six switching devices and only three of them are independent. The combination of these three switching states gives out eight possible voltage vectors. At any time, the inverter has to operate one of these voltage vectors. Out of eight voltage vectors, two are zero voltage vectors (V_0 and V_7) and remaining six (V_1 to V_6) are active voltage vectors. In the space vector plane, all the voltage vectors can be represented as shown in Fig 2.

For a given set of inverter phase voltages (V_{an}, V_{bn}, V_{cn}), the space vector can be constructed as

$$V_s = \frac{2}{3}\left(V_{an} + V_{bn} e^{j\frac{2\pi}{3}} + V_{cn} e^{j\frac{4\pi}{3}}\right) \qquad (2)$$

From (2), it is easily shown that the active voltage vectors can be represented as

$$V_k = \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}} \quad \text{where } k = 1,2,...,6 \qquad (3)$$

By maintaining the volt-second balance, a combination of switching states can be utilized to generate a given sample in an average sense during a sub cycle. The voltage vector V_{ref} in Fig.2 represents the reference voltage space vector or sample, corresponding to the desired value of the fundamental components of the output phase voltages. But, there is no direct way to generate the sample and hence the sample can be reproduced in the average sense. The reference vector 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 durations with in a sampling time period such that the average vector produced over the sub cycle is equal to the sampled value of the reference vector, both in terms of magnitude and angle. As all the six sectors are symmetrical, here the discussion is limited to sector-I only. Let T_1 and T_2 be the durations for which the active states 1 and 2 are to be applied respectively in a given sampling time period T_s. Let T_z be the total duration for which the zero states are to be applied. From the principle of volt-time balance T_1, T_2 and T_z can be calculated as:

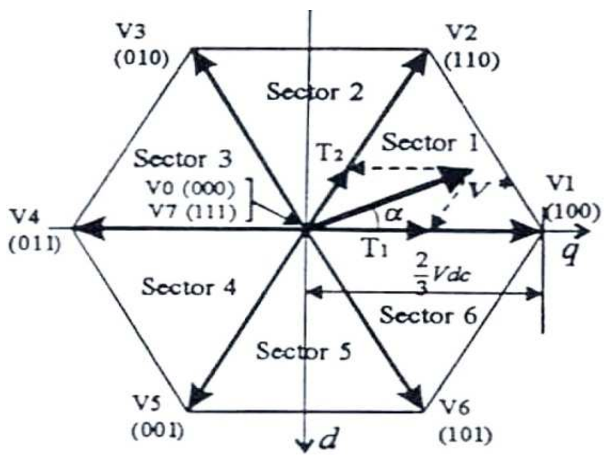

Fig -2 Voltage space vectors produced by a voltage source inverter

$$T_1 = \frac{2\sqrt{3}}{\pi} M\left[Sin(60^o - \alpha)\right]T_s \qquad (4)$$

$$T_2 = \frac{2\sqrt{3}}{\pi} M\left[Sin(\alpha)\right]T_s \qquad (5)$$

$$T_Z = T_s - T_1 - T_2 \qquad (6)$$

Where M is the modulation index and is given in (7).

$$M = \frac{2\mathrm{v}_{ref}}{3V_{dc}} \qquad (7)$$

In the SVPWM algorithm, the limit for modulation index is 0.866 [1]. In the SVPWM strategy, the total zero voltage vector time is equally distributed between V_0 and V_7. Further, in this method, the zero voltage vector time is distributed symmetrically at the start and end of the sub cycle in a symmetrical manner. Moreover, to minimize the switching actions of the inverter, it is desirable that switching should take place in one phase of the inverter should take place only for a transition from one state to another. Thus, SVPWM uses 0127-7210 in first sector, 0327-7230 in second sector and so on. Table-1 depicts the switching sequence for all the sectors.

Table 1: Switching sequences in all sectors for SVPWM

Sector number	On-sequence	Off-sequence
1	0-1-2-7	7-2-1-0
2	0-3-2-7	7-2-3-0
3	0-3-4-7	7-4-3-0
4	0-5-4-7	7-4-5-0
5	0-5-6-7	7-6-5-0
6	0-1-6-7	7-6-1-0

Also, with the SVPWM algorithm, the linear modulation range and dc bus utilization compared with traditional SPWM can be increased [1].

3. PROPOSED PWM ALGORITHM

As the CSVPWM is a continuous PWM technique, switching losses of the inverter are high. Where as in DPWM methods during each sampling period, each of the phases ceases the modulation and the associated phase is clamped to the positive dc bus or negative dc bus. Hence, the switching losses of the associated inverter leg during the period of clamping are eliminated. The performance of the PWM methods depends upon the modulation index. In the lower modulation range, the CPWM methods are superior to DPWM methods, while in the higher modulation range the DPWM methods are superior to CPWM methods. However at all the operating modulation indices, CPWM method has higher switching losses than DPWM methods. Hence, to reduce the switching losses of the inverter, now-a-days discontinuous PWM (DPWM) algorithms are becoming popular. The generation of these DPWM algorithms is given in detail in [6]-[8]. In the proposed method the zero state time T_z is divided between two zero states as $T_z X$ for V_0 and $T_z(1-X)$ for V_7 respectively, where X lies between 0 and 1 .considering different values for X in the range of 0 to 1 generates different DPWM method

$$T_z(1-X) \tag{8}$$

Where

X= 0.5 for CSVPWM

T0=0.5Tz and T7=0.5Tz

The total zero state time is spent equally in the two zero states V_O and V_7

With X=0, V0=0 and V7= Tz and

When X=1, V0=Tz and V7= 0

i.e; only one zero state is utilized with X=1 ,for any other value between 0and 1 except 0.5

When X = 1 any each of the phase is clamped to the positive bus for 120 degrees and when and X = 0 each phase is clamped to the negative bus for 120 degrees continuously with in a cycle. The modulation waveforms and their zero sequence signals of few popular DPWM methods including CSVPWM method are shown in Figure-2.

4. SIMULATION RESULTS AND DISCUSSIONS

To validate the proposed PWM algorithms, numerical simulation is performed using Matlab-Simulink. To maintain constant average switching frequency, the switching frequency of SVPWM algorithm is taken as 10KZ.For simulation, dc link voltage is taken as 600 V. The simulation results of the conventional SVPWM algorithm is shown in Fig.3 – Fig4 .Here, modulating waveforms and pole voltages of the inverter have shown. From the results it is concluded that SVPWM algorithm generates continuous modulating wave andhence continuous pulses to the inverter and hence gives more switching losses in the inverter.

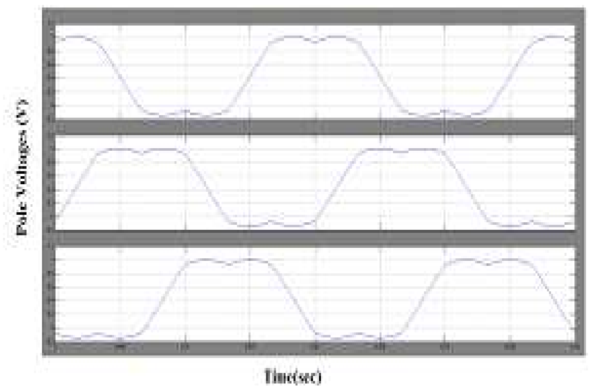

Fig-3 Simulation Results of CSVPWM Algorithm modulating waves

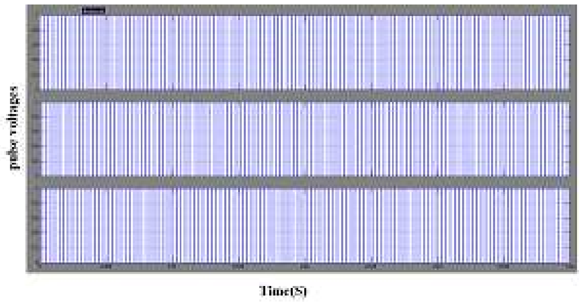

Fig- 4 Simulation Results of Proposed CSVPWM Algorithm Pulses

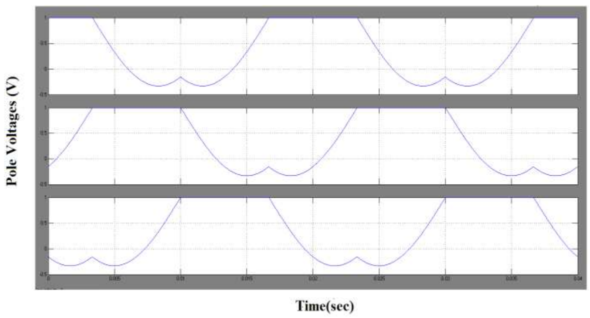

Fig-5 Simulation Results of Proposed DPWMMIN Algorithm modulating waves

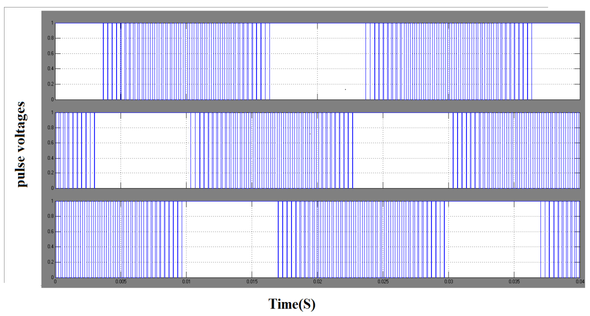

Fig-6 Simulation Results of Proposed DPWMMIN Algorithm modulating waves

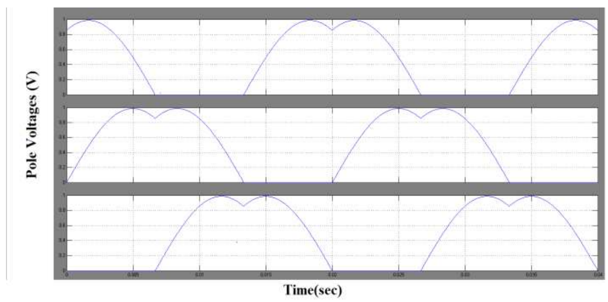

Fig-7 Simulation Results of Proposed DPWMMAX Algorithm modulating waves

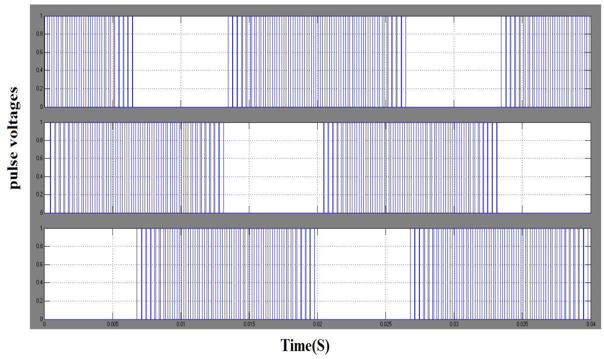

Fig-8 Simulation Results of Proposed DPWMMAX Algorithm modulating waves

5. HARDWARE IMPLEMENTATION RESULTS AND DISCUSSIONS

The experimental setup of the proposed system is shown in Fig.5. The proposed algorithm has been implemented using the rapid prototyping and real time interface system dSPACE with DS1104 control card. DS1104 controller card is built by a German company called dSPACE. It is a powerful system which provides rapid control prototyping and Hardware-In-Loop (HIL) simulations which can be used for many different applications. The obvious advantages of using hardware-in-loop simulations is that performance of systems can be compared both practically and theoretically. DS1104 Controller Board comes with software packages called Real Time Workshop and Control Desk. DS1104 control card includes the PowerPC 603e/250 MHz main processor and Texas instruments TMS320F240 sub processor.DS1104 control cards allows the user to construct the system in MATLAB/Simulink and then to convert the model files to real-time codes using the Real-Time interface(RTI) of the control.

The DPWM algorithm has been implemented using dSPACE board with TMS320F240. The dSPACE works on MATLAB/SIMULINK platform which is a common engineering software and easy to understand. Another feature of the dSPACE is the control desk which allows the graphical user interface, through the control desk the user can observe the response of the system, give command to the system through this interface. Real time interface is needed for the dSPACE to work. RTI is the link between dSPACE's real-time systems and the development software. MATLAB/ Simulink from the Math Works Power circuit for the drive consist a Semikron IGBT based voltage source inverter with opto-isolation and gate driver circuit SKHI22A. The dc voltage for the VSI is achieved through a three-phase diode bridge rectifier module. A capacitive filter is used at the dc link of this module to reduce the voltage ripples.

The motor used in this experimental investigation is a three phases, 3KW, 4 pole squirrel cage induction machine,

The CSVPWM Pulses are first designed in MATLAB/SIMULINK environment and relevant coding is written to generate the pulses and by using dSPACE software conversion tool the M-files are converted in to the C coding. Thus, the triggering pulses are given to the inverter and the induction motor is driven by Voltage Source Inverter (VSI). From the test done, control of induction motor was successfully implemented using dSPACE.

Fig -9 Real Time Implementation

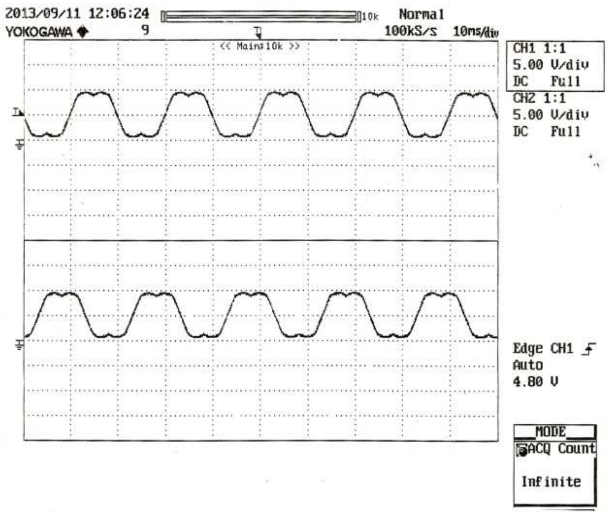

Fig -10 Real Time Results of CSVPWM

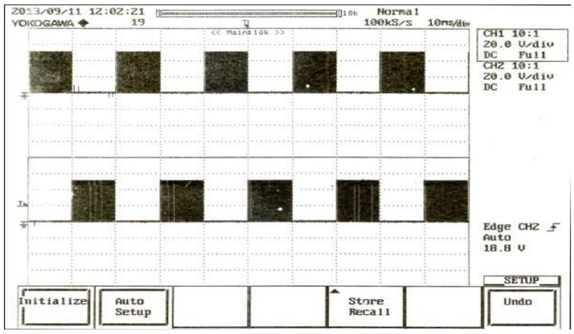

Fig -11 Real Time Results of CSVPWM PULSES

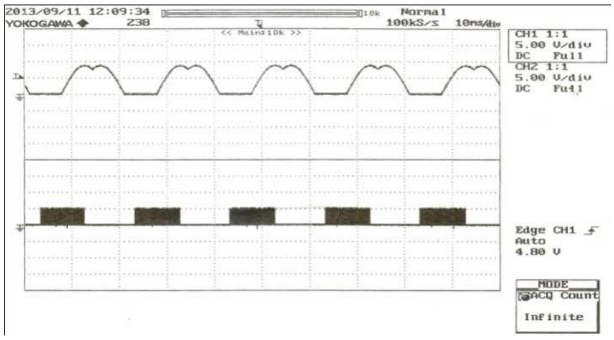

Fig -12 Real Time Results of DPWMMAX

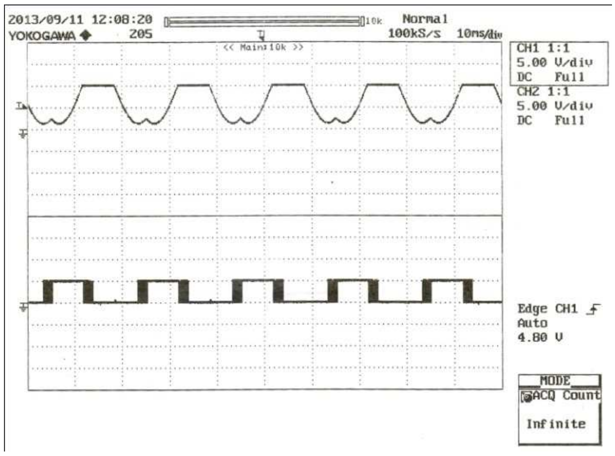

Fig -13 Real Time Results of DPWMMIN

CONCLUSIONS

Simulated DPWM algorithm has been developed, simulation and hard ware results are presented in this paper. The conventional space vector pulse width modulation algorithm gives more switching losses and total harmonic distortion. where as in DPWM methods during each sampling period, each of the phases ceases the modulation and the associated phase is clamped to the positive dc bus or negative dc bus. Hence, the switching losses of the associated inverter leg during the period of clamping are eliminated. There by reducing switching losses to 1/3rd with the CSVPWM. Moreover, the proposed algorithm uses sector and angle calculations requires the angle and sector calculations and hence involved rigorous calculation taken by the controller. From the test done, control of induction motor was successfully implemented using dSPACE which means this process is feasible. Speed of the Induction motor is controlled successfully by varying the frequency or voltage by declaring these two as control parameters in the dSPACE control desk without disturbing the hard ware setup which is already running.

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BIOGRAPHIES

J.Jona is born in 1983 in India. Presently she is doing post graduation in Power Electronics and Electrical drives Specialization at RGM College of Engineering and Technology, Nandyal. Her main areas of interest include Induction motor drives, Electrical machines, power Electronic converters and Power Electronic Drives
E-mail: jona_jana@yahoo.co.in

Y.Chintu Sagar is born in 1989 in India .He is graduated from RGM College of Engineering and Technology, Nandyal in 2010.Presently he is doing post graduation in Power Electronics and Electrical drives Specialization at RGM College of Engineering and Technology, Nandyal. His main areas of interest include Induction motor drives, Electrical machines, power Electronic converters and Power Electronic Drives E-mail: chintu215@gmail.com

Dr. K.Sri Gowri received the B.Tech degree from SVU college of Engineering, Tirupati in 1997, the M.Tech degree from RGM College of Engineering and Technology, Nandyal and has been awarded Ph.D in the area of Power Electronic Control of Electric Drives from JNTU Kakinada in 2010. She is currently Professor in the Department of EEE in RGMCET, Nandyal, A.P. Her areas of interest include Power Electronics, Pulse Width Modulation Techniques, Drives and Control, Renewable Sources of Energy. E-mail: gowrivasu.3@gmail.com

G. Kumaraswamy is born in 1983 in India. He is graduated from JNTU University in 2005 and pursued Post graduation from the same university. He is currently working as a Assistant professor in the department of electrical and electronics engineering R.G.M college of engineering and technology, Nandyal, Andhra Pradesh, India. He has eight years of teaching experience. He has attended several National workshops. His main areas of research include Photovoltaic cells, multilevel inverters. Email: kumar1718@gmail.com