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THD Analysis of Five Phase VSI at Load using Time Equivalent Space Vector Pulse Width Modulation Technique

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ABSTRACT

Lots of controlling techniques are available in past to control the output results of voltage source inverters especially for three and five phase. Among all the techniques time equivalent space vector pulse width modulation scheme is very effective due to its simple implementation and better results as compared to other PWM techniques. Due to various benefits and applications (electric ship propulsion, electric/hybrid vehicles, traction etc) of five phase, author presented in this article THD analysis of five phase VSI at load using time equivalent space vector pulse width modulation technique. The results are verified using Matlab/Simulink (Matlab2014a) model of proposed system. Presented system is better utilized in high power medium voltage applications like warehouse.

Keywords: Harmonic distortion, Modulation, Simulation,Two-level VSI.

I. INTRODUCTION

The voltage source inverter produces three phase voltage which have changeable magnitude, phase angle and frequency. The modulation scheme which produces variable-width pulses to descrie the magnitude of an input analog signal known as Pulse width modulation. According to the literature the pulse width modulation schemes are of two types: Carrier based as well as Space vector pulse width modulation. The algorithm which is used to control the Pulse Width Modulation is commonly known as space vector modulation (SVM).The most popular modulation scheme due to their benefits of better dc bus utilization and easier digital implementation, Space vector pulse width modulation (SV-PWM) generate six voltage vectors by voltage source inverter for the first stage of multiphase i.e. three phase which is used to control the frequency, phase angle and amplitude of three-phased permanent magnet or three-phased induction machine.

In 1964, A. Schönung and H. Stemmler describe the maiden PWM technique known as sinusoidal PWM technique[1]. The benefit of this technique is easier implementation due to which this technique has wide range of applications but on account of its limitations of output range during its linear operation dc bus voltage utilization is poor. To improve utilization of dc bus voltage, in 2005 A. Iqbal and E. Levi proposed the space vector modulation technique [2]. Along with better dc bus utilization, possible optimization of the switching losses and output total harmonic distortion and suitability with the digital controller is the other benefit of this scheme. It has been broadly utilized for multi-phase drive frameworks and it demonstrated that the nonappearance of neutral conductor in star-associated frameworks gives the level of flexibility in deciding the duty cycles of the switching components.

In 1997, according to V. Blasko, it is seen that this degree of freedom is also achieved in SPWM by infusion of fitting zero sequence signal (ZSS)[3]. Due to the random value of voltage between neutral of load and the reference of the DC source, zero sequence signal not only changes the duty cycles of the switching components but also modulating signals. The advantages of adding ZSS enhance the quality of wave shape, decrease switching losses without influencing the output, enhance the linear range of the voltage developed. In 2003, it has been demonstrated by G. D. Holmes and T. A. Lipo that the yield voltage was enhanced to 90.7 % of the maximum fundamental voltage produced from the SVPWM[4].

In this article, author first review the various PWM controlling schemes and focused on time equivalent SVPWM techniques to analyze the total harmonic distortion for five phase systems at load. In last various simulation results are presented to verify the concept.

II. PWM COTROL SCHEME: A REVIEW

To balance current and reduction of higher harmonics three minute size three-phase coupling reactors having special windings are taken in use in the nine-pulse inverter driving system.For waveform improvement and voltage control using a three-phase coupling reactor adequate PWM pulse design were given to the six-phase inverter system to provide double three-phase construction.1993 H. Takami has apply the PWM control to the nine-phase inverter driving system.As compared to the six-phase PWM inverter driving system this system contains a biggerdimensions also improve waveforms of output current [5]. To avoid fifth and seventh harmonics in the motor voltage for every inverter is drivenbytraditional three-phase space vector modulation at low speed, a PWM technique is suggested for a split phase IM drive by K.Gopakumar et.al. in 1993[6]. To abolish the 5th, 7th, 17th, 19th, ...harmonics with nocomprehensivecalculations depend on three-phase SVM schemes , a fresh and effectual space vector PWM control of six-phase VSI fed split-phase IM is proposed by A. R. Bakhshai in 1997[7]. Kelly, J.W.et.al. has extended the conventional three-phase Space Vector Pulse Width Modulation for high order phase systems and examine an n-leg, n-phase inverter and demostratevarious schemes for n- SVPWM [8]. In 2002 for dual IM drives having three-phase, aabsolutereview and a relativeanalysis of various digital PWM schemes is performed by R Bojoi et.al. This comparision is depend on harmonicsreduction, software and hardware accomplishment intricacy with small price fixed-point DSP backgrounds. The merits anddemerits of every scheme are verified by simulation results[9].

In 2002 K KMohapatraet.al. presented a switchingtechnique for induction type motor having six phase. In thispresentedmethod, a switchingmethod to wipe out the 6n/splplusmn/1(n=1,3,5 etc.,) harmonics , even in the absence of filters, from phase of stator of a six phase induction type motor drive is explained[10]. In 2003 depend on a two star synchronous motor in which supply is given by two P.W.M. I.G.B.T. inverters, a novelproduction of ship electric drive is presented by S. Siala et. Al. In this there is given twofundamental control schemes named torque controlling and current balancing has been proposed and validated with 20MW propulsion power on a two-poded cruise ship [11]. J. W. Kelly et. al presented schemes for n-phase space vector pulse width modulation (SVPWM) for analyzing an n-leg, n-phase DC to AC converter .Specially a model of nine-phase SVPWM is produced and executed on a nine winding induction motor. Also compared the results with nine phase sine-triangle PWM in terms of direct current bus application[12]. In 2003 D. Hadiouche et.al., perform a detailed analysis, investigate new SVPWM techniques suitable for dual three-phase ac machines and a performance evaluation to decrease extra harmonics, demerits of dual three-phase ac machines, whileenergized by a voltage-source inverter (VSI), amplitude.[13].

In 2004 P.S.N. de Silva et.al. compared various modulation schemes for the five-phase inverter.Also with the development of auxiliary and main space vector domains, a novel interpretation of five-phase to orthogonal axis transformation is presented and It is shown that harmonic distortion in the five phase system is produced by the auxiliary space vector domain. To produce voltage in the main domain while cancelling components in the auxiliary domain in a sinusoidal system a novel space vector modulation strategy is developed. Along this to reduce switching a dead-banding scheme is also implemented [14]. In 2004 X Kestelynet. al. proposed and explained by example on a three-phase drive, a new fast mechanism to calculate the duty span of every VSI leg using the equivalence between a pair of assumed single-phase or double phase drives and a multi-phase machine those are not dependent in magnetic way but having coupling in reference to mechanical and electrical circuit. It is shown that compared to classical techniques, there is no need to search position of basic vector for obtaining the duty span of every leg. [15].

Since the waveform of phase voltages of a multiphase motors are not sinusoidal. Most of the conventional study on a multiphase is confined to a sinewavel phase voltage.Hence In 2005 H. M. Ryuet.al. extended it to a nonsinwave phase voltage and proposed a freshstudy on a multiphase SVPWM, based on a multiple d-q spaces concept, to amalgamate an random nonsinuwave phase voltage and also extended it to an n-phase inverter[16]. The Methods of speed control of three-phase AC machines are equally applied to the multiphase AC machines. Lots of methods of speed control have been used till now such as Constant Voltage /frequency control, vector control, Direct torque control, PWM control schemes. Among all the emphasis is towards the PWM control schemes due to its advantage of very low power losses in the switching devices. Because of on/off nature of switching devices, PWM also used well with digital controls and required duty cycle can be easily set. To avert generation of lower-order unwanted harmonics carrier-based PWM methods are undoubtedly a very simple approach [17].

In 2005 Ojo, O. et.al.to actuate multi-phase electric machines, investigate the possibilities accessible by multi-phase converters to serve two purpose. First is by by means of the air-gap third harmonics flux density to produce increased torque and second one by taking an extended composite-variable type reference edge renovation, to connection numerous machinery in succession with sovereign speed or torque control[18]. In 2005 A Iqbal et.al.analysedvarious SVPWM techniques for a five-phase VSI and demonstrated a thorough replica of a five-phase voltage source inverterregarding space vectors.The offered procedure of utilizing merely large space vectors is also demonstrated. A complete efficiency assessment of the offered and recently formulatedtechnique is demonstrated in provisions of superiority of the output voltage waveforms. [2]. In 2005 R Kianinezhadpresented a innovative space vector modulation (SVM) procedure for IM having six-phase (SPIM). For reducing harmonic currents, the projected multi-vector SVM is extra competent as compared to some traditional techniques,it is also shown that it is simple as well asrequired less very calculation span[19]. In 2005 and 2006author proposed two fresh multiphase SVPWM techniques and five-phase PMSM drive system is taken in application to explicate these methods[20,21]. The development in direct current bus deployment reduces by zero-sequence harmonics injections as the counting of phases rises [22]. A. Iqbal. et. al. describe carrier-based PWM, in which offset addition empowers an perfection in direct current bus deployment exclusive of goingacross over-modulation area, at the same time yielding sinusoidal output phase voltages. For a five-phase VSI giving power to two series-connected five-phase machines an suitable carrier-based PWM method with offset addition is created in 2006[23]. M. J. Duran present a SVPWM technique for multi-phase VSI, based on a multi-dimensional space approach and for appropriate selection of the voltage space vectors in the multi-dimensional case describe the mathematical analysis that establishes the necessary conditions. For the selection of the VSI space vectors, different criteria for the general n-phase case are also presented in 2006[24]. A. Iqbal et.al. proposed a scheme by using space vector PWM to generate inverter output voltages. With this approach independent control of two five-phase series-connected machines is achieved with a least communication between the two machines [25].

III. TIME EQUIVALENT SPACE VECTOR PULSE WIDTH MODULATION SCHEME (TESVPWM)[27]

The presented time equivalent space vector PWM provide the sinusoidal output results for which this scheme produce the turn on time. To produce theturn on time signal this scheme uses the reference input voltages (V_1, V_2, V_3, V_4& V_5) which are sampled. The detail discussion about this time equivalent SVPWM scheme is presented in [26].The time period, for which reference voltages are sampled, is identical to switching time. This amplitude which is sampled is transformed into equivalent time waveform. The yielded time waveforms are imaginary parameters because it becomes negative with negative reference voltage magnitude. Therefore to find out the turn on time for every leg of inverter, the time offset is included toyielded time waveforms. Because of which the active switching voltage vectors exist in centre within switching time interval. The approach of scheme is illustrated for first sector and same is used for next 9 sector[27]. Figure 1 displays switching patter for VSI having fivephase using TESVPWM for first sector. This patter is identical to that of SVPWM.

3.1 ALGORITHM

1. Utilize voltages V_1, V_2, V_3, V_4& $V_5$for sampling during every and eachperiod Ts.
2. Find out the analogous times T_1,T_2, T_3,T_4& T_5using equation

$$T_{zs} = V_{zs} \times \frac{T_s}{V_{dcu}}; \quad z = a,b,c,d \ \& \ e$$

3. Find out T_{offset} usingequation

$$T_{offset} = \frac{T_S}{2} - \frac{T_{\max} + T_{\min}}{V_{dc}}$$

4. In last switching time sigalsfor leg of ivertercan be achieved as

$$T_{gz} = T_z + T_{offset}; \quad z = a, b, c, d \ \& \ e$$

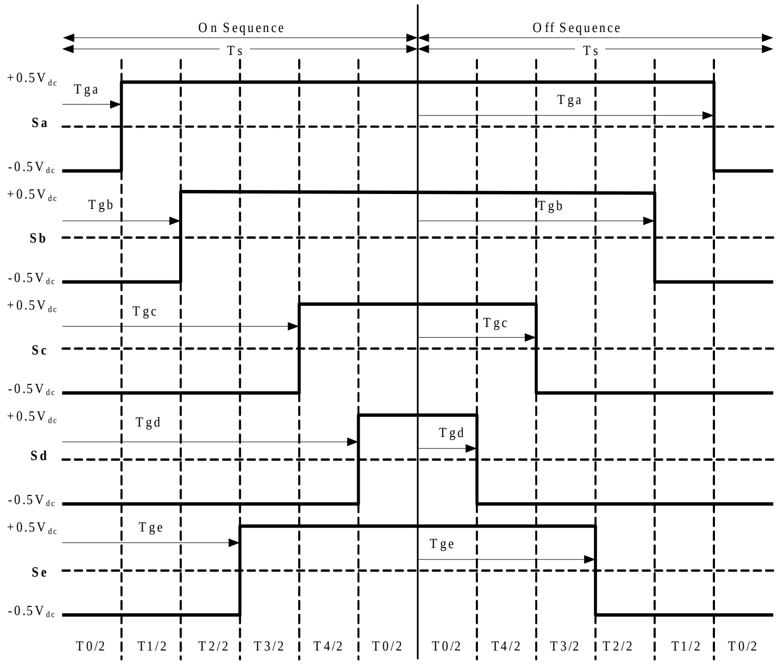

Fig.1. Switching Patter for Five Phase VSI using TESVPWM

IV. SIMULATION RESULT AND DISCUSSION

For the validation of concept and to provide the desired output results, matlab/simulink model for five phase VSI is displayed in fig. 2. The reference voltages at input for all the five phase sinusoidal are developed utilizing function matlab block at 72^0 shifted in phase.During the simulation process for THD analysis of five phase VSI at load, generated switching is shown in figure 3.

Fig. 4 displays offset time signals after calculation and it display the maximum and minimum of offset as well as offset time signal while the resultant modulating signalsubsequently including offset waveform to analogous time waveform for every phase is represented byfig. 5. Fig. 6 & 7 represents the output voltage across load without and with filter.

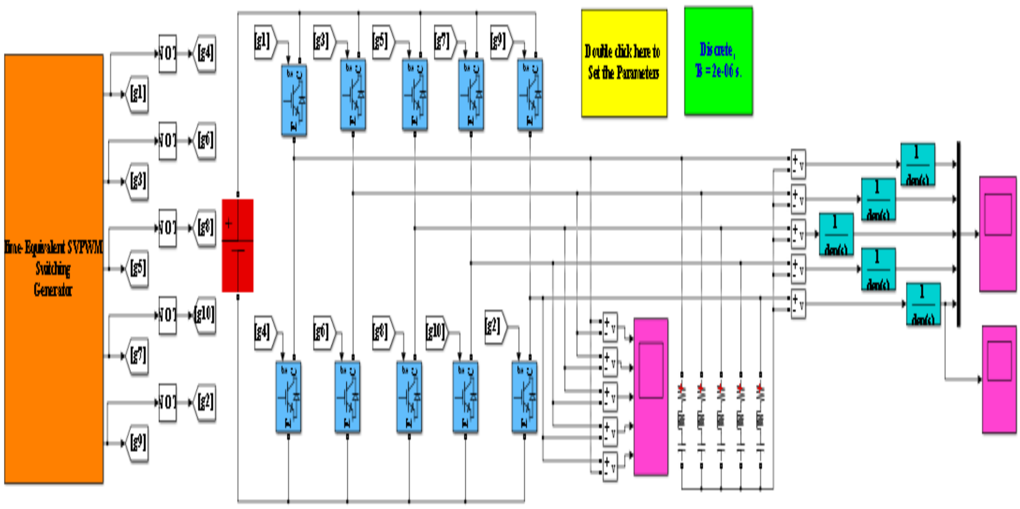

Fig.2.Matlab/Simulink Model for Five Phase VSI

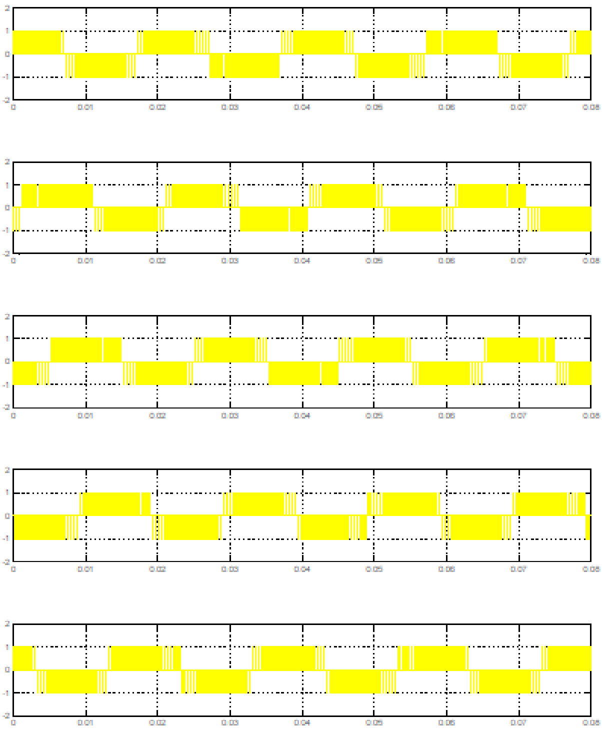

Fig.3.Generated Switching During Simulation

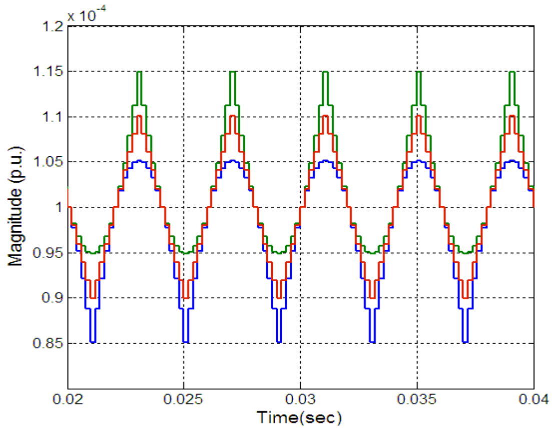

Fig.4.Offset Time Signals

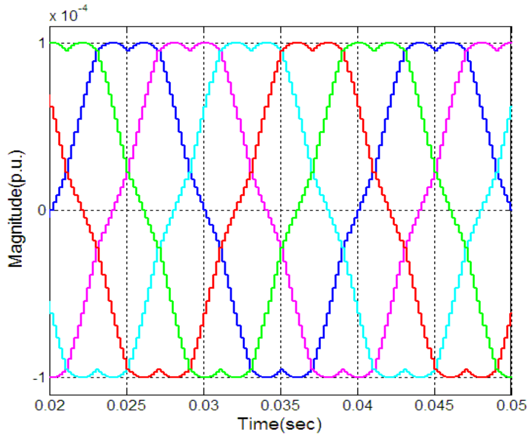

Fig.5.Modulating Signals

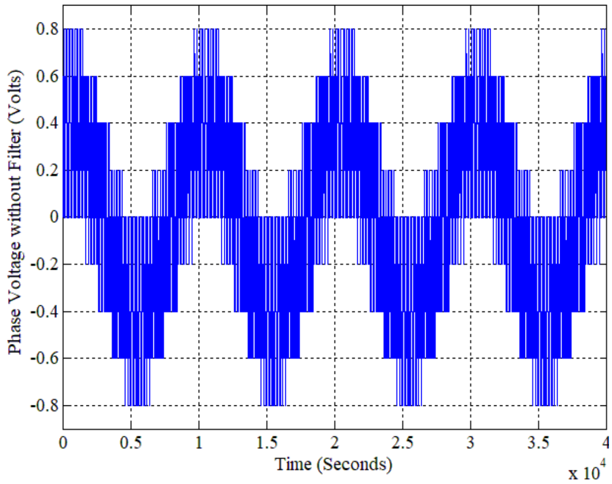

Fig.6.Output Voltage AcrossLoad without Filter (Volts)

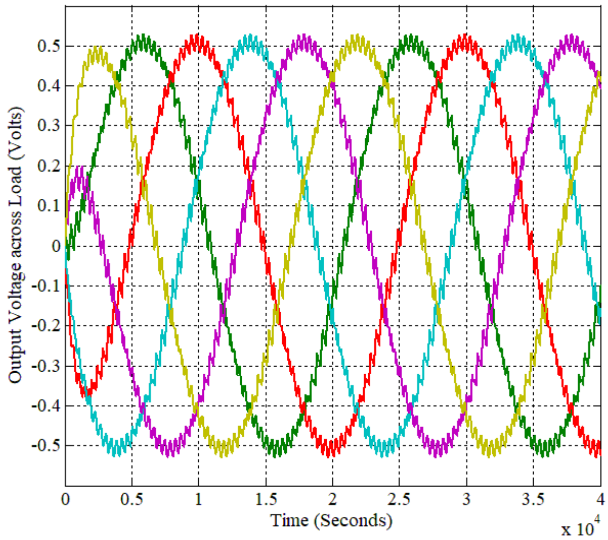

Fig.7.Output Voltage across Load(Volts)

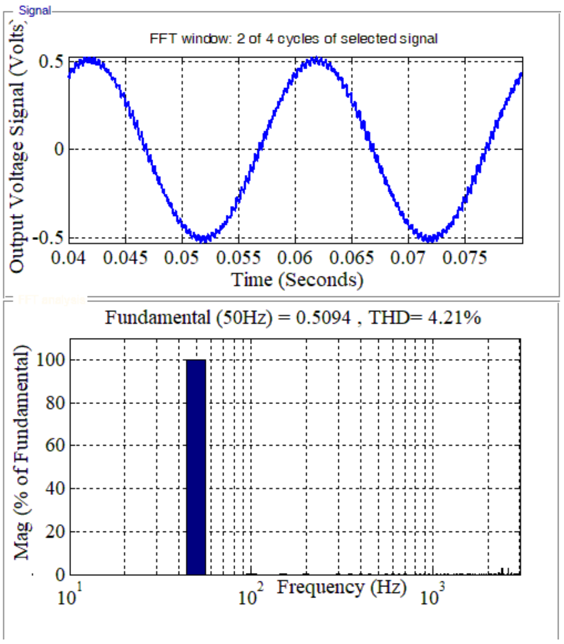

Fig.8.Spectrum of Harmonicwith FFTfor Output Phase Voltage

The simulation attributes are dc-link voltage, switching frequency and fundamental frequency which are set as unity, 5 kHz and 50 Hz respectively. Figure 8 represent the harmonic spectrum of voltage ‘a’ consisting FFT analysis for the output phase It has a only fundamental voltage having amplitude of 0.3602 per unit root mean square (0.5094 peak) at frequency 50 Hz. Total distortion inharmonic(THD) in yielded output is 4.21% of the fundamental. The output is clearly sinusoidal.

V. CONCLUSION

In this article, THD analysis is presented of five phase VSI at load using time equivalent space vector PEM scheme. The author found the results are satisfactory, sinusoidal and have least THD at load which is equal to 4.21%. The scheme is reliable, simple in implementation and suited for majorpower intermediate voltage utilities. The outcome can be verified experimentally in near future.

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