ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

Space Vector Modulation Based Zscc Reduction between Parallel Inverters and Motor Control

Navadeep.S[1], Mr.R.Karthik[2]

Pg Scholar, Department of EEE, CSI College of Engineering, Ketti [1]

Assistant Professor, Department of EEE, CSI College of Engineering, Ketti [2]

Abstract: The Space vector Modulation (SVM) is most appropriate modulation technique used for power converters/inverters among the various Pulse Width Modulation (PWM) techniques. SVM plays major role in the reduction of Total Harmonic Distortion (THD) due to rapid switching inherent and it is well suitable for motor applications rather than other PWM techniques. Harmonics is one of the major drawbacks in most of the application. SVM has the major advantage is that complementary operation of switches takes place in a leg that is only one switching device is made to turn on at a particular period. The proposed model has the effect of eliminating the lower order harmonics using SVM technique and the effect of Zero Sequence Circulating Current (ZSCC) when inverters are connected in parallel. MATLAB/Simulink is used develop the model. Results that were obtained from the simulation confirmed the performance and effectiveness of proposed method.

Keywords: Space Vector Modulation, Inverters, Harmonic elimination, Pulse Width Modulation, Zero Sequence Circulating Current

I. INTRODUCTION

Inverters/converters plays major role in the field of power electronics, the inverters in the power electronic domain denotes a class of power conversion(Power Conditioning) circuits which are required for converting from one source to other either from dc to ac and vice versa depending on the source given to the circuit. The inverters were evolved in the year 1960 [1]. Inverters are broadly categorized depending on the supply they are voltage source (VSI) and current source inverters (CSI).In voltage source inverter the input is provided as dc voltage supply and one can similarly think of a current source inverter (CSI), where the input to the circuit is a current source. The VSI has the direct control over the output (ac) voltage where as CSI controls output ac current. The output voltage waveform shape of an ideal VSI is independent of load connected at the output. VSI are mainly classified into two categories mainly based on the gate pulses. Gating pulses are of PWM based and square pulses. Based on power conditioning they are broadly categorized in to three uncontrolled, semi controlled and fully controlled. In case of uncontrolled and semi controlled the output ac voltage is uncontrolled and partially controlled but in the case of fully controlled converter the output voltage is fully controlled and which is most preferable. For large power conversion it requires inverters connected back to back .Parallel operation of inverter/converter is employed in large power applications. The important drawback of inverters is that it contains harmonics of lower order when they are applied to lower or medium power applications. These lower order harmonics are caused due to different modulation techniques. The lower order harmonics can be effectively minimized using PWM technique .The harmonics are minimized by varying the width of pulse using different PWM techniques. When inverters are connected back to back Zero sequence path is established between the inverters the major case for zero sequence circulating current is zero sequence harmonic. One simplest form of minimizing the zero-sequence circulating current is to remove the zero-sequence harmonics within the harmonic- elimination region which is said to be Selective Harmonic Elimination PWM technique (SHEPWM).

When inverters are connected in parallel they establish two modes they are with zero sequence circulating current mode and without zero sequence circulating current mode. The most preferable technique is with zero sequence circulating current rather than without zero sequence modes in which the parallel connected inverters are operated simultaneously and the power factor and efficiency can be increased and they have appropriate control over the output voltage. Different PWM techniques such as Sinusoidal Pulse Width Modulation (SPWM), Discontinuous Pulse Width Modulation (DPWM), are used however they have limitations that when the quality of carrier wave is decreased output voltage quality of inverter is degraded.

The evolution of SVM which overcome the drawbacks of different PWM techniques. Parallel operation of inverters/converters can be employed in motor drive systems rectifiers, micro grid systems, distributed generation systems, power systems, and distributed uninterrupted power systems. Among all the applications Variable Speed Drives (VSD) perform dominant role which is prescribed using different modulation technique. Where the VSD's are capable of changing the frequency and voltage rapidly depend upon the speed and other parameters. In SVM the entire unit of inverter is

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

considered to be one. Other than PWM technique SVM has finite number of switching states. In which they consist of six active vectors and two zero vectors, totally eight switching states.

This SVM technique has an advantage that it can be expanded from existing three phase inverters to multilevel inverters depending on its parameters and usage. Minimization of the harmonic content in the power electronics circuits is tedious and which lead to major power quality issue. The harmonics can be minimized using several techniques they are as follow as HEPWM, SHEPWM, usage of Isolation transformer at the output side, etc., among the all Selective Harmonic Elimination (SHE) technique is most preferable for harmonic reduction. Where the usage of transformer makes system bulkier. The switching pulses are programmed by using Optimization algorithms [5], [6]. When numbers of inverters are connected in parallel ZSCC problem arises between the inverters [7]. The ZSCC can be reduced by connecting current-sharing inductors. The main cause for ZSCC is triplen harmonics . The proposed real-time method reduces the triplen harmonics which in turn reduces the ZSCC.

The rest of this paper is organized as follows. Section II reviews the theoretical background of the SVM technique. The implementation of SVM in three phase inverter is detailed in Section III. Section IV presents the simulation and experimental results of the proposed method. The final section contains conclusions of this paper.

II. SPACE VECTOR MODULATION

SVM is similar to that of Sine+3rd harmonic PWM technique which is the modification of sinusoidal PWM technique. The SVM technique differs from the actual PWM by implementation. In SVM the combination of three phases is considered to be one vector. In which the three phase inverter instantaneous voltage differs from phase voltages. However the instantaneous magnitude of inverter is matched with the phase voltage at six discrete instants at the instant one of the phase voltage has maximum positive or negative peak magnitude and other two have half of the peak magnitude where the polarity of peak magnitude varies from the other two phases. Initially three phases are submerged into two phases for simplicity [2]. Here space vectors are demonstrated as time varying quantities which always sum to zero and are separated by 120 degree are expressed as space modulating vectors. The three phase systems are given as *Va(t), Vb(t), Vc(t)*) can be represented uniquely by a rotating vector,

$$V=VA(t) + VB(t)\, e^{j2\Pi/3} + VC(t)\, e^{-j2\Pi/3} \quad (1)$$

Where,

$$VA(t) = Vm \sin\omega t \quad (2)$$

$$VB(t) = Vm \sin(\omega t - 2\pi/3) \quad (3)$$

$$VC(t) = Vm \sin(\omega t + 2\pi/3) \quad (4)$$

Here three phase frames are converted into two phase frames by using different transformation. The different transformation for transforming static to rotating frames are Park, Kron, Clarks transform etc., Among the above Clarks transformation is preferred for three phase to two phase transformation. In a three-phase system, the vectorial representation is achieved by the 3/2 transformation given in figure1.

$$\begin{bmatrix} A_\alpha \\ A_\beta \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix}$$

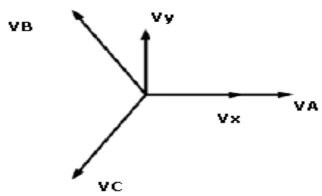

Figure1. Relation between Stationary frames and rotating xy frames

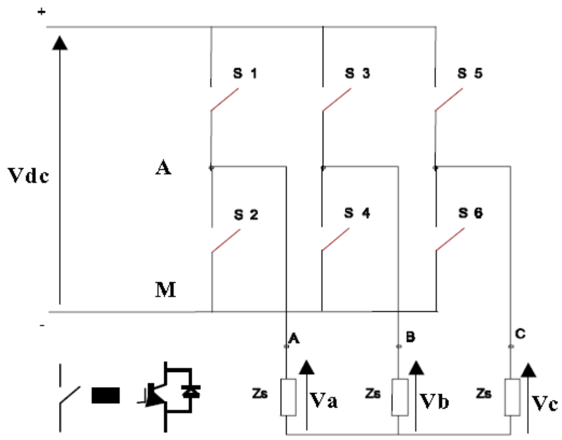

Figure2. Three phase inverter configuration

The orthogonal two phase system are given as (Vx, Vy), Where, V=Vx+jVy (3) The VSI configuration is shown in figure 2. Shows a three-phase voltage source inverter whose output terminals are fed to the three terminal of a three-phase ac machine. Three phase normal inverter is used here and the inverter is connected to the voltage source of Vdc. From the knowledge of 3-phase voltage source inverters, it may be obvious that the two switches of each inverter leg don't conduct at the same instant. Thus the six switches of the three legs will have a probability of eight different switching combinations are stated as shown in table 1.

TABLE I
switching logic and voltage magnitude of SVM

Voltage in Vectors	Switching Vectors			Line - Neutral Voltage			Line - Line Voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

Among the eight combinations, two combinations in which when all the upper switches or all the lower switches of each pole are simultaneously turned ON at the same instant result in zero output voltage from the inverter. These two combinations are referred as **null states/vectors** of the inverter. The remaining six switching combinations, wherein either two of the high side (upper) switches and one of the low side (lower) switch conduct, or vice-versa, are **active states/vectors**. The active voltage vectors have the magnitude of V_{dc} and the null voltage vectors consist of zero magnitude. The non-zero vector namely V1 to V6 shape the hexagon axis as shown in figure 3 and the angle between two non-zero vectors is 60 electrical degree. The null vectors V0 and V7 represent the short circuit on the output, where others are vectors in x-y plane. These eight vectors are called the space vectors.

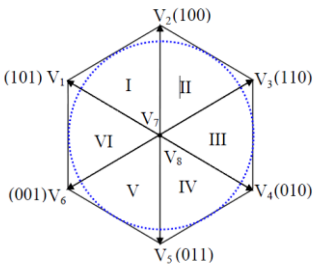

Figure3. The voltage space-vectors output by a 3-phase VSI inverter

III. BLOCK DIAGRAM

The proposed technique is to reduce the zero sequence circulating current between the inverters when more than two inverters connected parallel for bulk power application. In advance they are quite different from the different PWM techniques which can be employed for motor control applications by minimizing the Total harmonic distortion. The overall system consists of a Space Vector PWM (SV-PWM) pulse generator, power inverter module and a three phase induction motor load

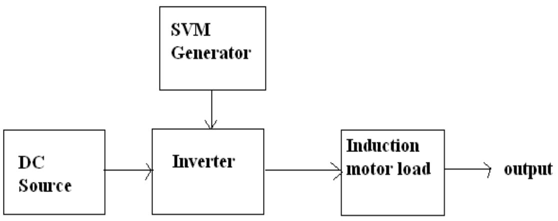

Figure4. Block diagram of the system

Figure 4 gives the one line diagram of an inverter connected to a motor load which is lead by the SVM pulses. In this category minimization of THD is only concentrated and in which they does not have any effect of Zero Sequence Circulating Current (ZSCC) since they have only one inverter configuration.

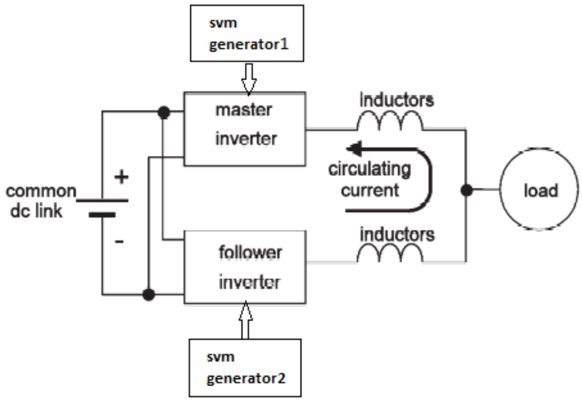

Figure5. Block diagram for two inverters that were connected in parallel

In this session the block Figure 5 represents the overall operation of the proposed system. The SVM pulses are generated using SVM pulse generator and those where given as input to the inverters. The inverters are operated between the common dc and the ac bus. The resistance of both current sharing inductors and inverters is negligible. Three phase induction motor load is used here and effect of Zero Sequence Circulating Current (ZSCC) and the harmonics are studied using the proposed system.

IV. SIMULATION AND RESULTS

As shown in the figure 6(a) two three phase inverters are connected in parallel forwarded to a motor load. The inverters are provided with three phase SV-PWM pulses and the zero sequence circulating current is plotted using mathematical model.

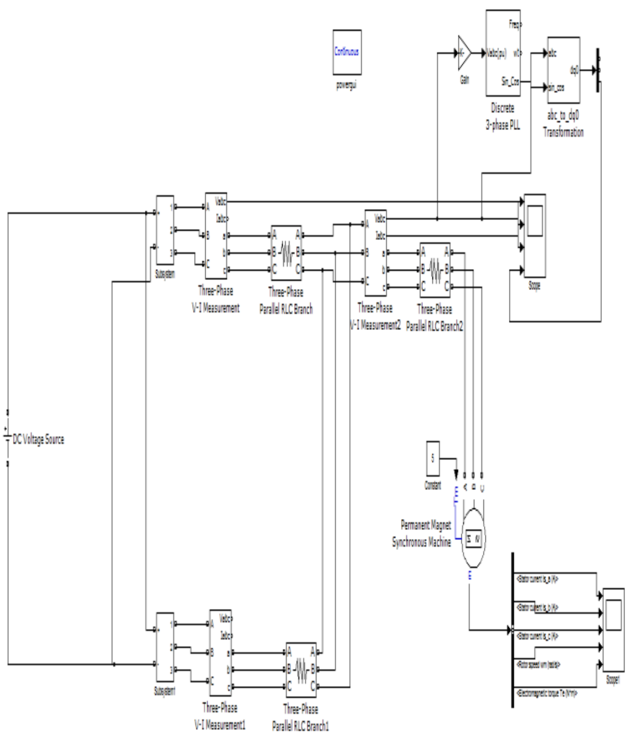

Figure6(a). Parallel inverter connected to motor load.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

As shown in the figure 6(b), the three phase SV-PWM switching signals are sent out of the SV-PWM function generator to the input ports of the multiplexer. A three phase SVM gated inverter with Permanent magnet Synchronous motor load is considered. A complete mathematical model of the SV-PWM is obtained and simulated using MATLAB/Simulink to estimate the performance of a three phase inverter. Similarly two inverters are connected in parallel provided with SVM to study the ZCSS performance and which is plotted in figure 9.

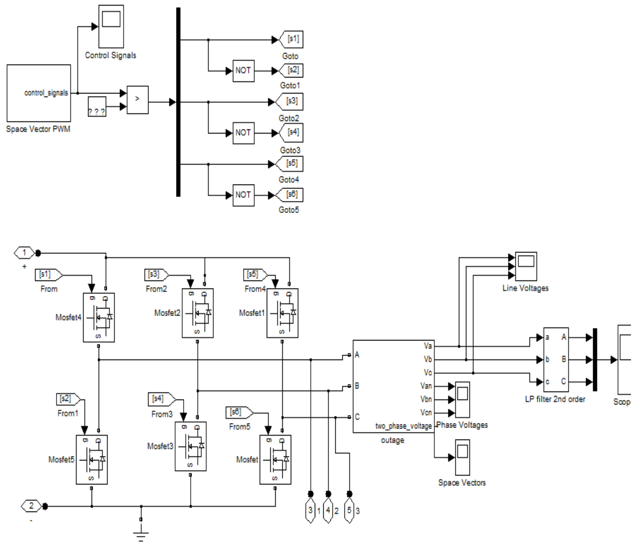

Figure6(b). Simulation of three phase inverter with SVM technique

RESULTS

Figure 7 shows the induction motor stator current produced in the system

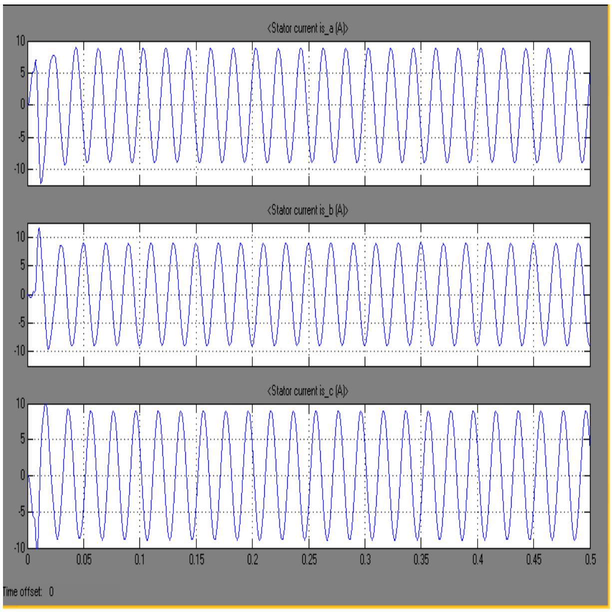

Figure7. Motor Current results

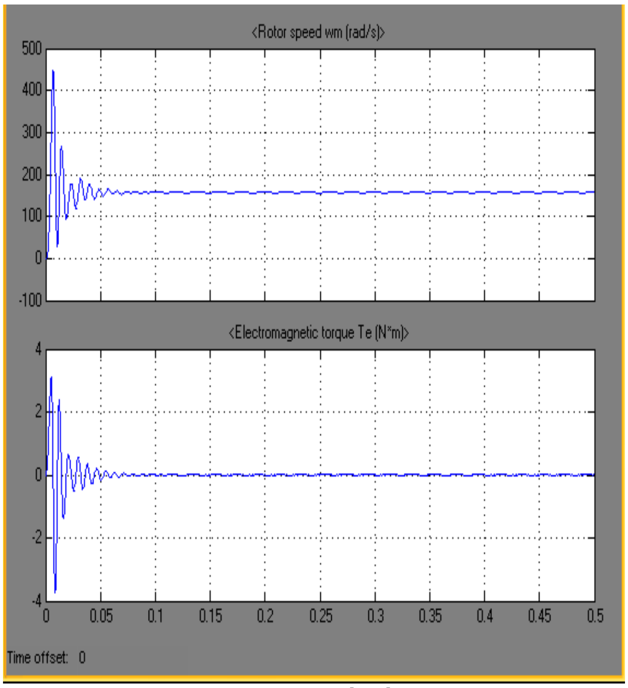

Figure8. Motor speed and Torque

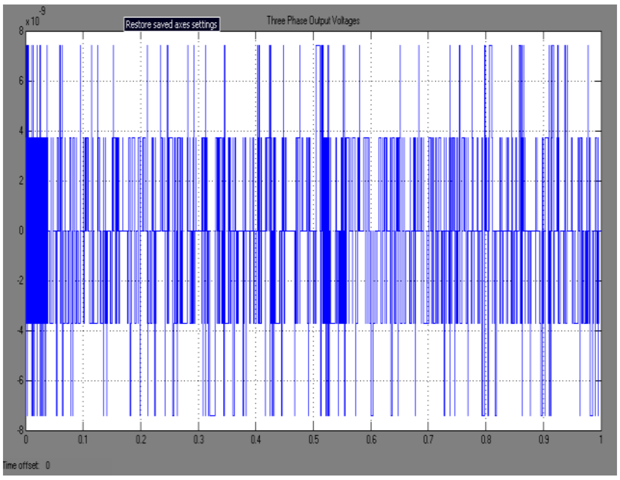

Figure9. Zero Sequence Circulating Current

Figure 8 represents the speed and the electromagnetic torque of the motor. The THD values are calculated after the development of the system and they are tabulated to analyse the performance of the system. The THD is mainly depends on the stator phase output current. The harmonics present in the three phases are obtained using the simulation results. The simulation result concludes that harmonic content in the system is less when compared with different PWM technique. The tabulation shows the values of the harmonics in the system and also the system appendix

TABLEII
THD analysis of load currents

	Voltage in volts	Frequency in Hertz	M.I	THD of phase current
Phase a	400	50	0.8	0.48
Phase b	400	50	0.8	0.47
Phase c	400	50	0.8	0.49

V.CONCLUSION

Here the proposed SVM based three phase inverter system is designed and simulated using MATLAB/Simulink. Rather than comparing with different PWM technique such as SHEPWM, SPWM, the SV-PWM has the best result of reduction of harmonics. In which the harmonic content is brought down from 17.09% in SV-PWM when compared to conventional PWM techniques. The proposed technique eliminates Zero Sequence Circulating Current (ZCSS) at MI around unity and medium or low MI**.** This model can be applied to various motor applications and also to non-linear loads to get a less distortion output. The main advantage contributes to bump less transfer. Experimental results that were obtained from the SV-PWM analysis validate the performance and effectiveness of the proposed method for motor control and ZCSS reduction in parallel inverter operations.

ACKNOWLEDGMENT

I take this opportunity to express my sincere gratitude and thanks to Mrs. P. Pradeeba M.E. , head of department electrical and electronics engineering for her able guidance in the execution of my project and Mr. B. Murthy M.E., project coordinator department electrical and electronics engineering for assisting in the synchronization of work done at various stages of the project work. Mr. R.Karthik M.E., assistant professor department electrical and electronics engineering for his great hand in guiding my project in the right path and obtaining a valid result for the work done so far.

REFERENCES

[1] B. K. Bose, “Adjustable speed AC drives – A technology status review,” Proceedings of the IEEEIECON, vol. 70, pp. 116-135.

[2] V.G. Agelidis and M. S. A. Dahidah, “Selective harmonic elimination PWM control for cascaded multilevel voltage source converters: A generalized formula,” IEEE Transactions on Power Electronics, vol. 23, no. 4, pp. 1620 – 1630, 2008.

[3] V. G. Agelidis, A. Balouktsis, I. Balouktsis, and C. Cossar, “Multiple sets of solutions for harmonic elimination PWM bipolar waveforms: Analysis and experimental verification,” IEEE Trans. Power Electron., vol. 21,no. 2, pp. 415–421, Mar. 2006.

[4] P. N. Enjeti, P. D. Ziogas, and J. F. Lindsay, “Programmed PWM techniques to eliminate harmonics: A critical evaluation,” IEEE Trans. Ind.

[5] J. R. Wells, B. M. Nee, P. L. Chapman and. T. Krein,“ Selective harmonic control: a general problem formulation and selected solutions,” IEEE Transactions on Power Electronics, vol. 20, pp.1337-1345, Nov. 2005.

[6] Mehrizi-Sani and S. Filizadeh, “An optimized Space Vector Modulation Sequence for Improved Harmonic Performance,” IEEE Transactions on Industrial Electronics, vol. 56, no. 8, pp. 2894-2903, Aug. 2009.

[7] Tsung-Po Chen, „“Zero-Sequence Circulating Current Reduction Method for Parallel HEPWM Inverters Between AC Bus and DC Bus”“ in IEEE Transactions On Industrial Electronics, Vol. 59, No. 1, January 2012.

[8] S. R. Bowes and S. Grewal, “Novel space-vector-based harmonic elimination inverter control,” IEEE Trans. Ind. Appl., vol. 36, no. 2,pp. 549–557, Mar./Apr. 2000.

[9] Matsui, K., Murai, Y., Watenabe, M., Kaneko, M., and Ueda, F.: ‘A pulsewidth-modulation inverter with parallel connected transistors using current-sharing reactors’, IEEE Trans. Power Electron., 1993, 8, pp. 186–191.

[10] M. Hashii, K. Kousaka, and M. Kaimoto, “New approach to a highpower GTO PWM inverter for ac motor drives,” IEEE Trans. Ind. Applicat., vol. IA 23, no. 2, pp. 263–269, 1987.

[11] Park, R.H., “Two-Reaction Theory of Synchronous Machines”, AIEE Trans. No.48, 1929, pp.716-730 and no. 52, 1933, pp.352-355.

[12] Y.Murai, Y.Tsunehiro, “Improved PWM Method for Induction Motor Drive Inverters”, IPEC, Tokyo, 1983, pp.407-417.

[13] Y.Murai, Y.Gohshi, K.Matsui, I.Hosono, “High-Frequency Split Zero-Vector PWM with Harmonic Reduction for Induction Motor Drive”, Trans.on IA, vol.28, no.1, Jan/Feb. 1992, pp.105-112.

[14] Bowes, S.R.; Yen-Shin Lai, “The relationship between space-vector modulation and regular-sampled PWM“, IEEE Trans. on Industrial Electronics, vol. 44 5, pp. 670 -679.

[15] Jian Sun; Grotstollen, H. ,”Optimized Space Vector modulation and regular-sampled PWM: a Reexamination, Conf.Rec. of IEEE IAS '96., vol.2 , pp. 956 –963.

[16] T.-P. Chen and C.-H. Liu, “A load power angle tracking harmonic elimination discontinuous PWM strategy for switching loss minimization,” in IEEE PESC Rec., Vancouver, BC, Canada, Jun. 2001, pp. 96–101.

BIOGRAPHY

S. NAVADEEP received the B.E., degree in electronics and communication engineering from Sengunthar engineering college Tiruchengode under Anna University Chennai in 2012. From September 2012 to 2014 , he pursued his masters degree in power electronics and drives from C.S.I college of engineering Ketti under Anna University Chennai. His research interests include power-factor-correction circuits, active-power filters, uninterruptible power systems, distributed power systems, and nonlinear control.