Simulation of Five Phase Voltage Source Inverter with Different Excitation for Star Connected Load

M.A Inayathullaah [#1], Dr. R. Anita[*2]

[#] Department of Electrical and Electronics Engineering,
Periyar Maniammai University, Vallam,
Thanjavur Dist., Tamilnadu, India.
[1]mailtoinayath@yahoo.com

[*] Professor and Head of the Department,
Department of Electrical and Electronics Engineering,
Institute of Road and Transport Technology,
Erode Dist., Tamilnadu, India.
[2]anita_irtt@yahoo.com

Abstract— In order to reduce the torque ripple and harmonics for smooth operation of the machine and to reduce the amount of heat generated the motor has to be supplied with multi phase supply greater than three phase supply. Selection of even number of phases should be avoided, because it decreases the performance of the motor as poles coincide with each other. So, Five Phase Supply is preferred. A five phase five leg 10 switch inverter fed five phase star connected load operating with five different excitation is simulated and compared with that of three phase conventional inverter.

Keyword - Five Phase Supply (Voltage, Current and Power Relations), Five-Leg VSI, Excitation.

I. INTRODUCTION

Five phase ten-switch inverters are used in five phase VSI and CSI inverters [1]-[8]. For this reason, many researches have been recently investigating different types of fault that commonly occur in these inverters. Of these, the improvement of the output waveform and reduce harmonic distortion is very important. Therefore, using electronic devices, various excitation of inverters are presented, which can reduction harmonic and can lead to improve the output voltage too. Although, this inverters increase the quality of output voltage and current, but leads to other disadvantages, including increased size, weight and price [9]-[12]. In this paper, a new method for selecting conductive angle based on the power factor of load is presented. The conductive angle can vary from 36° to 180° according to these parameters. To achieve low THD and high RMS of output voltage, the conductive angle is changed from 36° to 180° for different power factor of lead and lag loads with simulation.

II. STRUCTURE OF THREE PHASE INVERTERS

In some structures, the voltage source is divided into two equal parts, and the junction of these two sources, are connected to ground as a reference [13] for supplying balanced load.

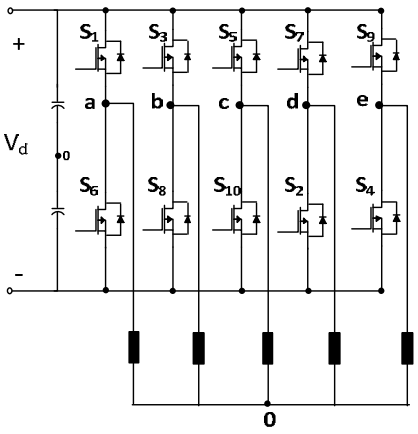


Fig. 1(a). Five phase inverter with Load

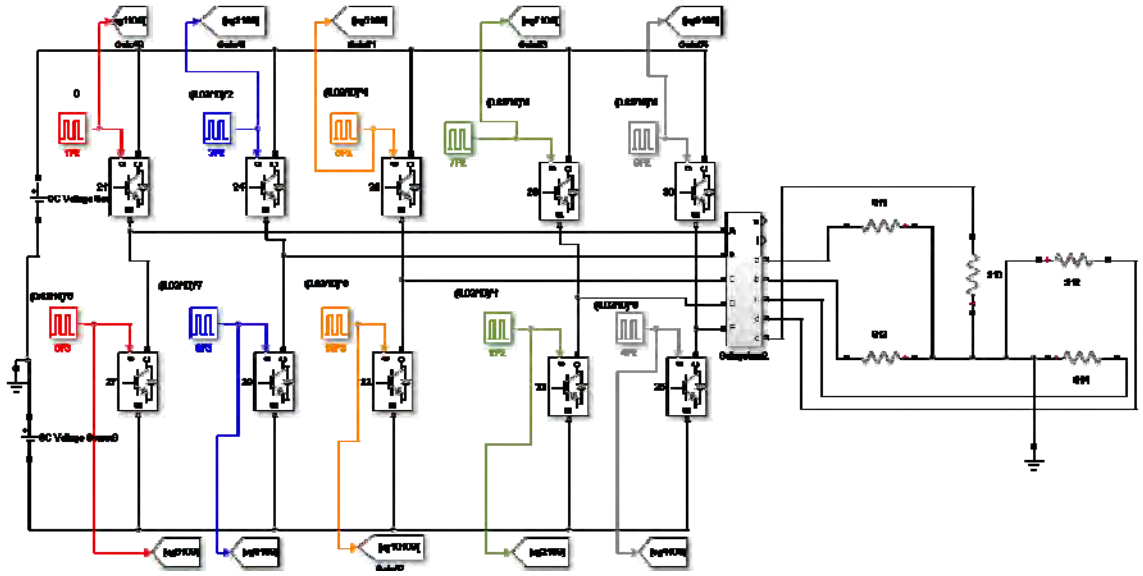


Fig. 1(b). Simulink View of five phase inverter with Load

There are five leg for five phase supply. Each leg has two switches with antiparallel diodes across each switch. The load considered here may be resistive or inductive or a motor load. The gating signal of five phase inverters should be advanced or delayed by 72°. With respect to each other to obtain a five phase balanced (fundamental) voltages. If the five phase output voltages are not perfectly balanced in magnitudes and phases, there are not balanced. A five phase output can be obtained from a configuration of ten transistors and ten diodes as shown in Fig. 1(a). and the Simulink view of the topology is shown in Fig. 1(b). Control signals can be applied to the switches at 36°, 72°, 108°, 144° and 180°. Their performances are compared in this paper.

III. MODES OF EXCITATION

The modes of operation of an inverter is a vital parameter since it determines the nature of current and indirectly in inverter fed drive, the modes of excitation will decide the nature of the air gap flux and inturn the performance of the drive.

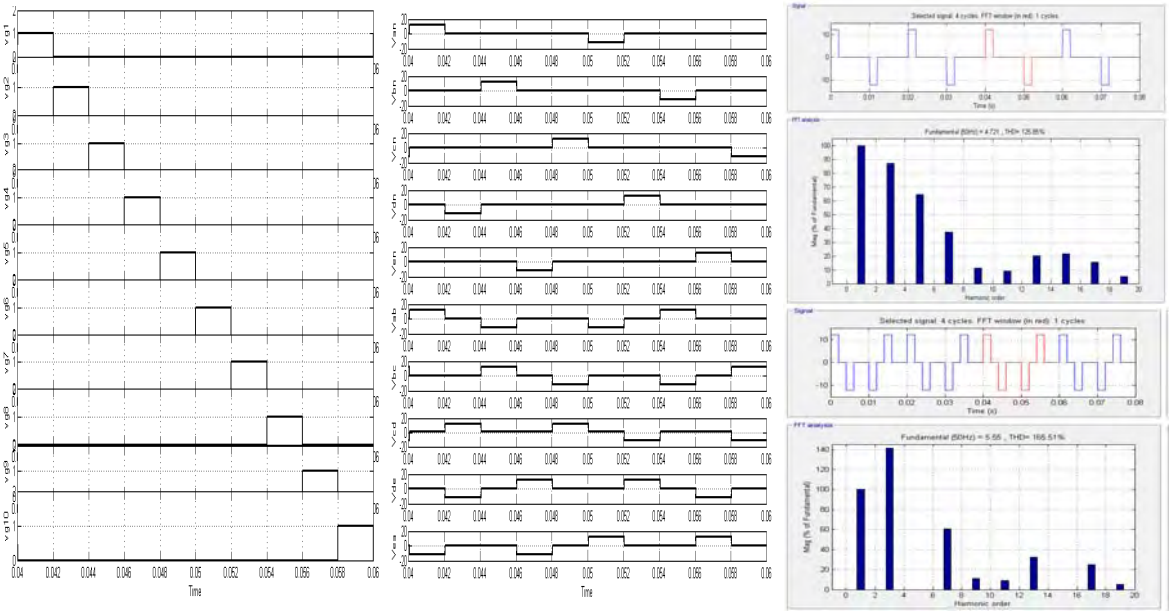
A. 36 Degree Mode of Conduction

Each switches conducts for 36° as shown in conduction Table I. Only one transistor remains on at any instant of time.

TABLE I
Conduction table for 36°

Phase	36	72	108	144	180	216	252	288	324	360
PH1	S1					S6				
PH2			S3					S8		
PH3					S5					S10
PH4		S2					S7			
PH5				S4					S9	

When the switch S1 is switched on, the terminal ‘a’ is connected to the positive terminal of the DC input voltage (V_d). When the switch S1 is switched on, the terminal ‘a’ is connected to the negative terminal of the DC input voltage (V_d).There are ten modes of operation in a cycle and the duration of each mode is 36°. The switches of any leg of the inverter (S1 and S6, S3 and S8, S5 and S10, S7 and S2 or S9 and S4) cannot be switched on simultaneously to avoid short circuit across the supply dc voltage. Similarly, to avoid undefined states in the output ac voltage the switches of any leg of the inverter cannot be switched off simultaneously.



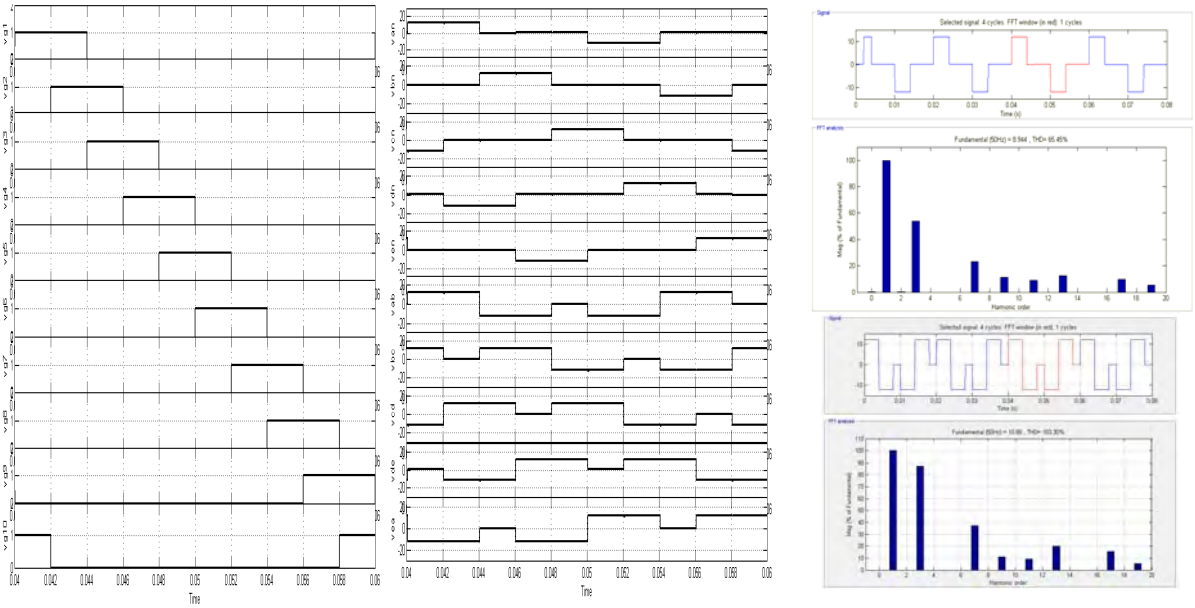
(a) 36° Switching pulses (b) 36° Phase and Line Voltages (c) FFT of 36° Phase and Line voltage

Fig. 2. Five phase inverter with Load for 36° Excitation.

The phase voltages and line voltages are shown in Fig. 2. The total harmonic distortion (THD) for phase voltage is 125.83% and for line voltage is 165.51%. Since the THD is far beyond the acceptable level this scheme of conduction is not in use.

B. 72 Degree Mode of Conduction

Each switches conducts for 72° as shown in conduction Table II. Only two transistor remains on at any instant of time.



(a) 72° Switching pulses (b) 72° Phase and Line Voltages (c) FFT of 72° Phase and Line voltage

Fig. 3. Five phase inverter with Load for 72° Excitation.

The waveforms for the switching pulses, phase and line voltages and corresponding FFT analysis for 72 degree mode of excitation is shown in Fig.3.

TABLE II
Conduction table for 72°

Phase	36	72	108	144	180	216	252	288	324	360
PH1	S1	S1				S6	S6			
PH2			S3	S3				S8	S8	
PH3	S10				S5	S5				S10
PH4		S2	S2				S7	S7		
PH5				S4	S4				S9	S9

The total harmonic distortion (THD) for phase voltage is 65.45% and for line voltage is 103.30%. Since the THD is far beyond the acceptable level this scheme of conduction is not in use.

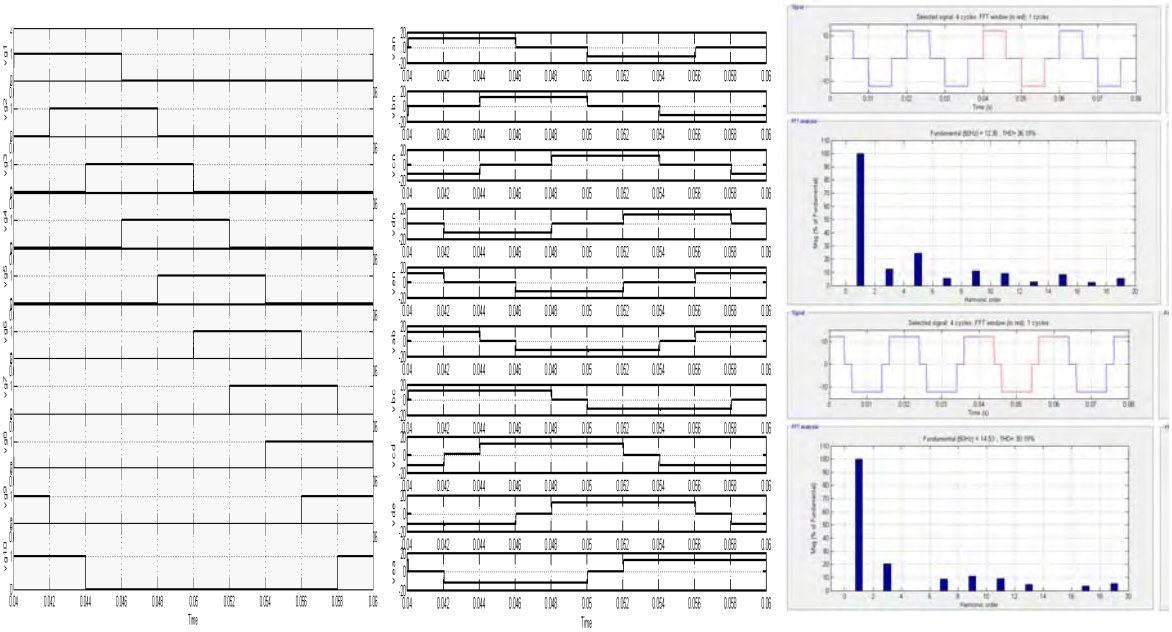
C. 108 Degree Mode of Conduction

Each switches conducts for 108° as shown in conduction Table III. Only three transistor remains on at any instant of time.

TABLE III
Conduction table for 108°

Phase	36	72	108	144	180	216	252	288	324	360
PH1	S1	S1	S1			S6	S6	S6		
PH2			S3	S3	S3			S8	S8	S8
PH3	S10	S10			S5	S5	S5			S10
PH4		S2	S2	S2			S7	S7	S7	
PH5	S9			S4	S4	S4			S9	S9

The wave forms for the switching pulses, phase and line voltages and corresponding FFT analysis for 108 degree mode of excitation is shown in Fig.4.



(a) 108° Switching pulses (b) 108° Phase and Line Voltages (c) FFT of 108° Phase and Line voltage

Fig. 4. Five phase inverter with Load for 108° Excitation.

The total harmonic distortion (THD) for phase voltage is 36.18% and for line voltage is 30.19%. Meanwhile the THD is far lower than the 36 and 72 degree mode of excitation but due to high harmonic content in the phase voltage this scheme of conduction is used rarely.

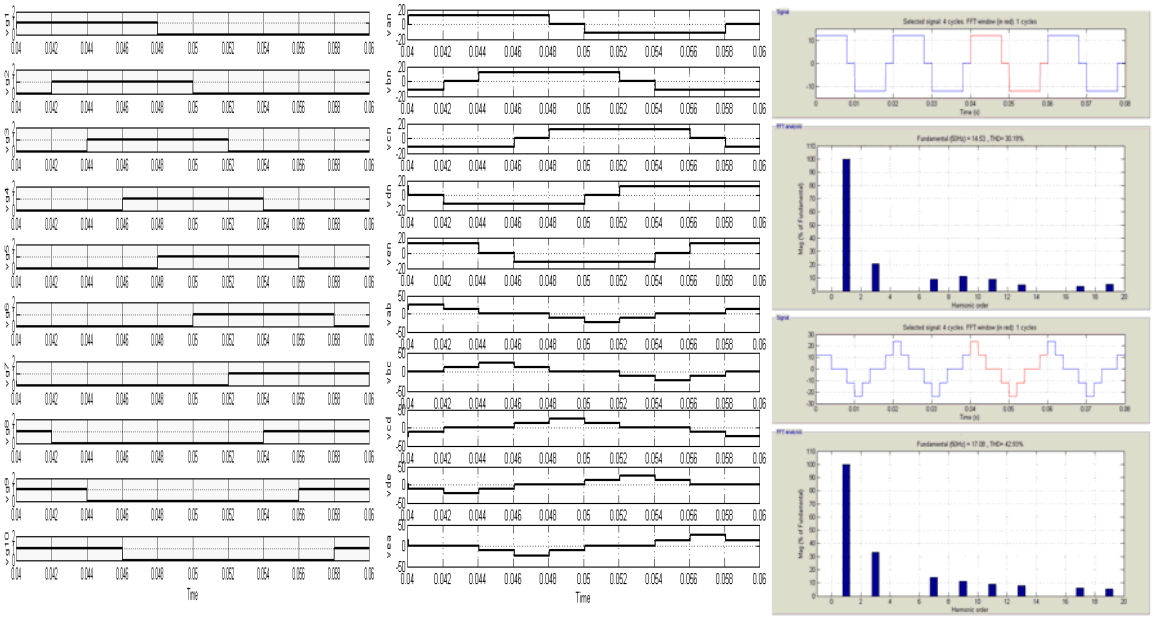
D. 144 Degree Mode of Conduction

Each switches conducts for 144° as shown in conduction TABLE IV.Only four transistor remains on at any instant of time.

TABLE IV
Conduction table for 144°

Phase	36	72	108	144	180	216	252	288	324	360
PH1	S1	S1	S1	S1		S6	S6	S6	S6	
PH2	S8		S3	S3	S3	S3		S8	S8	S8
PH3	S10	S10	S10		S5	S5	S5	S5		S10
PH4		S2	S2	S2	S2		S7	S7	S7	S7
PH5	S9	S9		S4	S4	S4	S4		S9	S9

The wave forms for the switching pulses, phase and line voltages and corresponding FFT analysis for 144 degree mode of excitation is shown in Fig.5.



(a) 144° Switching pulses (b) 144° Phase and Line Voltages (c) FFT of 144° Phase and Line voltage

Fig. 5. Five phase inverter with Load for 144° Excitation.

The total harmonic distortion (THD) for phase voltage is 30.19% and for line voltage is 42.93%. The THD level is low in this mode compared to earlier mode of excitation, and so phase voltage harmonics is also less. This excitation is preferred in drive application where high torque is required at comparatively low power.

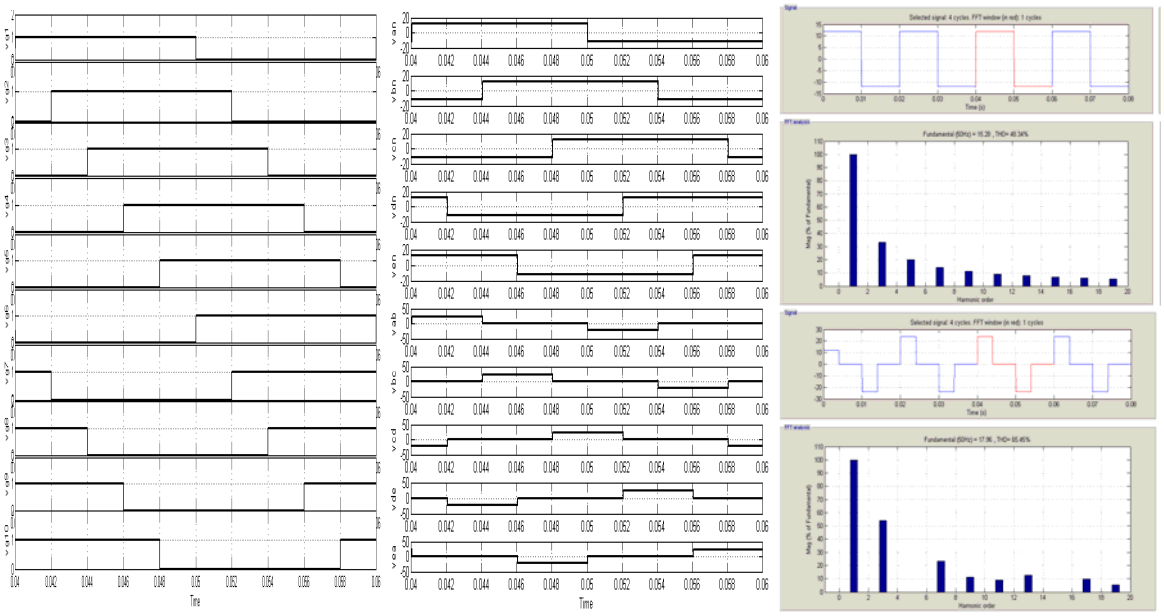
E. 180 Degree Mode of Conduction

Each switches conducts for 180° as shown in conduction TABLE V. All five transistor remains on at any instant of time.

TABLE V
Conduction table for 180°

Phase	36	72	108	144	180	216	252	288	324	360
PH1	S1	S1	S1	S1	S1	S6	S6	S6	S6	S6
PH2	S8	S8	S3	S3	S3	S3	S3	S8	S8	S8
PH3	S10	S10	S10	S10	S5	S5	S5	S5	5S	S10
PH4	S7	S2	S2	S2	S2	S2	S7	S7	S7	S7
PH5	S9	S9	S9	S4	S4	S4	S4	4S	S9	S9

The wave forms for the switching pulses, phase and line voltages and corresponding FFT analysis for 180degree mode of excitation is shown in Fig.6.



(a) 180° Switching pulses (b) 180° Phase and Line Voltages (c) FFT of 180° Phase and Line voltage

Fig. 6. Five phase inverter with Load for 180° Excitation.

The phase voltages and line voltages are shown in Fig. 5. The total harmonic distortion (THD) for phase voltage is 42.93% and for line voltage is 65.45%. Since the THD is far beyond the acceptable level this scheme of conduction is not in use

IV. RESULTS AND DISCUSSIONS

The five phase inverter is supplied with 24V DC voltage. This voltage source inverter feeds a star connected resistive load of 1KΩ. The RMS value of Phase voltage for all the excitation and RMS value of Line voltage for all the excitation at 50Hz frequency are shown in Fig.7 (a). and tabulated in TABLE VI. A similar analysis is done for three phase inverter as shown in Fig.7 (b) for comparing the THD.

TABLE VI
Comparison of three phase and five phase inverters

S.No.	Parameters	Three Phase Inverter		Five phase Inverter				
		120°	180°	36°	72°	108°	144°	180°
1.	RMS Value of Phase Voltage (Van) in volts	9.838	11.27	5.368	7.611	9.305	10.73	12
2.	RMS Value of Line Voltage (Vab) in volts	16.93	19.51	6.305	8.940	10.930	12.604	14.096
3.	THD in Phase Voltage (Van) in percentage	30.90	30.99	125.8	65.45	36.18	30.19	42.93
4.	THD in Line Voltage (Vab) in percentage	30.99	30.90	165.5	103.3	30.19	42.93	65.45

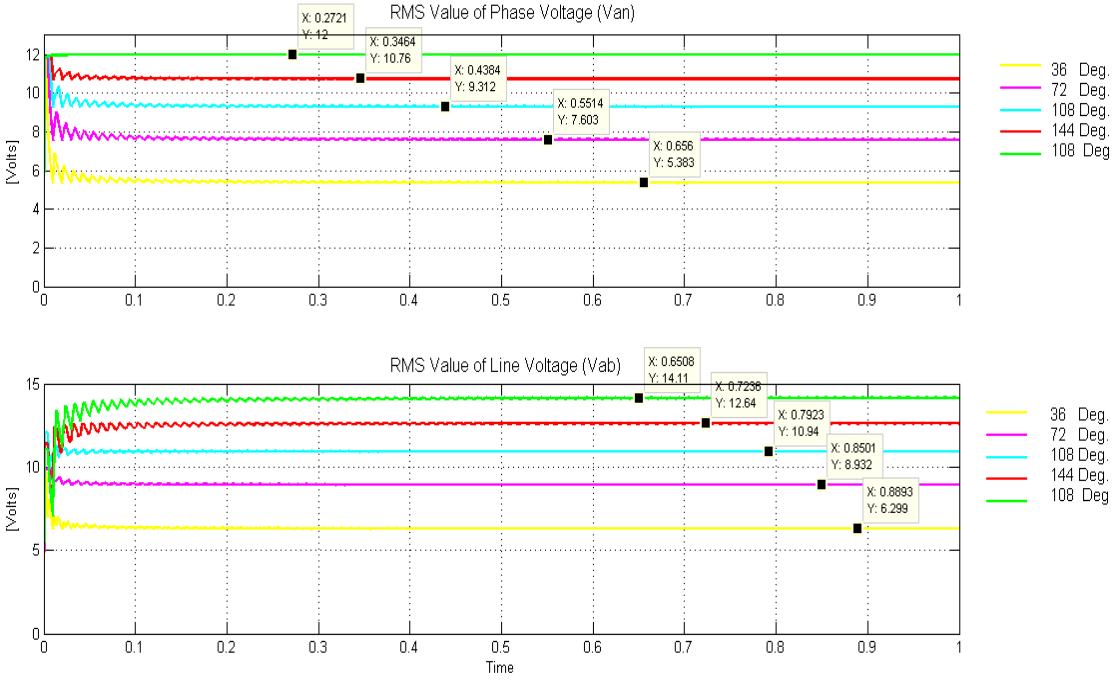


Fig. 7(a). Comparison of phase voltage and Line voltage for five phase Inverter .

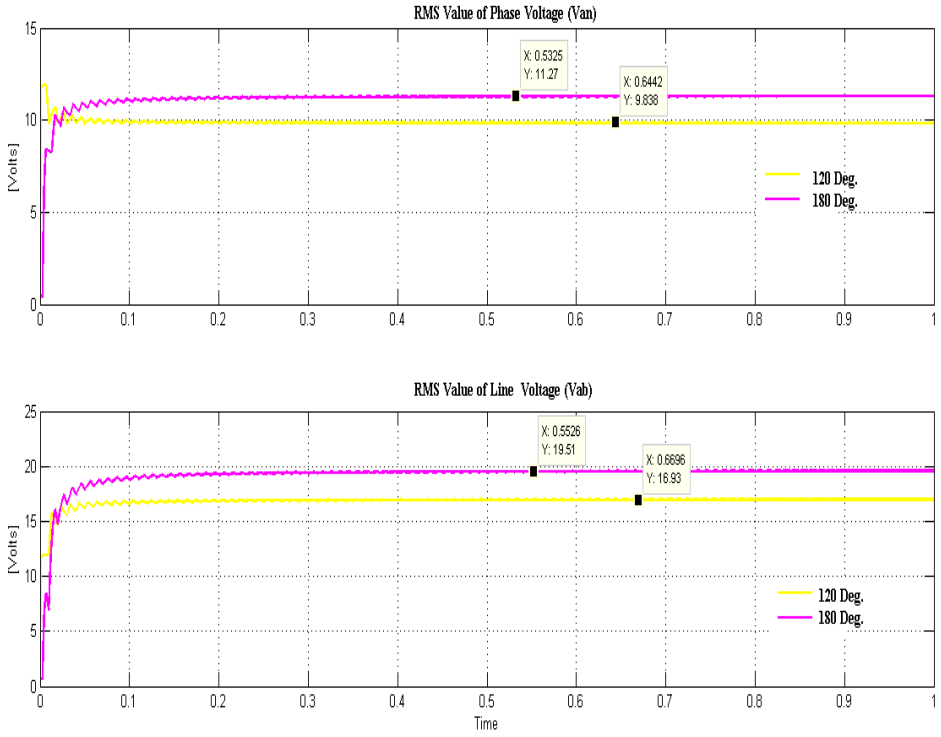


Fig. 7(b). Comparison of phase voltage and Line voltage for three phase Inverter .

It is seen that the RMS value of phase voltage for the five phase 144° degree excitation is more compared to traditional three phase 120° mode. Moreover the THD is also less in five phase 144° degree excitation as compared to traditional three phase 120° mode.

V. CONCLUSION

In this paper five different modes of excitation is compared for a five phase VSI fed inverter feeding a star connected load. It is inferred from the results that out of 36°,72°,108°,144° and 180° , less than 108° degree excitation has THD more than 100% which is not desirable. Comparing more than 108° excitation 108° and 144° degree excitation yields less THD in line to line voltage compared to 180° excitation. But the RMS line voltage and phase voltage are more in 180° excitation. But to avoid commutation problem, a better compromise is done on THD and maximum line to line and phase voltage and 144° excitation is preferred.

REFERENCES

[1] G. Renukadevi, and K. Rajambal, "Field programmable gate array implementation of space-vector pulse-width modulation technique for five-phase voltage source inverter," Power Electronics, IET Journals & Magazines, vol. 7, Issue- 2, pp. 376- 389, Nov. 2014.

[2] O. Dordevic, M. Jones, and E. Levi, "A Comparison of Carrier-Based and Space Vector PWM Techniques for Three-Level Five-Phase Voltage Source Inverters," Industrial Informatics, IEEE Transactions on, Vol. 9, Issue- 2, pp. 609-619, Nov. 2013.

[3] G. Grandi, and J. Loncarski, "Evaluation of current ripple amplitude in five-phase PWM voltage source inverters," EUROCON, IEEE Conference Publications, pp. 1073- 1073, Nov. 2013.

[4] H. Liu, G. Wang, and H.Yu, "Simplified circuit and modulation scheme for five-phase three-level voltage source inverter," Electronics Letters, Vol. 49, Issue- 22, pp. 1404- 1405, Nov. 2012.

[5] M.S.B. Zulkifli, W.N.B.W.A. Munim, H.C.M. Haris, "Five Phase Space Vector Modulation Voltage Source Inverter using large vector only," IEEE Symposium on Computer Applications and Industrial Electronics (ISCAIE), pp. 5-9, Nov. 2012.

[6] Hongwei Gao, Jianyong Su, Guijie Yang, and Jian Liu," SVPWM equivalent algorithm based on carrier for five-phase voltage source inverter" Power Electronics and Motion Control Conference (IPEMC), Vol. 1, pp. 758-769, Nov. 2012.

[7] O. Dordevic, M. Jones, and E. Levi, "A comparison of PWM techniques for three-level five-phase voltage source inverters," Power Electronics and Applications (EPE 2011), European Conference on Proceedings of the 2011-14th, pp. 1-10, Nov. 2011.

[8] S. Karugaba, O. Ojo, M. Abreham, "Carrier based PWM scheme for a three-level diode-clamped five-phase voltage source inverter ensuring capacitor voltage balancing," Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE, pp. 1194-1201, Nov. 2011.

[9] D. Dujic, M. Jones, E. Levi, J. Prieto, and F. Barrero, "Switching Ripple Characteristics of Space Vector PWM Schemes for Five-Phase Two-Level Voltage Source Inverters–Part 1: Flux Harmonic Distortion Factors," Industrial Electronics, IEEE Transactions, Vol. 58, issue- 7, pp. 2789-2798, Nov. 2011

[10] Guopeng Chen, Shengjie Fu, and Xiafu Peng, "A novel PWM strategy for five-phase voltage source inverters," Mechatronics and Automation (ICMA), pp. 529-535, Nol. 2010.

[11] A. Iqbal, H. Abu-Rub, P. Cortes, and J. Rodriguez, "Finite control set model predictive current control of a five-phase voltage source inverter," Industrial Technology (ICIT), pp. 1787-1792, Nov. 2010.

[12] M. M. Irfan, P. H K . Prasad, and P.V. Rao, "Simulation of five-level five-phase SVPWM voltage source inverter" Power, Control and Embedded Systems (ICPCES), pp. 1-5, Nov. 2011.

[13] M. Jones, D. Dujic, E. Levi, and S.N. Vukosavic, "Dead-time effects in voltage source inverter fed multi-phase AC motor drives and their compensation," Power Electronics and Applications, pp. 1-10, Nov. 2009.