A Comparative Study of Fixed Frequency and Variable Frequency Phase Shift PWM Technique for Cascaded Multilevel Inverter

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Abstract

Multilevel Inverters (MLI) are best suited for high power applications due to their improved harmonic profile and high power ratings. In this paper, asymmetric multilevel inverter has been considered over the other topologies. Several modulation strategies for MLI have been proposed mainly to improve the harmonic profile. This paper focuses on variable frequency phase shift pulse width modulation technique. The main objective is to balance the switching actions thereby minimize the stresses on the switches by employing phase shift PWM technique. In this paper, the variable frequency phase shift PWM technique has been employed for asymmetric MLI with induction motor load. The performance of the inverter with the proposed modulation technique has been compared with the fixed frequency phase shift PWM technique. The simulation was performed using MATLAB/Simulink and the results of comparison are discussed in detail.

Keywords – Asymmetric MLI, Fixed frequency phase shift PWM (FFPSPWM), variable frequency phase shift PWM (VFPSPWM), Total Harmonic Distortion (THD).

I. INTRODUCTION

MLI have been gaining a lot of attention in recent years mainly because they overcome the limitations imposed on voltage ratings of the power devices [1]. It facilitates in obtaining high voltages without the use of transformers or series connected synchronized switching devices [2]. The main function of the MLI is to generate the desired voltage waveform from several levels of DC voltages. Three topologies of MLI have been reported in the literature: Diode clamped inverters, flying capacitor MLI and cascaded MLI [3]. Out of these, cascaded MLI is quite popular mainly because of its simple and robust structure [4] facilitating simpler control and operation. The number of devices required to generate the specified voltage level is less when compared to other topologies and the structure is also modular. This saves cost, reduces complexity and also facilitates easier maintenance. One drawback associated with the cascaded H-bridge MLI is that it requires separate DC sources. Asymmetric cascaded MLI are used to overcome this drawback. With the asymmetric cascaded MLI, the required number of DC sources can be reduced.

The performance of the MLI is generally evaluated based on the modulation strategy incorporated which plays a vital role in the reduction of harmonics [5]. Out of the various modulation strategies reported, multicarrier PWM technique is generally preferred as it is easy to implement. This paper focuses on phase shift PWM technique in which the carriers employed are displaced from one another by an angle θ, called the phase shift angle.

The remarkable attribute of this technique is that the phase shift angle can be used to control the output voltage of the MLI with induction motor load. A comparative study between fixed and variable frequency phase shift PWM technique has been done. The results indicate that switching actions are balanced in case of variable frequency phase shift PWM and this also enhances the output of the MLI. The results are elucidated in detail in the sections to follow.

II. ASYMMETRIC CASCADED MLI

The cascaded H-Bridge inverters can be classified as symmetrical inverters in which the magnitude of the sources employed are the same and asymmetrical inverters in which sources are of different magnitudes. Asymmetric MLI is popular as the desired voltage level can be generated with reduced number of sources when compared to a symmetric MLI. The asymmetric multilevel inverter can produce $N=2^{n+1}-1$ [6], levels (n is the number of sources and N is the number of levels in the inverter output). The asymmetric configuration minimizes the redundant output levels and this offers an advantage over symmetric MLI [7].

The proposed asymmetric cascaded MLI (single phase structure) is shown in the Fig.1. The magnitudes of the sources employed are in the ratio 2:1 to generate seven level output. The topology offers various benefits such as: simple control, low electromagnetic interferences etc [8].

The single phase structure asymmetric MLI has two H-bridges connected in series in the AC side. Each bridge can generate three different voltage levels (V_{DC},0,-V_{DC}). By series connection seven level output can be obtained. The magnitude of the voltage sources were taken to be 50V and 100V for simulation. The lower bridge with a source of magnitude 50V can generate voltage levels of magnitude +50V, 0 and -50V. The upper bridge on the other hand can generate 100V, 0 and -100V. The seven voltage levels in the output of the asymmetric cacaded MLI is: 150V, 100V, 50V,0, -50V, - 100V, -150V.

A specific voltage level can be obtained by triggering the appropriate switches. Thus, to obtain a voltage level of 150V, the switches S1,S2, S5 and S6 has to be triggered. The other switches remain in the OFF state. The conduction pattern to obtain a seven level output is shown in Table I.

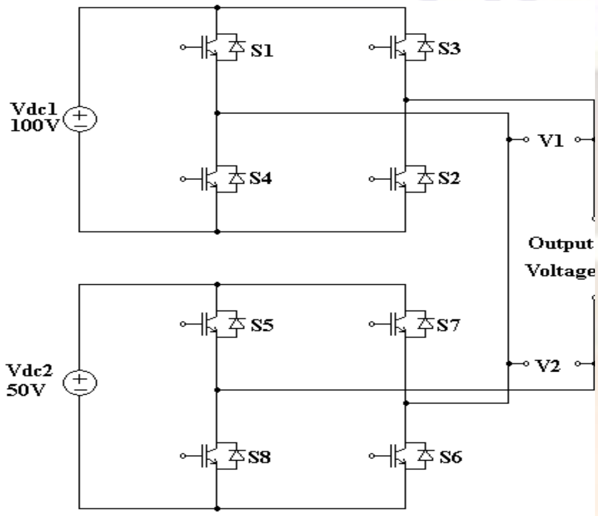

Fig.1: Proposed asymmetric cascaded MLI with three phase Induction motor load

TABLE I
Conduction Sequence for Asymmetric Cascaded Multilevel Inverter

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	OUTPUT
1	1	0	0	1	1	0	0	$1.5V_{dc}$
1	1	0	0	1	0	1	0	V_{dc}
1	0	1	0	1	1	0	0	$0.5V_{dc}$
0	0	0	0	0	0	0	0	0V
0	1	0	1	0	0	1	1	$-0.5V_{dc}$
0	0	1	1	0	1	0	1	$-V_{dc}$
0	0	1	1	0	0	1	1	$-1.5V_{dc}$

The work has been carried out with a three phase asymmetric MLI with 220V, 1500rpm induction motor load with the mechanical input of 11.9Nm. The modulation index of the MLI was taken to be 0.9.

III. CARRIER PHASE SHIFT PWM TECHNIQUE

The performance of the MLI greatly depends on the modulation strategy adopted. It plays a vital role in harmonic reduction and thus improves the harmonic profile of load voltage and load current [9]. Different modulation strategies have been proposed for MLI in the literature. The strategies can be broadly classified as: space vector modulation, Pulse width modulation and selective harmonic elimination [10], [11]. In case of MLI, multicarrier PWM is widely employed. The idea is to use several triangular signals and one modulating signal. The number of carriers employed depends on the number of levels in the output voltage. They are related as: N=m-1[12], where N denotes the number of carriers and m denotes the number of levels in the output voltage.

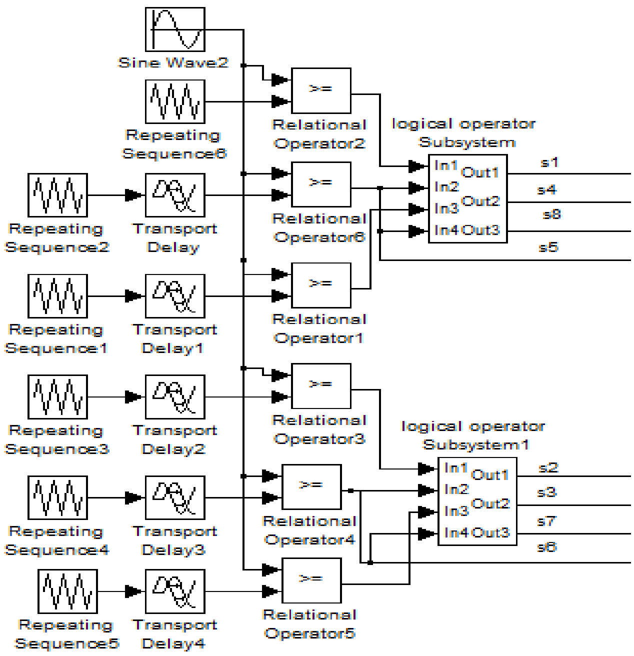

Fig.2: Circuit for carrier phase shifted PWM technique

Further, the PWM technique can be classified as level shifted PWM and phase shift PWM technique based on how the carriers are displaced from one another. In case of phase shift PWM technique, the carriers are horizontally displaced. This introduces a new parameter θ (phase shift angle) for controlling the output voltage. The output voltage is found to be greatly dependent on the phase shift angle. The performance of the inverter can be enhanced by carrier phase shift PWM technique [13]. The circuit for implementing carrier phase shift PWM technique is shown in the Fig.2.

IV. FIXED FREQUENCY PHASE SHIFT PWM TECHNIQUE

The carrier phase shift PWM technique can further be classified based on the frequency of the carriers used as: fixed frequency phase shift PWM and variable frequency phase shift PWM. A further categorization can be made based on how the angle is computed. Either 180/N or 360/N [14] mode can be employed. Here, N denotes the number of levels. 180/N mode improves the performance of the inverter than 360/N mode and hence 180/N mode was used for the study. The angle computed was approximated to 45º for a seven level output. In case of FFPSPWM, the frequency of all the carriers used is the same. It was chosen to be 3150Hz. The reference and the carrier signals used are shown in the Fig.3. The gating pattern obtained by incorporating FFPSPWM is shown in the Fig.4.

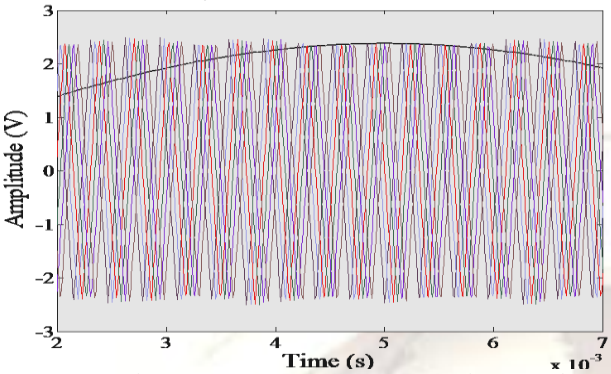

Fig.3: Reference and carrier waveforms for FFPSPWM technique

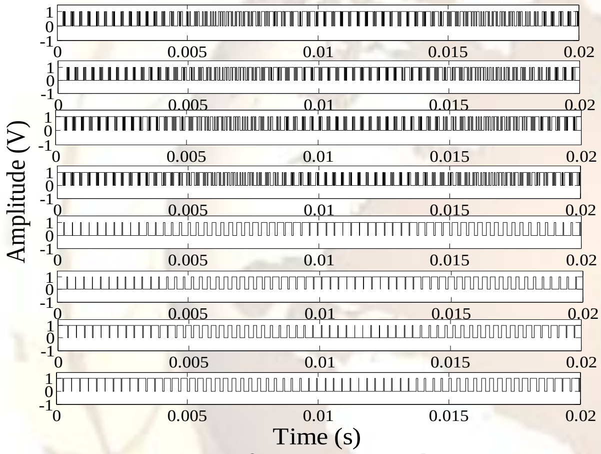

Fig.4: Gating pattern of FFPSPWM technique

The drawback associated with this technique is that the switching actions in this case are not balanced. The switches operated to generate the highest voltage level are stressed more when compared to the other switches. The seven level phase and the thirteen level line voltages obtained are shown in the Fig.5 and Fig.6 respectively.

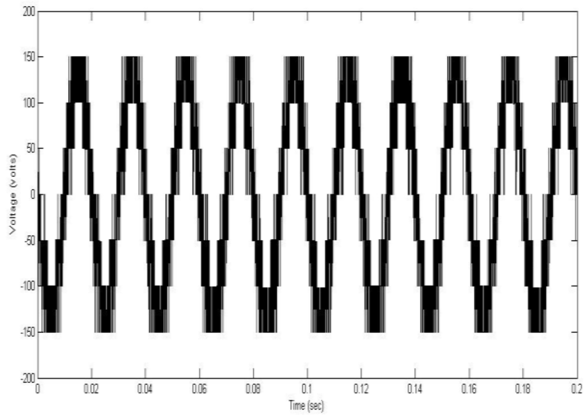

Fig.5: Phase voltage (seven) of asymmetric MLI with FFPSPWM

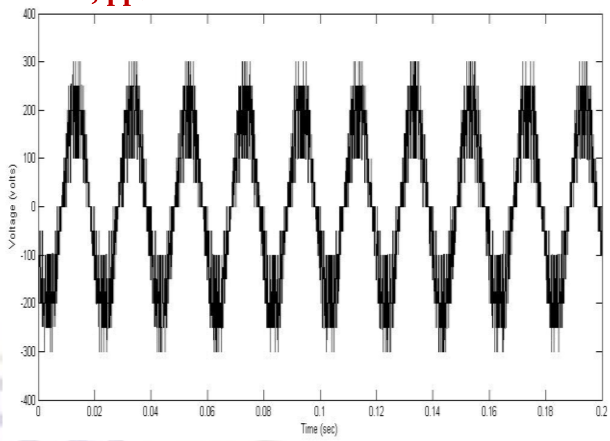

Fig.6: Line voltage (thirteen) of asymmetric MLI with FFPSPWM

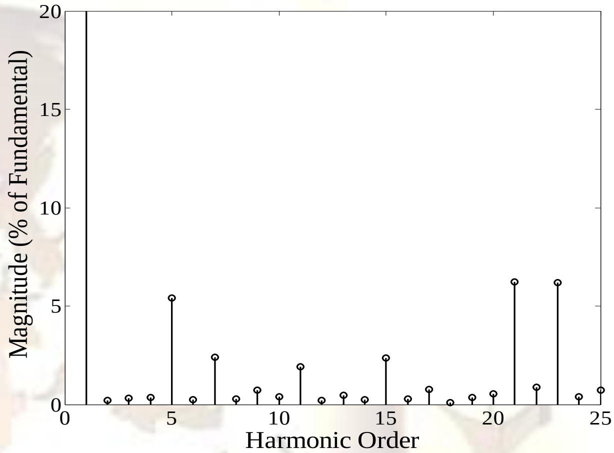

Fig.7: Frequency spectrum of phase voltage of asymmetric MLI with FFPSPWM

The frequency spectrum of the phase and the line voltage are shown in the Fig.7 and Fig.8 respectively. The THD of the phase voltage was computed to be 14.127% and that of line voltage was 12.935%.

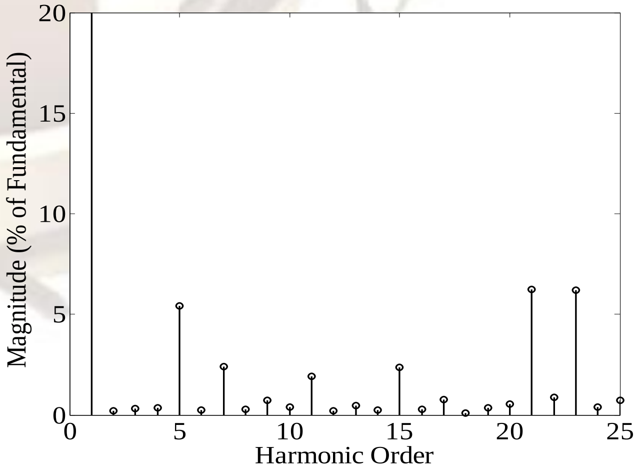

Fig.8: Frequency spectrum of line voltage of MLI with FFPSPWM

The stator current waveform and its frequency spectrum are shown in the Fig.9 and Fig.10 respectively. The THD of the stator current is 6.22%. Also, the switching losses were found to be 37.68W.

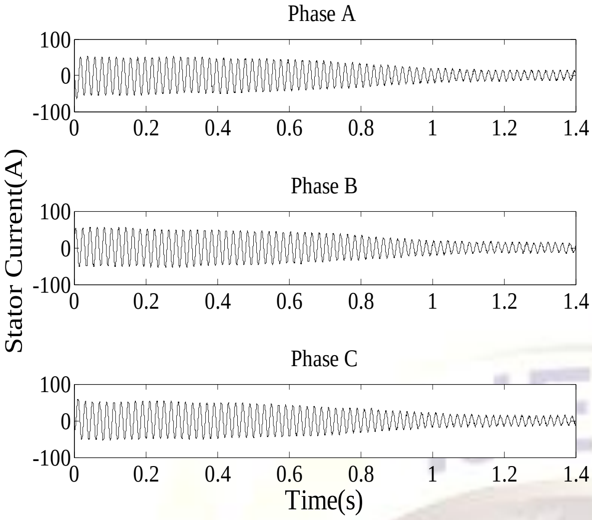

Fig.9: Stator current waveform of MLI with FFPSPWM

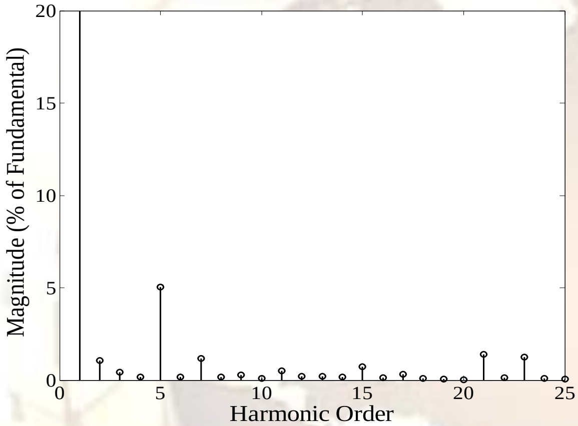

Fig.10: Frequency spectrum of stator current of MLI with FFPSPWM

The torque and the speed characteristics of the three phase induction motor load are shown in the Fig.11 and Fig.12.

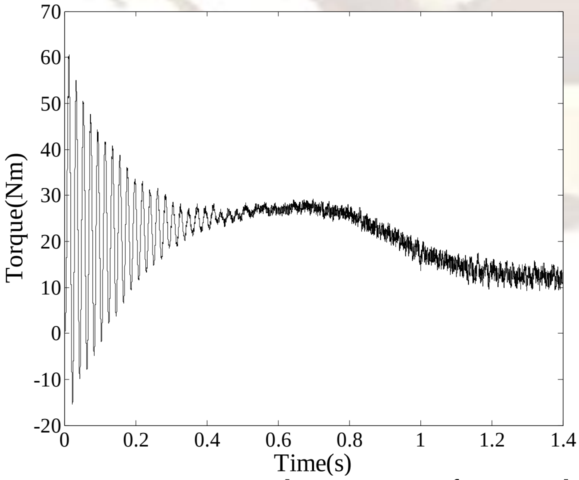

Fig.11: Torque vs. time characteristics of MLI with FFPSPWM

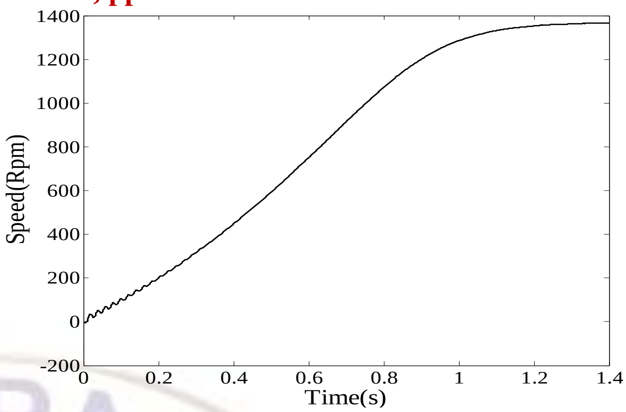

Fig.12: Speed vs. time characteristics of MLI with FFPSPWM

V. VARIABLE FREQUENCY PHASE SHIFT PWM TECHNIQUE

The drawback associated with FFPSPWM technique can be overcome by incorporating VFPSPWM. In this case, the frequencies of the carriers employed are not the same. They are varied based on the slope of the modulating signal [15].

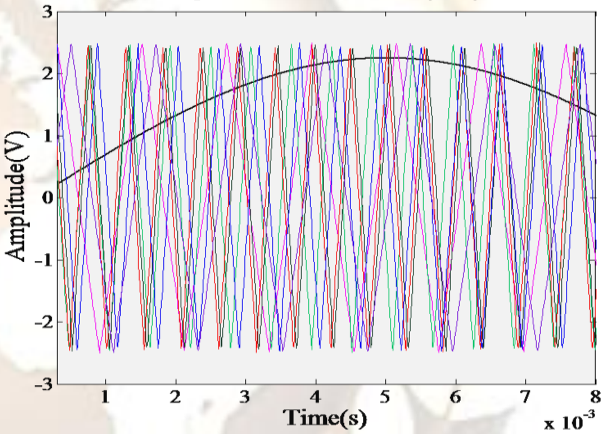

Fig.13: Reference and carrier waveforms of VFPSPWM technique

The frequencies were calculated to be 1650, 3450 and 3750Hz. The reference and carrier waveforms of the VFPSPWM technique are shown in the Fig.13 and the gating pattern is shown in the Fig.14.

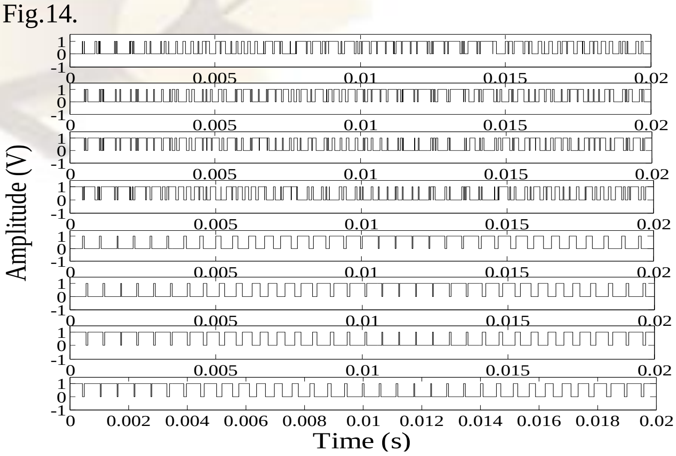

Fig.14: Gating pattern of VFPSPWM

The lowest frequency is associated with the highest voltage level. Thus, by increasing the dwell time of the switches, the switch utilization is enhanced drastically and also the switching action is balanced.

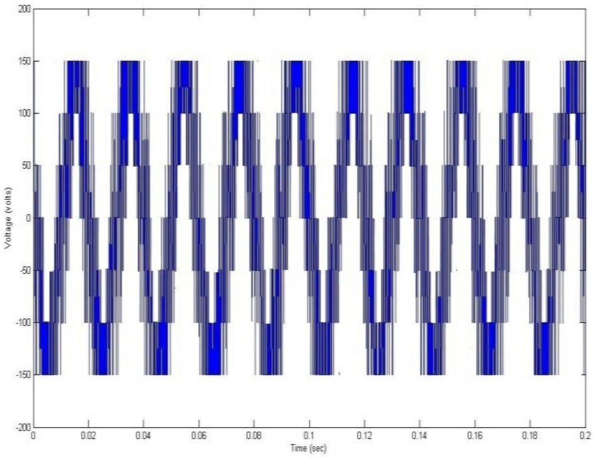

Fig.15: Phase voltage (seven) of asymmetric MLI with VFPSPWM

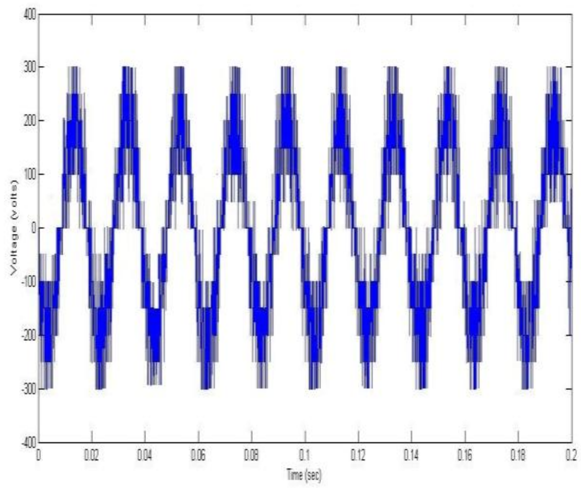

Fig.16: Line voltage (thirteen) of MLI with VFPSPWM

The seven level phase and the thirteen level line voltage obtained is shown in Fig.15 and Fig.16 respectively. The THD of the phase voltage is 10.754% and that of line voltage is 5.4421%. The frequency spectrum of the phase and line voltage is shown in the Fig.17 and Fig.18 respectively.

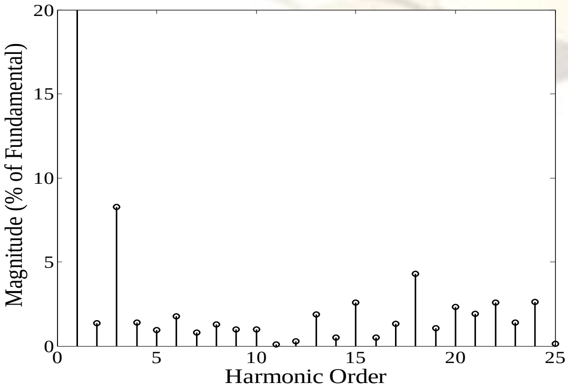

Fig.17: Frequency spectrum of phase voltage of MLI with VFPSPWM

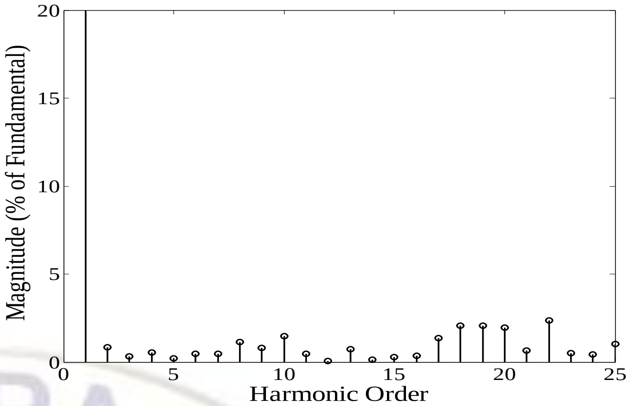

Fig.18: Frequency spectrum of line voltage of MLI with VFPSPWM

The THD of the stator current was calculated as 1.988%.With VFPSPWM technique, the performance of the motor is also improved. The torque characteristics and speed characteristic of the induction motor are shown in the Fig.19 and Fig.20. The harmonic profile of the stator current has been improved by incorporating VFPSPWM technique. Further, reduction in torque ripples can also be observed. The switching losses were computed to be 26.43W which is less when compared to FFPSPWM.

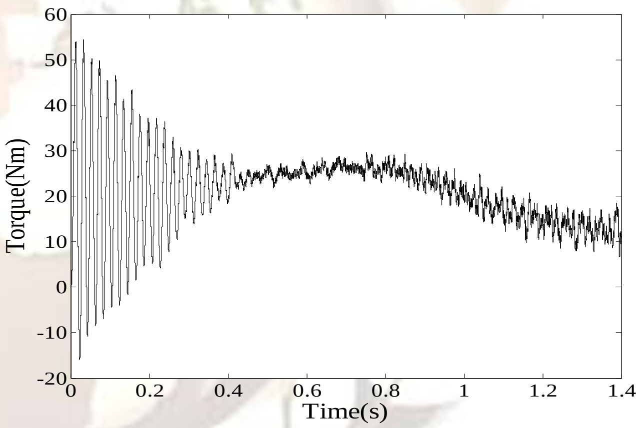

Fig.19: Torque vs. time characteristics of MLI with VFPSPWM

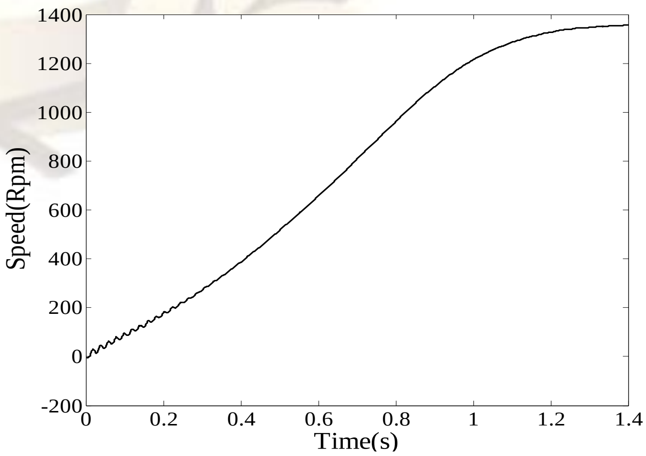

Fig.20: Speed vs. time characteristics of MLI with VFPSPWM technique

VI. CONCLUSION

The study has revealed that carrier phase shift technique based asymmetric MLI is suited for vehicle applications. The VFPSPWM improves the performance of the drive train employed by reducing the distortions in the output and also by minimizing the torque ripples. The switching actions are balanced and the losses are also reduced by this technique. The VFPSPWM makes the drive efficient thereby increasing the fuel efficiency and lowering emissions.

REFERENCES

[1] Ilhami Colak, Ersan Kabalci, and Seref Sagiroglu, "The Design and Analysis of a 5-Level Cascaded Voltage Source Inverter with Low THD," International Conference on Power Engineering, Energy and Electrical drives, pp.575-580, March 18-20, 2009

[2] Leon M.Tolbert, Fang Zheng Peng, Thomas G.Habetler, "Multilevel Converters for Large Electric Drives," IEEE Transactions on Industry Applications, Vol.35, No.1, pp.36-44, Feb 1999.

[3] Jose Rodriguez, Jih-Sheng Lai, Fang Zheng Peng, "Multilevel Inverters: A Survey of Topologies, Controls and Applications," IEEE Transactions on Industry Applications, vol.49, no.4, pp.724-738, August 2002.

[4] Khoucha F, Ales A, Khoudiri A, Marouani K, Benbouzid M E H, Kheloui A, "A 7-level DC Source Cascaded H-Bridge multilevel Inverter Control using Hybrid Modulation", International Conference on Electrical Machines, pp.1-5, Sept 2010.

[5] Brendan Peter McGrath and Donald Grahame Holmes "Multicarrier PWM Strategies for Multilevel Inverter," IEEE Transactions on Industrial Electronics, vol.49, no.4, pp.858-867, August 2002.

[6] R.Seyezhai, "carrier overlapping pwm methods for asymmetrical multilevel inverter," International Journal of Engineering Science and Technology (IJEST), ISSN: 0975-5462, Vol. 3, No. 8, August 2011.

[7] Deepa K, Savitha.P and Vinodhini.B "Harmonic Analysis of A Modified Cascaded Multilevel Inverter," IEEE 2011 1st International conference on electrical energy systems, pp.92-97, January 2011

[8] Hasan Bayat, J. S. Moghani, S. H. Fathi, M. Taheri, "Reduction of Switching Frequency using Reference Phase Disposition PWM Technique in Multilevel H-Bridge Inverters," 2nd Conference on Power Electronics, Drives and Technologies, pp. 27-31, February 2011.

[9] A. Keith Corzine, W. Mike Wielebski, Fang Z. Peng and Jin Wang, "Control of Cascaded Multilevel Inverters", IEEE Trans. Power Electronics, Vol. 19, NO. 3, pp.732-738, 2005.

[10] Giuseppe Carrara, Simone Gardella, Mario Marchesoni, Raffaele Salutari and Giuseppe Sciutto, "A New Multilevel PWM method: A Theoretical Analysis", IEEE Transactions on Power Electronics, vol.7, no.3, pp.497-505, July 1992.

[11] Roozbeh Naderi and Abdolreza Rahmati, "Phase-Shifted Carrier PWM Technique for General Cascaded Inverters" IEEE Transactions on Power Electronics, vol.23, no.3, pp.1257-1269, May 2008.

[12] Leon M.Tolbert, Thomas G.Habetler, "Novel Multilevel Inverter Carrier-Based PWM Method," IEEE Transactions on Industry Applications, vol.35, no.5, pp. 1098-1107, October 1999.

[13] Cao Yi long, Jiang You-hua, Tang Zhong, and Tan Wen, "Research On Different Carrier Phase-shifted Angle with Output Voltage Performance of Cascade Multilevel Inverter," International Power Electronics and Motion Control Conference, pp.1448-1451, May 2009.

[14] N Benaifa, H Bierk, B ajayi, E Nowicki, "Parallel operated inverters as multilevel case," Canadian Conference on electrical and computer science, pp.002003-002006, May 2008.

[15] R. Seyezhai, B. L. Mathur, "Investigation of Variable Frequency ISPWM Control Method for Asymmetric Multilevel Inverter," International Journal of Electrical and Computer Sciences, vol.9, no.10, pp. 55-64, October 2011.