Comparison of Induction and BLDC motor drives for Hybrid Electric Vehicles

Swetha C, Surasmi N L

Department of EEE, Mar Baselios College of Engineering and Technology, Thiruvananthapuram, India

***Abstract*— *This paper proposes a converter -inverter fed both induction motor and BLDC motor drives which can be used in hybrid electric vehicle or electric vehicle. The advantage of this PWM technique is that by eliminating the zero vectors the switching loss can be reduced. Both motors utilize dc link voltage under varied and constant voltage condition. The simulation of the system had been done using MATLAB/SIMULINK. It can be seen that the THD is relatively less than 5% under both conditions. This technique is feasible for applications which require high efficiency, high power density, low cost. The advantages and disadvantages when both types of motors are used are also seen.*

Keywords*— *SVPWAM, Induction motor, BLDC motor, 6ω dc link voltage, constant dc link voltage, Switching loss reduction, FFT analysis.

I. INTRODUCTION

Hybrid electric vehicles (HEV) make use of both conventional fuel and electric energy which is stored in the battery. The battery can be charged utilizing electricity from grid which costs less and reduces fuel consumption compared to conventional vehicles. These vehicles can also reduce emissions depending on the electricity source.

The general circuit diagram is shown in figure 1. HEV consists of converter, inverter and motor which use energy stored in a battery. The batteries in HEV can be charged in several ways that is by an outside electric power source, by the internal combustion engine or else by regenerative braking.

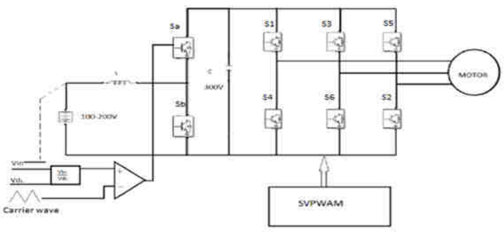

Fig.1: Circuit diagram of the system

A battery is used to store the electrical energy which powers the motor. These vehicles require less maintenance due to few moving parts. Currently two topologies are used in plug in hybrid electric vehicles they are the conventional three phase inverter with high voltage battery which imposes high stress on switching devices that can be eliminated by using three phase PWM inverter with dc-dc boost at the front end. In order to reduce the winding loss and core loss the switching frequency of inverter should be in the range 15 to 20 kHz which results in high switching losses. PWM schemes can be used to reduce such problems like Sinusoidal pulse width modulation and Space vector pulse width modulation. SVPWM is widely used because of their easier digital realization and better dc bus utilization.

Soft switching methods were used to reduce switching losses effectively [2]-[6]. Instead of dc/dc converters active switching rectifier or diode rectifier with small dc link capacitors are proposed in [7]-[11]. Regenerative capability was not attained in such system. The conventional SVPWM method was proposed in [12] which reduce the switching loss by 13% compared to SPWM technique. Another prominent technique is discontinuous PWM [13] which reduces the number of switching instances up to one-third of fundamental period. But it causes unwanted stress in the power semiconductor devices. A method similar to SVPWAM technique is seen in [14] which reduce the average switching frequency by a factor of three to reduce the switching power loss.

In this paper space vector pulse width amplitude modulation (SVPWAM) method for a voltage source inverter fed Induction motor drive with 6ω varied dc link voltage and same method for constant dc link voltage fed BLDC motor drive is implemented by using MATLAB/SIMULINK. The advantages of using Induction motor and BLDC motor in electric vehicle are also discussed.

II. SVPWAM METHOD

A. Operating Principle

Space vector pulse width modulation (SVPWM) is a special switching sequence of the upper three switches of a three phase inverter. It has advantages like less harmonic distortion in the output voltages which are applied to the phases of an AC motor and to provide more efficient use of supply voltage compared with sinusoidal modulation technique. Among the eight possible switching states for which two of them are zero vectors and six of them are active switching states. The conventional zero vectors are eliminated in each sector in Space vector pulse width amplitude modulation technique thus V_{ref} will be at its maximum amplitude. Thus SVPWAM method is a combination of amplitude modulation and pulse width modulation such that each inverter leg is switched during one third of fundamental period. The modulation principle of SVPWAM is shown in figure 2.

The voltage vectors only follow the sides of the hexagon. As zero vector are not utilized during each sector two switches and their complementary switches does not change its state and thus only one pair of switches need to do PWM switching which reduces the switching instances and hence switching losses.

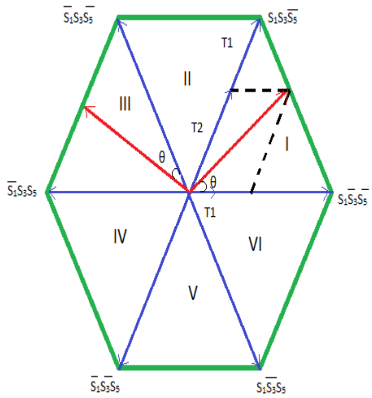

Fig.2: Representation of inverter states

Compared to conventional SVPWM technique the vector placement is also changed which does not have a transition to zero vector time period. The vector placement within one switching cycle in each sector is shown in figure 3.

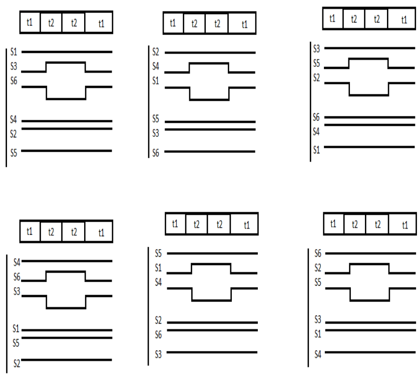

Fig.3: Vector placement diagram

III. BUCKBOOST CONVERTER

A converter is present at the front end for energy flow from battery to the dc link and from dc link to battery. The unidirectional dc/dc converter can be replaced by diodes with controllable switches as individually buck converter and boost converter do not have bidirectional power flow capability. By operating the switches both buck and boost operations are possible. The bidirectional switches carries current in both directions and thus double sided power flow occurs. Generally IGBT or MOSFET are used in parallel with diode.

Here a 6ω varied feature is to be present at the dc link. In SVPWAM control, dc-link voltage has to vary with a voltage ripple whose frequency is six times of output frequency. This kind of ripple is called 6ω. [15] The peaks of the ripple are corresponding to the peaks of output three phase line-to-line voltage. The converter generates this ripple. This is the input to the inverter with SVPWAM. The block diagram of control circuitry of Induction motor drive is shown in figure 4.

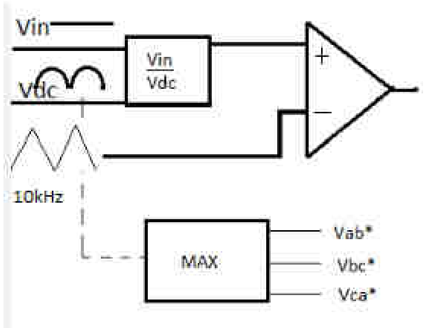

Fig.4: Control circuitry for Induction motor drive

This provides nearly sinusoidal variation in the output voltage and the percentage in THD can be reduced [16]. Another added advantage is that the size of dc link capacitor can be reduced. Thus the size of the system can be reduced which increases the power density.

By applying SVPWAM control the dc link can be a varied one. But when a motor like BLDC motor is used the backemf of the motor must always remains constant so the dc link voltage has a constant magnitude [17]. The block diagram of control circuitry for BLDC motor drive is shown in figure 5.

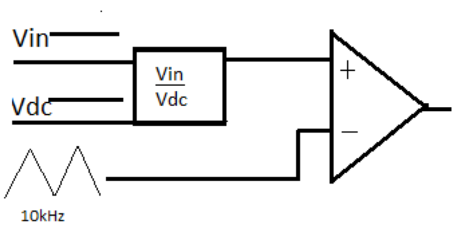

Fig.5: Control circuitry for BLDC motor drive

The dc converters output will be given as the input of inverter which drives the motor. In order to maintain a constant dc link voltage at dc link a capacitor of comparatively larger value should be used which can increase the size of the system.

IV. DIFFERENT TYPES OF MOTOR

The induction motor is well suited for hybrid electric vehicle application because of its robustness, low maintenance, low price and reliability. Recently a new induction motor technology has been developed [20] for vehicle application which can produce the torque of a permanent magnet motor without using permanent magnet material. It also includes features like reduced manufacturing costs and operation of higher temperature and higher speed.

The BLDC motor has a permanent magnet rotor surrounded by a wound stator. The windings in the stator are commutated electronically. The composition of the BLDC motor also keeps the machinery inside a vehicle cooler and thermally resistant. Green car manufacturers prefer BLDC motor due to its high peak point efficiency.

V. SIMULATION RESULTS

The simulation results for SVPWAM for a voltage source inverter fed Induction motor and BLDC motor has been simulated using MATLAB/SIMULINK. The simulations are carried out for 1HP motors. The dc input to the inverter is controlled by the bidirectional dc/dc converter through the control circuitry by which a 6ω varied voltage is generated. Whereas in the other case a constant dc link voltage is generated. The following waveforms were obtained. The complementary pulses generated using converter is shown in figure 6. The simulation parameters are V_{in} =100V, L=1mH, C=2μF, f_s=10kHz for Induction motor drive system. The simulation parameters for BLDC motor drive system are V_{in}=100V,L=24 μ H, C= 17mF, f_s=10kHz.

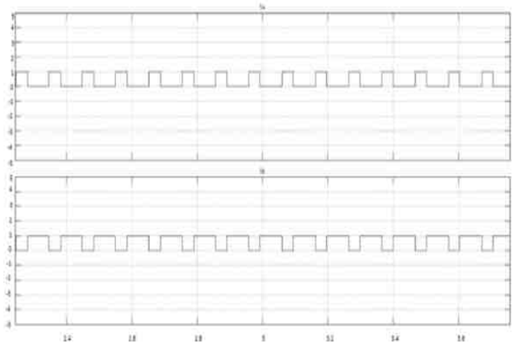

Fig.6: Complementary pulses for dc/dc converter (x axis: 0.2s/div, y axis: 1V/div)

The reference dc link voltage given to the converter with magnitude of V_{dc}=300V. The output of the dc-dc converter is shown in figure 7 and 8 by applying certain control in the input side.

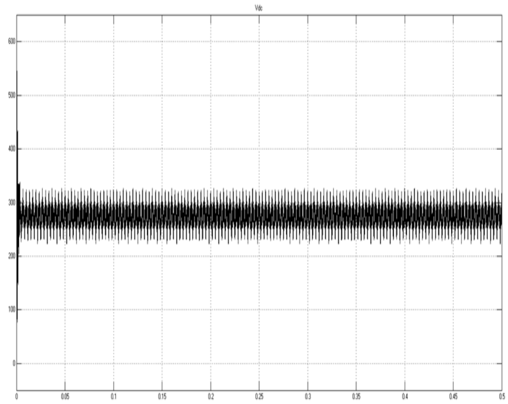

Fig.7: A 6ω dc link voltage (V_{dc}=300V) (x axis: 0.05s/div, y axis: 100V/div)

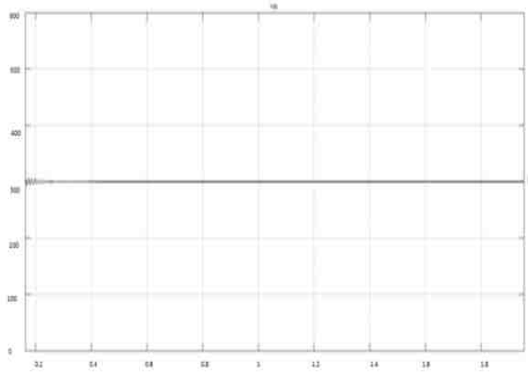

Fig.8: Constant dc link voltage (V_{dc}=300V)(x axis: 0.2s/div, y axis: 100V/div)

The switching pulses for the inverter are shown in figure 9 where we can see the number of switching's reduced.

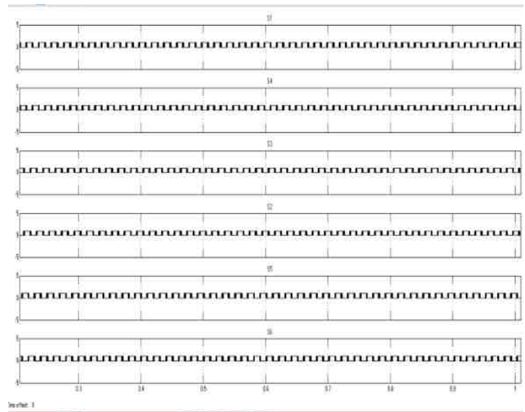

Fig.9: Switching pulses for SVPWAM method (x axis: 0.1s/div, y axis: 5V/div)

The line voltage has nearly sinusoidal variation as shown in figure 10 when a 6ω varied dc link voltage is used. A constant line voltage is fed to BLDC motor drive as in shown in figure 11.

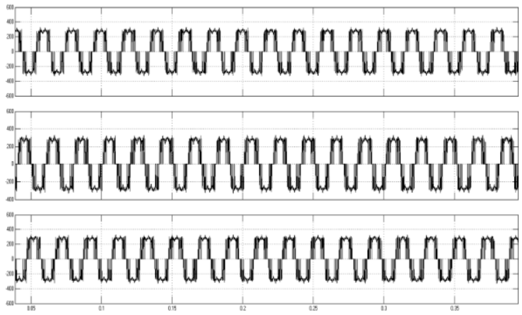

Fig.10: Line voltage for the inverter Vin = 100 V, Vdc avg = 300 V, Po = 1 HP, fo = 50 Hz, fsw = 10 kHz. (x axis: 0.02s/div, y axis: 200V/div)

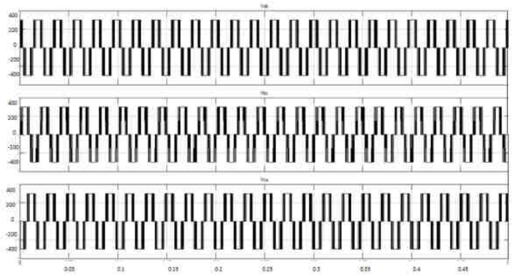

Fig.11: Line voltage for the inverter with SVPWAM Vin = 100 V, Vdc avg = 300 V, Po = 1 HP, fo = 50 Hz, fsw = 10 kHz.(x axis: 0.05s/div, y axis: 200V/div)

The torque response of the machines is shown in figure 12-13. The speed responses of both machines are shown in figure 14 -15.

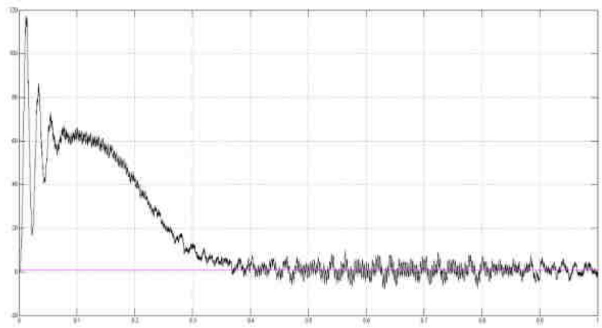

Fig.12: Torque waveform for SVPWAM inverter fed motor drive for a load torque of 2Nm (x axis: 0.1s/div, y axis: 20Nm/div)

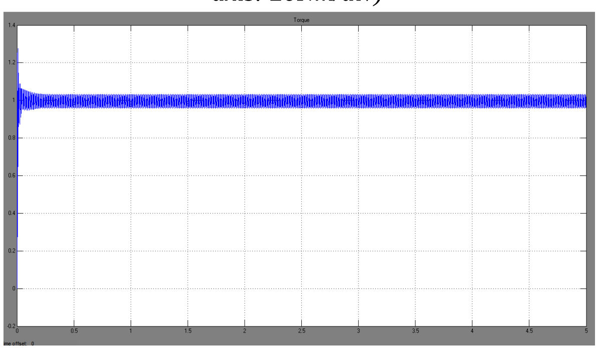

Fig.13: Torque waveform for SVPWAM inverter fed BLDC motor drive for a load torque of 1Nm (x axis: 0.5s/div, y axis: 0.2Nm/div)

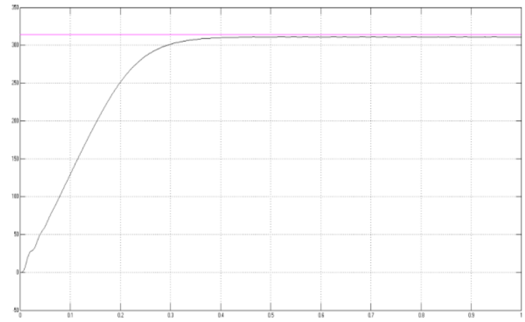

Fig.14: Speed waveform for SVPWAM inverter fed motor drive (x axis: 0.2s/div, y axis: 200rad/s/div)

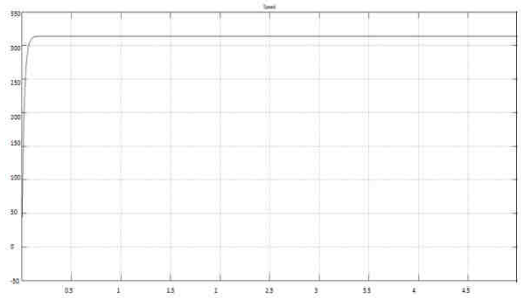

Fig.15: Speed waveform for SVPWAM inverter fed BLDC motor drive (x axis: 0.5s/div, y axis: 50rad/s/div)

VI. FFT ANALYSIS

By using FFT analysis overall THD of the output voltage is calculated. THD stands for Total Harmonic Distortion which is often used to define the degree of harmonic content in an alternating signal. Also keeping low THD values on a system will ensure proper operation of equipment and longer equipment and a longer equipment life span. In the case of SVPWAM the modulation index is always kept at its maximum value. When FFT analysis is done for converter - inverter fed Induction motor drive system it was found to be 4.57% as shown in figure 16. Now the same system when fed with constant dc link voltage BLDC motor the FFT analysis has been done and it was found to be 4.97% as shown in figure 17.

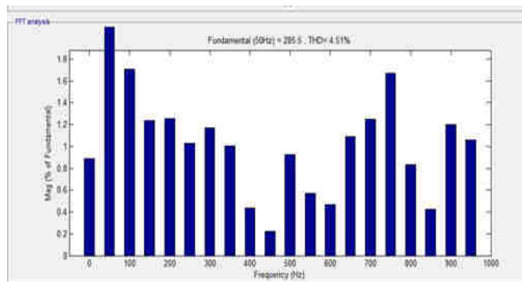

Fig.16: THD analysis of the system with Induction motor

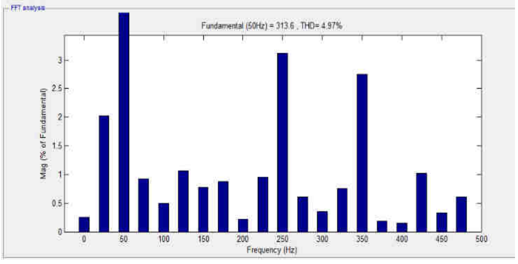

Fig.17: THD analysis of the system with BLDC motor

VII. CONCLUSION

The implementation of SVPWAM method for a voltage source inverter fed Induction motor drive and BLDC motor drive which has application in hybrid electric vehicle is done using MATLAB/SIMULINK. The SVPWAM method was found to have less switching loss and THD when compared to any other PWM techniques. A rippled dc link voltage is maintained at the dc link and a constant dc link voltage is maintained using bidirectional dc/dc converter. Another advantage is use of small heat sink due to reduced losses. The SVPWAM method can also be implemented with Current Source Inverter. Speed control of the machine can be implemented with closed loop operation of dc/dc converter.

REFERENCES

[1] Qin Lei, Fang Zheng Peng, "Space Vector Pulsewidth Amplitude Modulation for a Buck–Boost Voltage/Current Source Inverter, "*IEEE Transc*. vol. 29, no. 1, Jan 2014,pp.266-274.

[2] D. M. Divan and G. Skibinski, "Zero-switching-loss inverters for high power applications," IEEE Trans. Ind. Appl., vol. 25, no. 4, Jul./Aug. 1989, pp. 634–643.

[3] W.McMurray, "Resonant snubbers with auxiliary switches," IEEE Trans. Ind. Appl., vol. 29, no. 2Mar./Apr. 1993, pp. 355–362.

[4] J.-S. Lai, R. W. Young, Sr., G. W. Ott, Jr., J. W. McKeever, and F. Z. Peng, "A delta-configured auxiliary resonant snubber inverter," IEEE Trans. Ind. Appl., vol. 32, no. 3, May/Jun. 1996, pp. 518–525.

[5] J. S. Kim and S. K. Sul, "New control scheme for ac-dc-ac converter without dc link electrolytic capacitor," in Proc. 24th Annu. IEEE Power Electron. Spec. Conf., Jun. 1993, pp. 300–306.

[6] K. Rigbers, S. Thomas, U. Boke, and R. W. De Doncker, "Behavior and loss modeling of a three-phase resonant pole inverter operating with 120°A double flattop modulation," in Proc. 41st IAS Annu. Meeting IEEE Ind Appl. Conf., Oct. 8–12, 2006, vol. 4, pp. 1694–1701.

[7] H. Haga, K. Nishiya, S. Kondo, and K. Ohishi,, "High power factor control of electrolytic capacitor less current-fed single-phase to three-phase power converter," in Proc. Int. Power Electron. Conf., Jun. 21–24, 2010, pp. 443– 448.

[8] X.Chen and M. Kazerani, "Space vectormodulation control of an ac-dc-ac converter with a front-end diode rectifier and reduced dc-link capacitor," IEEE Trans. Power Electron., Sep. 2006 vol. 21, no. 5, pp. 1470–1478.

[9] M. Hinkkanen and J. Luomi, "Induction motor drives equipped with diode rectifier and small dc-link capacitance," IEEE Trans. Ind. Electron., vol. 55, no. 1, Jan. 2008, pp. 312–320.

[10] J. Jung, S. Lim, and K. Nam, "A feedback linearizing control scheme for a PWM converter-inverter having a very small dc-link capacitor," IEEE Trans. Ind. Appl., vol. 35, no. 5, Sep./Oct. 1999, pp. 1124–1131.

[11] L. Malesani, L. Rossetto, P. Tenti, and P. Tomasin, "AC/DC/AC PWM converter with reduced energy storage in the dc link," IEEE Trans. Ind. Appl., vol. 31, no. 2, , Mar./Apr. 1995 pp. 287–292.

[12] F. Blaabjerg, S. Freysson, H.-H. Hansen, and S. Hansen, "A new optimized space-vector modulation strategy for a component minimized voltage source inverter," IEEE Trans. Power Electron., vol. 12, no. 4, Jul. 1997, pp. 704–714.

[13] L. Asiminoaei, P. Rodriguez, and F. Blaabjerg, "Application of discontinuous PWM modulation in active power filters," IEEE Trans. Power Electron., vol. 23, no. 4, , Jul. 2008,pp. 1692–1706.

[14] H. Fujita, "Switching loss analysis of a three-phase solar power conditioner using a single-phase PWM control method," in Energy Conversion Congress and Exposition (ECCE), 2010 IEEE, pp. 618- 623

[15] Xianhao Yu, Qin Lei, Fang Zheng Peng,, "Boost converter -inverter system using PWAM for HEV/EV motor drive," in 2012 Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 5-9 Feb. 2012, pp.946-950.

[16] Swetha C and Surasmi N L," Implementation of SVPWAM Method for A VSI Fed BLDC Motor Drive", *JECET*,Sec. C, Vol.5. No.3, pp no.267-277,June 2016- August 2016.

[17] Swetha C and Surasmi N L, "Space Vector Pulse Width Amplitude Modulation for a VSI Fed Induction Motor Drive", *IJAREEIE*; Vol 5, Issue 6,pp no.4528-4535,June 2016.

[18] Yi Huang, Chunquan Li "Model and system simulation of Brushless DC motor based on SVPWM control" 2nd International Conference on

Electronic & Mechanical Engineering and Information Technology (EMEIT-2012)

[19] Dorin O. Neacsu, "Space Vector Modulation–an introduction," The 27th annual conference of the IEEE industrial electronics society.

[20] Mounir Zeraoulia, Mohamed Benbouzid, Demba Diallo. Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study. IEEE VPPC'05, Sep 2005, Chicago, United States. pp.280-287, 2005

[21] Burak Ozpineci, Leon M.Tolbert, ―Simulink Implementation of Induction Machine Model-A Modular Approach‖, International Conference on Electric Machines and Drives (IEMD), 2003,pp 728-734.