SVPWAM for a VSI fed Induction motor drive for Solar Powered Electric Vehicles

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Abstract - In the last years, increasing attention has been spent towards the applications of solar energy to EV/HEV. Hybrid Solar Vehicles might represent a valuable solution to face both energy saving and environmental issues. This paper proposes a PV powered converter-inverter fed induction motor drive system which can be used in such vehicles. The switching losses in the inverter can be reduced using SVPWAM method. A 6ω varied voltage is kept at dc link to reduce the size of dc link capacitor which makes the system smaller and also increases the power density. The simulation of the system had been done using MATLAB/SIMULINK. The theoretical analysis for switching loss calculation is also derived.

Key Words**: SVPWAM, PV array, Induction motor, 6ω dc link voltage, Switching loss reduction, FFT analysis.**

1. INTRODUCTION

The energy demand for petroleum resources across the world is increasing at a high rate due to the large dependency of the transportation sector on petroleum as the primary fuel. Also due to this reason, there is a vast greenhouse gas emission that is degrading the quality of air and causing harm to life and environment. This has aroused a tremendous interest for the design of the vehicles with lesser or no dependency on the petroleum resources. And therefore the alternate propulsion technologies have been increasingly pursued by the automobile industries and this has led to the increased development rate of the of the Electric Vehicle (EV) technology in the past two decades. By adding renewable energy sources to these adds more advantage. The use of renewable source in electric vehicle will not harm the environment and are of prime importance. The majority of the energy requirements is satisfied by fossil fuels but by the use of photovoltaic systems could help in supplying the energy demands. The general block diagram of the system is shown in Fig 1.

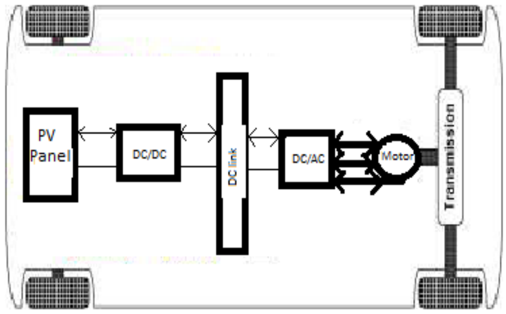

Fig 1: Block diagram of the system

Solar powered EV consists of PV panel, converter, inverter and motor. While we consider plug in hybrid electric vehicle the batteries in PHEV can be charged in several ways that is by an outside electric power source, by the internal combustion engine or else by regenerative braking. Here it is substituted with solar cells. These vehicles require less maintenance due to few moving parts.

Currently two topologies are used in 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. The switching frequency of the inverter will be from 15 to 20 kHz which results in high switching losses. So in order to reduce switching losses in the inverter different techniques were introduced.

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

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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 is implemented by using MATLAB/Simulink. The simulations have been done for a 2HP Induction motor. The switching loss calculation compared to conventional sinusoidal PWM technique is done. FFT analysis had been done for the whole system and was seen to be 4.57%.

2. SVPWAM METHOD

2.1 Operating Principle

The most important feature required for a well-designed PWM technique is that it should not allow different phases to switch simultaneously. SVPWM is the only PWM technique which satisfies the above condition. Compared to conventional SVPWM 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 having its maximum amplitude [1]. 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 Fig 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.

In SVPWAM control the dc link voltage has to vary with input voltage by controlling the dc converter. The voltage gain equation for converter is:

$$V_{out} = \frac{1}{1-D_a} V_{in} \quad (1)$$

Here Da is the duty cycle of the converter. It can be related as:

$$D_a = 1 - \frac{V_{in}}{V_{out}} = 1 - \frac{V_{in}}{V_{dc}} \quad (2)$$

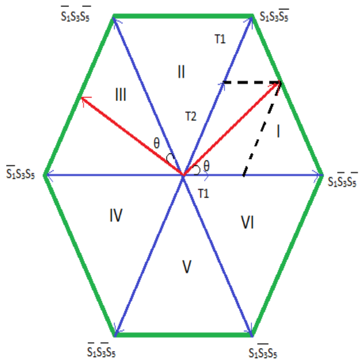


Fig 2: Representation of inverter states

The inverter switching pattern can be as shown in figure. Here S1, S3, S5 represents the upper switch of three phase inverter. Consider the case V1>V3>V5 as example [15]. Here phase a voltage is larger and is turned on all the time denoted by '1'.Phase c is the smallest upper switch is set to be off all time denoted as '0'.So only phase b is doing PWM switching denoted by '#' denoted in figure 3.Thus dc link voltage is directly generated from the output line to line voltage. So using this method only one phase leg of inverter is doing switching action. In all these cases zero vectors is eliminated from each sector which adds the benefit to reduce switching losses.

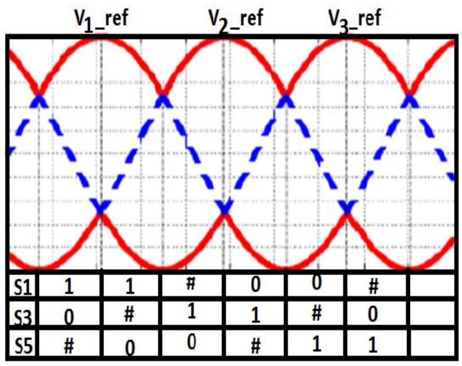


Fig 3: Switching pattern for SVPWAM method

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 Table1. The new time period [1] can be calculated as:

$$\frac{T1'}{Ts} = \frac{T1}{T1+T2} \quad (3)$$

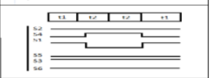
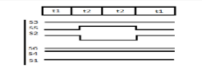
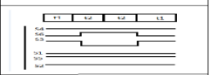
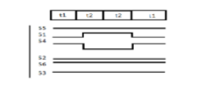
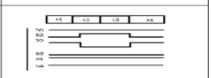
Where the time periods T1 and T2 are

$$T_1 = \frac{v_{ref}\sin(60-\theta)T_s}{V_d \sin 60} \quad (4)$$

$$T_2 = \frac{v_{ref}\sin\theta T_s}{V_d \sin 60} \quad (5)$$

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. This provides nearly sinusoidal variation in the output voltage and the percentage in THD can be reduced. 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.

Table 1: Switching pattern in SVPWAM

Sector	Upper Switches: S1,S3,S5	Lower Switches : S4,S6,S2	
1	$S_1= T_a+ T_b$ $S_3=T_b$ $S_5=0$	$S_4= 0$ $S_6= T_a$ $S_2= T_a + T_b$	
2	$S_1=T_a$ $S_3=T_a+ T_b$ $S_5=0$	$S_4= T_b$ $S_6= 0$ $S_2= T_a+ T_b$	
3	$S_1=0$ $S_3=T_a+T_b+0$ $S_5=T_b+0$	$S_4= T_a+T_b+0$ $S_6= 0$ $S_2= T_a$	
4	$S_1=0$ $S_3=T_a$ $S_5=T_a+ T_b$	$S_4= T_a+ T_b$ $S_6=T_b$ $S_2= 0$	
5	$S_1=T_b$ $S_3=0$ $S_5= T_a+ T_b$	$S_4= T_a$ $S_6= T_a+ T_b$ $S_2= 0$	
6	$S_1= T_a+ T_b$ $S_3=0$ $S_5= T_a$	$S_4= 0$ $S_6= T_a+ T_b$ $S_2= T_b$	

2.2 Inverter switching loss Calculations

There will be power losses in the system due to the inverter and converter side losses. By implementing the SVPWAM method the losses in the inverter can be reduced by a significant value. In order to understand the advantage of this method it is compared with conventional sinusoidal PWM method. The inverter switching loss per IGBT from [16] using conventional sinusoidal PWM in the inverter system is:

$$Psw_{\_spwm} = \frac{1}{2\pi}\int_0^{\pi}[E\,sw(on) + Esw(off)]d\omega t \quad (6)$$

Assume switching energy losses Esw (on) and Esw (off) are variables that change linearly with the product of drain to source voltage Vs and drain current Id. It can be expressed as:

$$\frac{Eon}{Eon,0} = \frac{Vs\ is}{Vs0\ Id0} \quad (7)$$

$$\frac{Eoff}{Eoff,0} = \frac{Vs\ is}{V's0\ I'd0} \quad (8)$$

Where is= Issinωt

So the switching loss of each IGBT can be represented as

$$Psw_{\_spwm} = \frac{VsIsfsw}{\pi}\left[\frac{Eon,0}{Vs0Id0} + \frac{Eoff,0}{V's0\ I'd0}\right] \quad (9)$$

Under unit power factor condition the SVPWAM has switching in two 60° sections thus the integration over 2π is limited down within two 60°. So the switching action is taken during the periods $(\frac{\pi}{6},\frac{-\pi}{6})$ and $(\frac{5\pi}{6},\frac{7\pi}{6})$.

The switching losses are given by:

$$Psw_{\_svpwam} = [Esw(on) + Esw(off)]\,\frac{1}{2\pi}\left[\int_{\frac{-\pi}{6}}^{\frac{\pi}{6}} \sin(\omega t)d\omega t\right] + \frac{1}{2\pi}\left[\int_{\frac{5\pi}{6}}^{\frac{7\pi}{6}} \sin(\omega t)d\omega t\right] \quad (10)$$

$$= \frac{2-\sqrt{3}}{2}\frac{VsIsfsw}{\pi}\left[\frac{Eon,0}{Vs0Id0} + \frac{Eoff,0}{V's0\ I'd0}\right]$$

Thus switching loss of SVPWAM method is calculated by

$$\frac{Psw_{\_svpwam}}{Psw_{\_spwm}} = \frac{2-\sqrt{3}}{2} \quad (11)$$

=13.4% compared to conventional sinusoidal PWM method

Bidirectional dc/dc converters are used in electric vehicles where battery charging and regenerative braking is required. The power flow in a bi-directional converter is usually from a low voltage end such as battery to a high voltage side known as boost operation. During regenerative braking, the power flows back to the low voltage bus to recharge the batteries know as buck mode operation. The control circuitry of the converter is shown in Fig 4. The modulating signal is compared with the carrier signal to generate the complementary pulses for the bidirectional dc/dc converter. Renewable energy sources supplement the main system at the time of energy deficit to provide the power at regulated level and get recharged through main system at the time of surplus power generation or at their lower threshold level of discharge. Therefore a bidirectional dc/dc converter is needed to be able to allow power flow in both the directions at the regulated level.

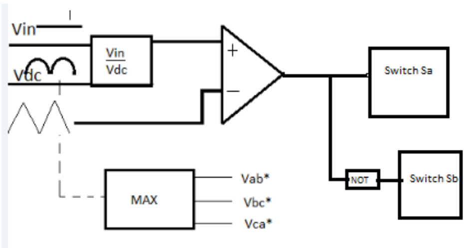


Fig 4: Control circuitry of dc/dc converter

3. MODELING OF PHOTOVOLTAIC SYSTEM

The increasing demand for energy led to the revolutionary development in renewable energy systems in the last decade. .PV systems convert the sun's radiation into usable electricity. Large number of solar cells, which is made up of semiconductor materials, is connected together in series and parallel combinations to form a solar array of required power. Modeling of PV modules or arrays is required in order to design and monitor these systems. Modeling of PV modules or arrays is required in order to design and monitor these systems. A PV system can be modeled by using the equations described in [19] and [20].

4. SIMULATION RESULTS

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 [21] 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 circuit diagram of the system is shown in Fig 5.

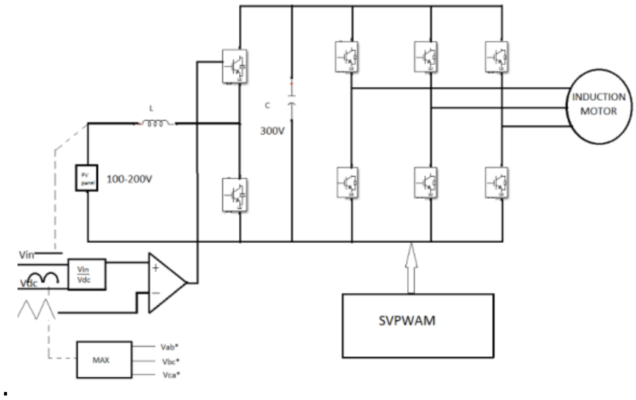


Fig 5: Converter Inverter fed Induction motor drive system

The machine specifications for which simulations are carried out is shown in detail in Table II.

Table II: Three Phase Induction Motor Specifications

Rotor Type	Squirrel Cage
Rated Speed	1450 rpm
Frequency	50 Hz
Rated power	2HP
Reference Frame	Stationary
Poles	4
R_s	0.435 Ω
R_r	0.816 Ω
L_{ls} =L_{lr}	2e-3 H
L_m	8e-3 H
J, Moment of inertia	0.089

The input dc voltage can be varied from 100 to 200V.The dc link voltage is made to be a have a voltage of 300V.

The simulation results for SVPWAM for a voltage source inverter fed Induction motor has been simulated using MATLAB/Simulink. The following waveforms were obtained. The simulation parameters are V_{in} =100V, L=1mH, C=2μF, f_s=10kHz.

The dc voltage can be generated using PV array. This can be given as the input to the converter as shown in Fig 6. The PV curve and IV curve of the PV array are shown in Fig 7 and Fig 8.

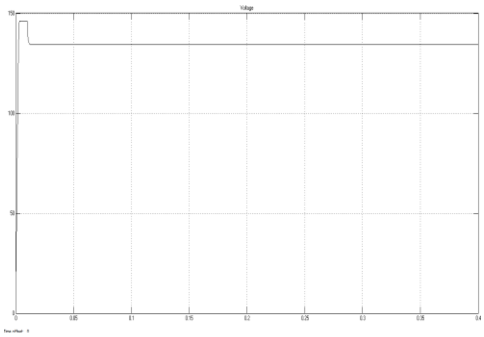


Fig 6: Input dc voltage from PV array

(x axis: 0.05s/div, y axis: 50V/div)

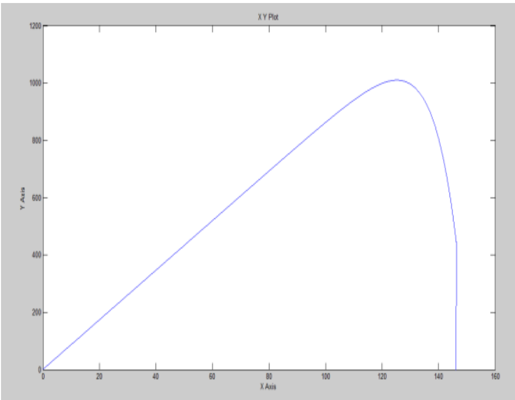


Fig 7: P-V curve of the PV array

(x axis: 0.002s/div, y axis: 50V/div)

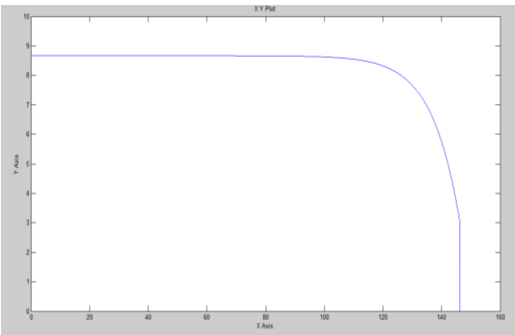


Fig 8: I-V curve of the PV array

(x axis: 0.002s/div, y axis: 50V/div)

The reference dc link voltage given to the converter with V_{dc}=300V is shown in Fig 9. The dc input to the inverter is controlled by the bidirectional dc/dc converter through the control circuitry as shown in Fig4 by which a 6ω varied voltage is generated. . The output of the dc-dc converter is obtained as shown in Fig 10.

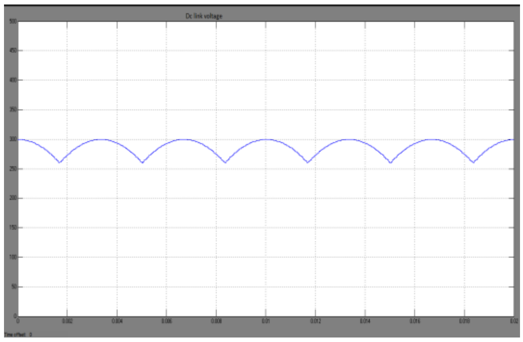


Fig 9: Reference dc link voltage (V_{dc}=300V)

(x axis: 0.002s/div, y axis: 50V/div)

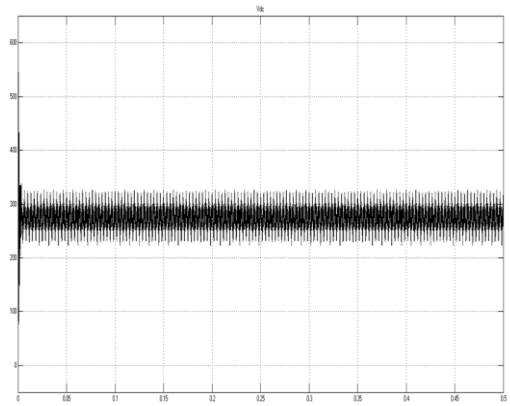


Fig 10: A 6ω dc link voltage (V_{dc}=300V)

(x axis: 0.05s/div, y axis: 100V/div)

The switching pulses for the inverter are shown in Fig 11 where we can see the number of switching's reduced by using SVPWAM. The line voltage has nearly sinusoidal variation as shown in Fig 12.

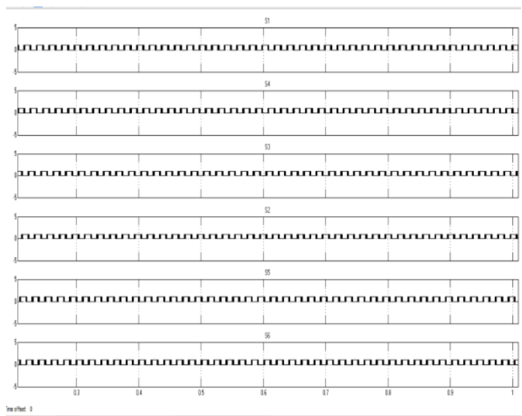


Fig 11: Switching pulses for SVPWAM method

(x axis: 0.1s/div, y axis: 5V/div)

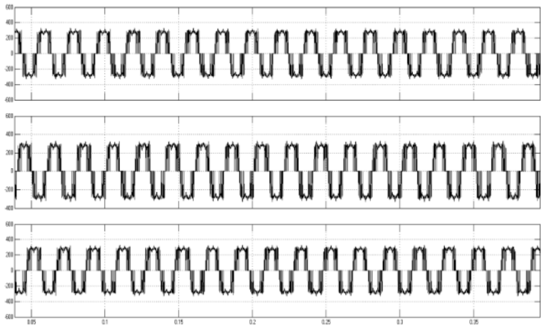


Fig 12: Line voltage for the inverter Vin = 100 V, Vdc avg = 300 V, Po = 1 HP, fo = 50 Hz, fsw = 10 kHz. (x axis: 0.02s/div, y axis: 200V/div)

The speed response and the torque response of the machine are shown in Fig 12 and Fig 13.The torque settles at a value of 2Nm. The speed of the machine is about 320m/s.

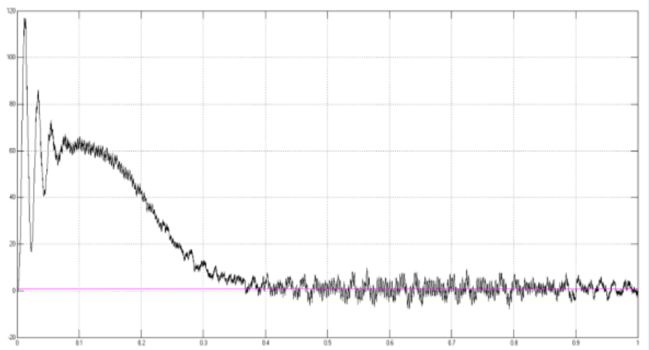


Fig 13: Torque waveform for SVPWAM inverter fed motor drive for a load torque of 2Nm(x axis: 0.1s/div, y axis: 20Nm/div)

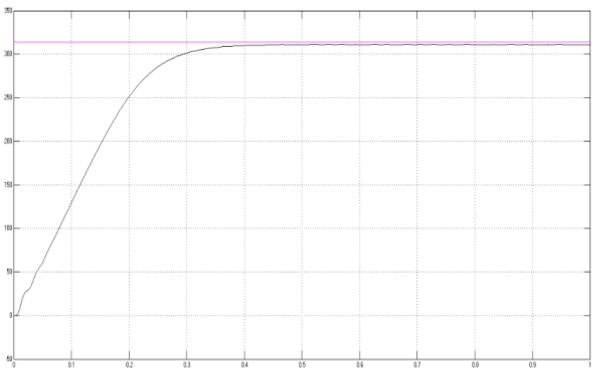


Fig 14: Speed waveform for SVPWAM inverter fed motor drive (x axis: 0.2s/div, y axis: 200rad/s/div)

5. 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 [23]. 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 Fig 13.

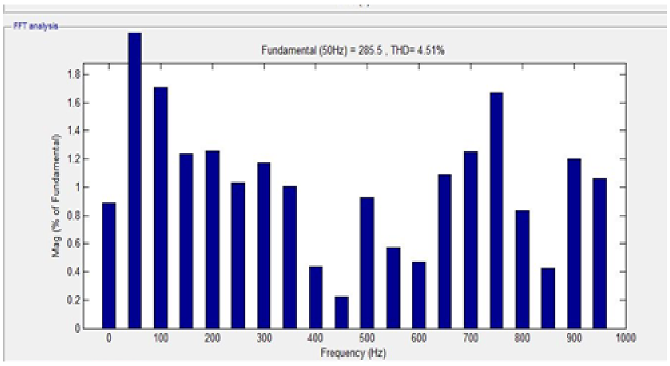


Fig 15: THD analysis of the line voltage of inverter

6. CONCLUSION

The solar powered converter inverter motor drive system has been implemented with SVPWAM method. It is seen that the inverter switching losses are reduced theoretically. The THD was found to be less in the proposed system. The system can be improved by applying any MPPT technique to the dc/dc converter. Also if the switching losses in the converter side can also be reduced then the system efficiency can be improved to a great extend.

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, pp.266-274 ,Jan 2014.

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

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

[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,pp. 518–525, May/Jun. 1996.

[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., pp. 300–306, Jun. 1993.

[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., vol. 4, pp. 1694–1701 ,Oct. 8–12, 2006.

[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., pp. 443– 448,Jun. 21–24, 2010.

[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., vol. 21, no. 5, pp. 1470–1478 ,Sep. 2006.

[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,pp. 312–320, Jan. 2008.

[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, pp. 1124–1131, Sep./Oct. 1999.

[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,pp. 287–292, Mar./Apr. 1995.

[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, pp. 704–714, Jul. 1997.

[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, pp. 1692–1706, Jul. 2008.

[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), pp. 618- 623, 2010 IEEE.

[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*), pp.946-950, 5-9 Feb. 2012.

[16] Datasheet: Powerex Duel-in-line intelligent power module 10 Amperes/600 Volts

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

[18] Keliang Zhou, and Danwei Wang, "Relationship between space vector modulation and three phase carrier-based PWM: A Comprehensive Analysis", *IEEE Transactions on Industrial Electronics*, vol. 49, No.1, pp.186-196, February 2002.

[19] Altas,I.H, Sharaf,A.M.. "A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment," Clean Electrical Power, 2007, *ICCEP '07.International Conference*, 21-23 , pp.341-345, May 2007 .

[20]E. Mboumboue, D. Njomo, " Mathematical Modeling and Digital Simulation of PV Solar Panel using MA TLAB Software," *International Journal of Emerging Technology and Advanced Engineering*, Volume 3, Issue 9, September 2013, ISSN 2250-2459.

[21] 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

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

[23] Swetha C , 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.