International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Comparative Analysis of SVPWM and DSVPWM Control Techniques for a Single-Phase to Three-Phase Conversion System

CH. Sridevi[1], I. Ravikiran[2]

[1]Electrical Department, GMRIT,
GMRIT Campus, Rajam, Andhra Pradesh, India
Sridevi.swathi9999@gmail.com

[2]Elextrical Department, GMRIT,
GMRIT Campus, Rajam, Andhra Pradesh, India
Ravikiran.i@gmrit.org

Abstract: ***This paper presents a Single-phase to Three-phase drive system with two parallel single-phase rectifiers, a three-phase inverter and an induction motor. It reduces the harmonic distortion at the input converter side, rectifier switch currents, reduction in the input current processed by parallel connection of rectifiers and reduction of the output voltage processed by series connection of inverters. The pulse pattern for rectifier is generated through pulse width modulation (PWM) technique. The switching pulse for inverter is generated through Space vector pulse width modulation (SVPWM) &Discontinuous space vector pulse width modulation (DSVPWM) techniques and both the techniques are implemented using MATLAB/SIMULINK and the response of the system is observed for SVPWM and DSVPWM.***

Keywords: Power conversion, pulse width modulation (PWM), space vector PWM, discontinuous space vector PWM and THD.

1. Introduction

A Single-phase system has lower cost features compared to Three-phase system in the power distribution system. Due to the usage of three-phase motors (because of better performance), it necessitates the conversion of Single-phase system to Three-phase system [1]. But the problems associated with this conversion system are increased number of components, distortion and irregular distribution of power among the switches of the converter, which may give rise to power quality issues in source side and performance issues in load side. An alternative topology as shown in Fig.1 studied, which reduces the rectifier switch-currents, harmonic distortion at the input converter side and it shows improvements in the fault tolerance characteristics [1]-[6]. By parallel connection of the rectifier, current processed at the input side reduces and reduction of the output voltage processed by series connection of inverter [7].

The development of this paper is done by implementing space vector PWM control technique in continuous & discontinuous modes for three-phase inverter. Three-phase SVPWM, increases the dc-bus utilization compared to PWM based on sine-triangle comparison technique[8] and DSVPWM can effectively reduce the switching loss & output current ripple compare to SVPWM[12].

2. Control Technique for Rectifier

The output voltage of the single-phase converter is controlled by pulse width modulation technique. Pulse width modulation (PWM) is a technique where the duty ratio of a pulsating waveform is controlled by comparing reference

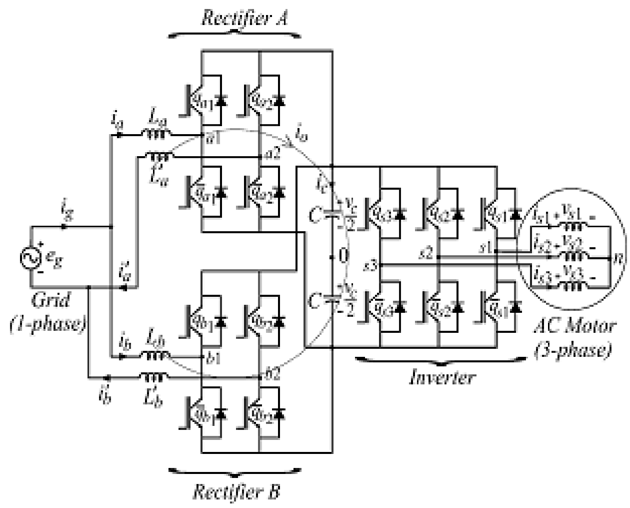


Figure1: Single-Phase to Three-Phase drive system

wave with carrier wave [8] (here triangular wave is considered as reference wave and dc signal is considered as carrier wave).

The output voltage of the converter can be determined in two steps. One, by considering only one pair of pulses, which are produced by comparing triangular wave with dc signal and if one pulse start at $wt = \alpha_1$ ends at $wt = \alpha_1 + \delta_1$ and the next pulse start from $wt = \pi + \alpha_1$ and ends at $wt = \pi + \alpha_1 + \delta_1$. Two, by joining the effects of all pairs [15].

If m^{th} pulse starts at $wt = \alpha_m$ and its width is α_m, the average output voltage due to 'p' number of pulses is found from

$$V_{dc} = \sum_{m=1}^{p}[\frac{2}{2\pi}\int_{\alpha_m}^{\alpha_m+\delta_m} V_m \sin wt d(wt)]$$

$$= \frac{V_m}{\pi}\sum_{m=1}^{p}[\cos\alpha_m - \cos(\alpha_m+\delta_m)]$$

3. Control Technique for Inverter

The output voltage of the inverter can be controlled by implementing space vector PWM control technique either in continuous and discontinuous mode.

3.1 Space Vector Pulse Width Modulation (SVPWM)

In the case of the neutral point of the load is isolated, neutral current does not exist and inverter line to line voltage is the only source to determine the load current subcarrier frequency component. Thus, the common mode voltage (CMV) can be freely varied. In such applications, the injection of the zero sequence-signal to the reference waves significantly shifts the reference waves in vertical direction with respect to carrier wave, which implies the average value of the inverter line to line voltage is not affected and it improves the voltage linearity, harmonic distortion and switching frequency characteristics [9].

One of the method to improve the harmonic distortion by injecting zero sequence signal is space vector pulse width modulation (SVPWM). SVPWM is an algorithm for the control of pulse width modulation. It is used for the creation of ac waveforms; most commonly to drive three-phase ac powered motors at varying speeds from dc using multiple class-D amplifiers.

In three-phase VSI, the carrier wave may be triangular or sawtooth for each phase can be randomly selected. On the other hand, the carrier wave of one phase is phase shifted with respect to the carrier wave of another phase. Conventionally one common carrier wave is used for all three phases due to its symmetrical switching sequence which results in low harmonic distortion and low switching losses.

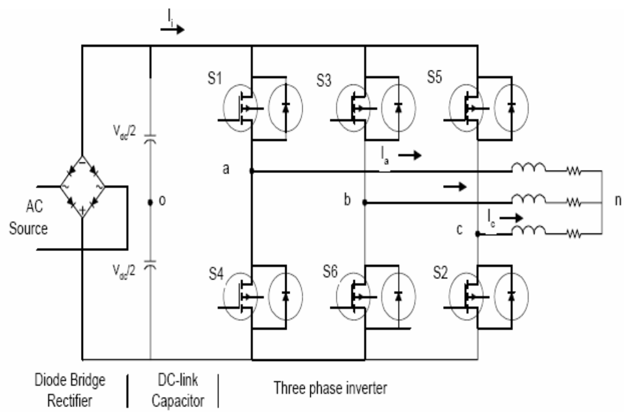


Figure 2: Three-Phase Voltage source Inverter

The circuit of the three-phase PWM inverter is shown in fig.2. When the upper switch of the inverter is turned on(a, b, c value is 1), then the corresponding lower switch is turned off(a, b, c value is 0). Then the three- phase inverter forms eight voltage vectors [7]. Out of these eight vectors, six vectors are non-zero vectors and two vectors are zero vectors. The output voltage of the inverter is calculated by using the following equations;

- Line to Line Voltage Vectors

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc}\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (1)$$

- Line to neutral Voltage Vector

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{1}{3}V_{dc}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ 1 & -1 & 2 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (2)$$

By substituting voltage vectors in equations(1)&(2), we can calculate the output voltage of the inverter and the voltages are shown in Table-1 [8].

Table1: Switching pattern and output vectors

Voltage vectors	Switching vectors			Line to neutral voltage			Line to line voltage		
	a	b	c	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
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

(Note that the respective voltage should be multiplied by V_{dc})

These voltage vectors form a hexagon, which consists of 6 sectors spanning 60^0 each [11]. Consider the reference voltage vector V_{ref} with an angle α as shown in fig-3.

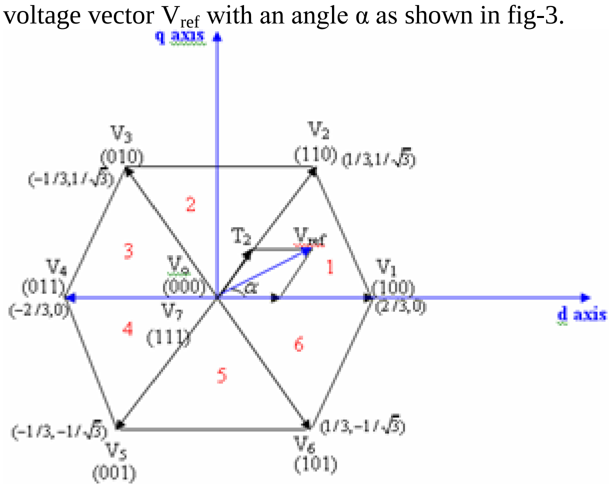


Figure 3: Basic switching vectors and sectors

For each sector we can determine the ON/OFF time period of each switch and this switching time in any sector is calculated by using equations (3) & (4) [7].

$$T_1 = \frac{\sqrt{3}T_s V_{ref}}{V_{dc}} \sin(\frac{n\pi}{3} - \alpha) \quad (3)$$

$$T_2 = \frac{\sqrt{3}T_s V_{ref}}{V_{dc}} \sin(\alpha - \frac{(n-1)\pi}{3}) \quad (4)$$

$$T_0 = T_s - T_1 - T \quad (5)$$

Here T_s is time period of the switching sequence.

By using these switching time periods, we can generate the switching time of each switch in any sector and the switching time of the switches are shown in table-2[10].

Table2: Switching time table at each sector

sector	Upper switches (S_1, S_3, S_5)	Lower switches (S_4, S_6, S_2)
1	$S_1=T_1+T_2+T_0/2$ $S_3=T_2+T_0/2$ $S_5=T_0/2$	$S_4=T_0/2$ $S_6=T_1+T_0/2$ $S_2=T_1+T_2+T_0/2$
2	$S_1=T_1+T_0/2$ $S_3=T_1+T_2+T_0/2$ $S_5=T_0/2$	$S_4=T_2+T_0/2$ $S_6=T_0/2$ $S_2=T_1+T_2+T_0/2$
3	$S_1=T_0/2$ $S_3=T_1+T_2+T_0/2$ $S_5=T_2+T_0/2$	$S_4=T_1+T_2+T_0/2$ $S_6=T_0/2$ $S_2=T_1+T_0/2$
4	$S_1=T_0/2$ $S_3=T_1+T_0/2$ $S_5=T_1+T_2+T_0/2$	$S_4=T_1+T_2+T_0/2$ $S_6=T_2+T_0/2$ $S_2=T_0/2$
5	$S_1=T_2+T_0/2$ $S_3=T_0/2$ $S_5=T_1+T_2+T_0/2$	$S_4=T_1+T_0/2$ $S_6=T_1+T_2+T_0/2$ $S_2=T_0/2$
6	$S_1=T_1+T_2+T_{0/2}$ $S_3=T_0/2$ $S_5=T_1+T_0/2$	$S_4=T_0/2$ $S_6=T_1+T_2+T_0/2$ $S_2=T_2+T_0/2$

3.2 Discontinuous Space Vector Pulse Width Modulation (DSVPWM)

To obtain SVPWM, we require two non zero voltage vectors and two zero vectors in each sector and one zero vector (000) start at the start of the switching period, another zero vector (111) end at the switching period[14]. It is possible to join the two successive half cycle non-zero voltage vectors, to eliminate one zero voltage vector resulting in discontinuous space vector PWM (DSVPWM). Because of this method, switching period of the sector is reduced, as a result switching losses are reduced [13]. There are two types of modulation schemes are available in DSVPWM depending on the variation in the placement of the zero vectors.

1. 120^0 Discontinuous modulation

a) DPWMMIN
b) DPWMMAX

2. 60^0 Discontinuous modulation

a) DPWM0
b) DPWM1
c) DPWM2

In 120^0 Discontinuous modulation, fix the lower dc bus as selected V_0(000) for all six sectors is called DPWMMIN and fix the upper dc bus as selected V_7(111) for all six sectors is called DPWMMAX.

In 60^0 Discontinuous modulation, alternatively place zero vectors for successive 60^0 segments. In this, DPWM1 is fixed at positive and negative dc bus for each sector which is suitable for resistive load. In DPWM0 and DPWM2, alternatively place zero vectors in each 60^0 variation depend up on the peak value of the load current at each 60^0. Both types give higher reduction in switching losses than DPWM1.all among these methods DPWM2 is the most preferable method for power factor correction operation [16].

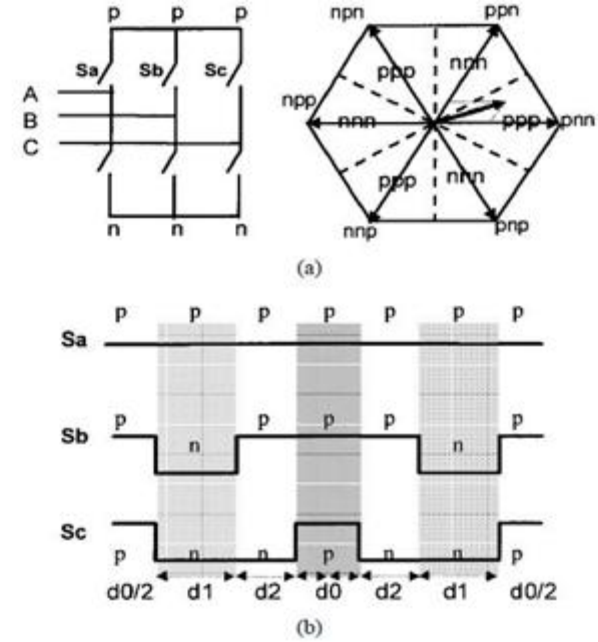


Figure 4: 60^0 Discontinuous modulation

In DPWM2 (30^0 lagging mode), to illustrate the modulation method, take S_a, S_b, Sc are the control signals for top switches for three phase inverter. If we consider reference vector as sector1, phase A voltage become the maximum voltage compare to other the phases. Therefore the top switches of the phase A will keep in conduction in sector1 [9]. According to this, the peak value of the phase A is positive at sector1 and negative at sector4. On the other hand the peak value of the phase B is positive at sector3, negative at sector6 and the peak value of the phase C is positive at sector5, negative at sector2[16].

4. Comparative analysis

We can show the improvement in the performance of single-phase to three phase system using DSVPWM compare to SVPWM by showing the improvement in total harmonic distortion (THD), common mode voltage (CMV), switching losses, power factor correction (PFC).

4.1 Total Harmonic Distortion (THD)

THD of a signal is measurement of the harmonic distortion present in that signal and this is defined by the ratio of the sum of the power of all harmonic components to the power of the fundamental frequency. THD is used for describe the power quality of electric power system.

Consider a system with an ac source and electric load (load is going to take to one of the two loads linear or non linear). If we consider linear loads, we can get sinusoidal current or voltage wave form, otherwise the current wave form deviates from a sinusoidal, because of this deviates distortion are created in that wave form, it is composite of multiple wave forms called harmonics [17].

Frequencies of harmonics are integral multiple of the fundamental frequency. Given 50HZ fundamental wave form, the 2nd, 3rd, 4th harmonic components will be at 100HZ, 150HZ and 200HZ respectively. THD can be calculated by using equation (6).

$$THD = \frac{\sqrt{\left(V_2^2 + V_3^2 + V_4^2 + ... + V_n^2\right)}}{V_1} * 100\% \qquad (6)$$

Where V_2, V_3, V_4…are the harmonic components of voltage wave form and V_1 is the fundamental component of voltage wave form.

In power system, lower THD means reduction in peak currents, heating, emissions and core loss in motors.

4.2 Common Mode Voltage (CMV)

The common mode voltage is defined as the difference between stator neutral point of the motor and electrical ground or dc bus mid-point.

By considering switching function of the inverter S_x using SVPWM and dc bus voltage, we can get the voltage at the neutral point of the motor. Then, the neutral point voltage is defined as

$$V_{xg} = V_{dc}(S_x - \frac{1}{2}) \qquad (7)$$

When S_x=1, the upper switch of the corresponding phase Arm of the inverter is turned-ON
S_x=0, the lower switch of the corresponding phase Arm of the inverter is turned-ON

Then Common mode voltage (CMV) here is defined as neutral voltage with respective to the dc bus mid-point. So

$$V_{com} = \frac{V_{dc}}{3} \sum_{x=a}^{c} S_x - \frac{V_{dc}}{2} \qquad (8)$$

Equation (8) shows that the CMV will have the magnitude of $\pm \frac{V_{dc}}{2}$ or $\pm \frac{V_{dc}}{6}$ depending up on the switching frequency.

Since the common mode voltage (CMV) changes among the above switching pattern of the inverter, it induces motor shaft voltages and bearing currents that can result in premature motor bearing failures. Also, the common-mode voltage can cause common-mode current to flow through the ground conductor of the motor and back into the power mains causing conducted EMI[18].

4.3 Switching Losses

In power electronics switching losses typically contribute a significant amount to the total system losses and it is the important parameter for analyzing the system efficiency, i.e. if we reduce the switching losses in the system, the point of load system efficiency increases. So, for the designers of converters accurate switching loss model become the important target. To improve reliability of the design based on the calculation of the junction temperature time behavior, it is necessary to calculate the switching losses[19].

The switching losses in the IGBT and the Diode are the product of switching energies & the switching frequency (f_{sw}).

$$P_{swT} = (E_{onT} + E_{offT}) \times f_{sw} \qquad (9)$$

$$P_{swD} = (E_{onD} + E_{offD}) \times f_{sw} \qquad (10)$$

Here the turn- on energy losses in IGBT (E_{onT}) can be calculated as the sum of the switch on energy without taking reverse recovery process in to account(E_{onTi}) and the switch on energy caused by the reverse recovery of the free-wheeling diode(E_{onTrr}) and turn-on energy in the diode consists mostly of the reverse-recovery energy(E_{onD}).

$$E_{onT} = E_{onTi} + E_{onTrr} \qquad (11)$$

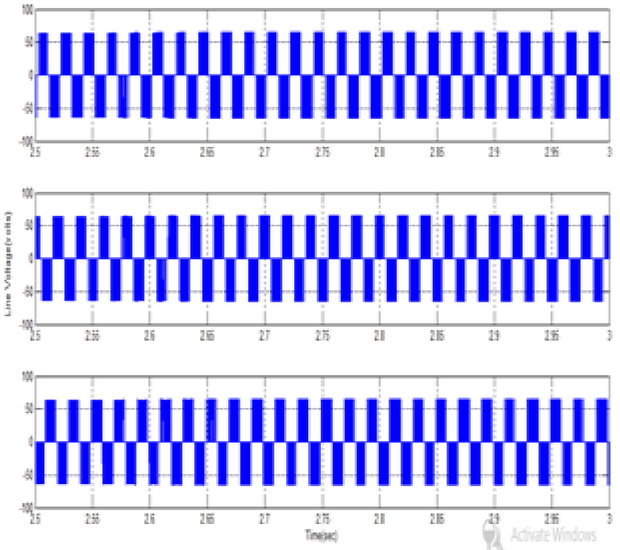
4.4 Power Factor Correction

Power factor is the ratio between the useful power (KW) to the total power (KVA) consumed by an item of a.c electrical equipment. The ideal power factor is unity. If the power factor of the equipment is less than one, extra power is required to get the unity value [20].

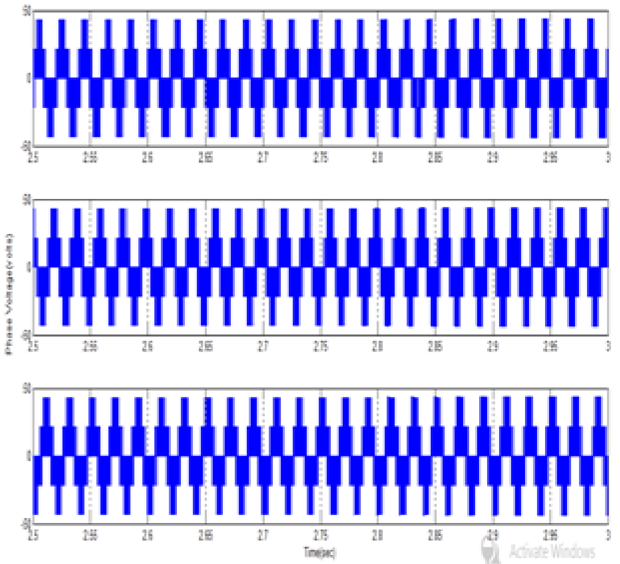
Basically the poor power factor is caused by the significant phase difference between the voltage and current at the load terminal or due to the high harmonic content or distorted current waveform.

5. Simulation Results

The simulation output voltages of the single phase to three phase system using SVPWM and DSVPWM control techniques are shown in Fig.5&6. The Total Harmonic Distortion (THD) of SVPWM&DSVPWM is shown in Fig.7&8 respectively. From that graphs we can observe that the THD of the DSVPWM is less compare to SVPWM. Because of the reduction in the THD, the power factor improves. The Common-mode Voltage (CMV) of SVPWM&DSVPWM is shown in Fig.9&10 respectively. From that graphs we can observe that the positive voltage of DSVPWM is less compare to SVPWM. So DSVPWM improves the Common-mode Voltage. In SVPWM technique four switches are conduction in each sector and only three switches are conduction in DSVPWM technique. So the switching losses are less in this system using DSVPWM technique compare to SVPWM technique.

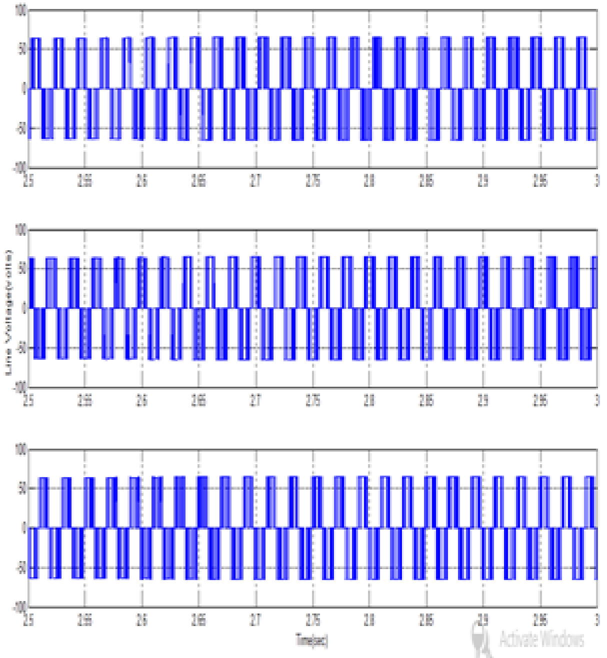


(a)

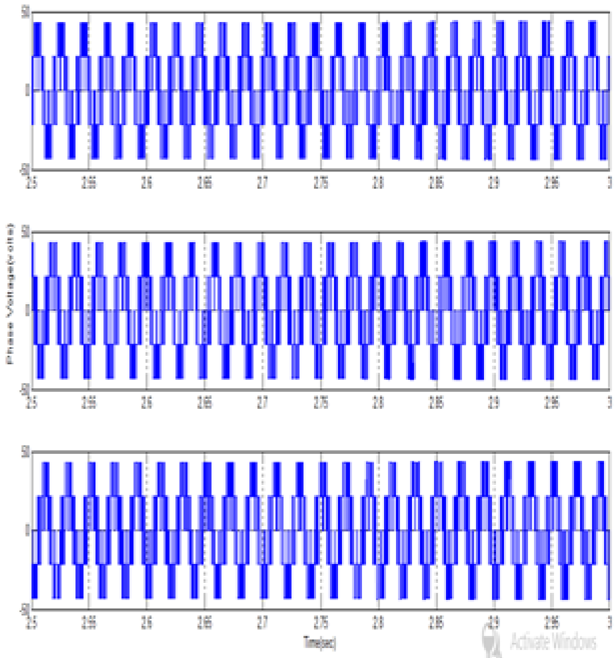


(b)

Figure 5: SVPWM Output Voltages a) Line Voltage b) Phase Voltage



(a)



(b)

Figure 6: DSVPWM Output Voltages a) Line Voltage b) Phase Voltage

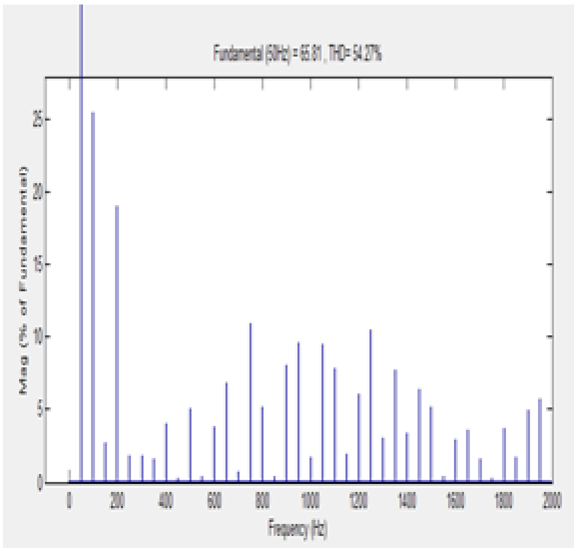


Figure7: Total Harmonic Distortion (THD) of SVPWM

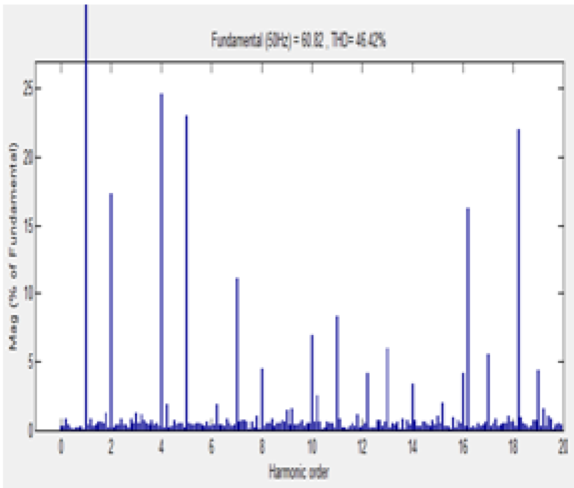


Figure 8: Total Harmonic Distortion (THD) of DSVPWM

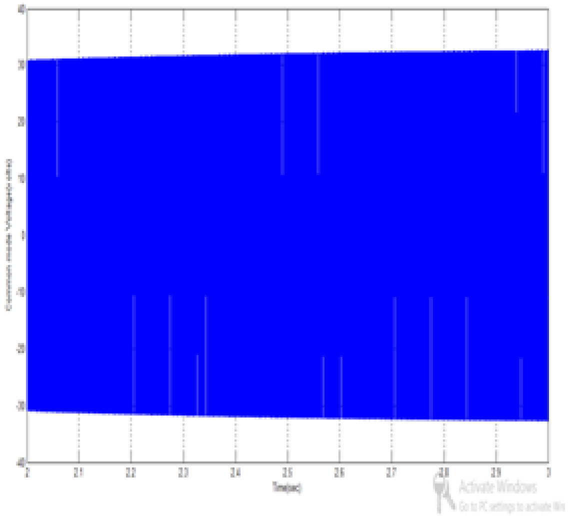


Figure 9: Common Mode Voltage (CMV) SVPWM

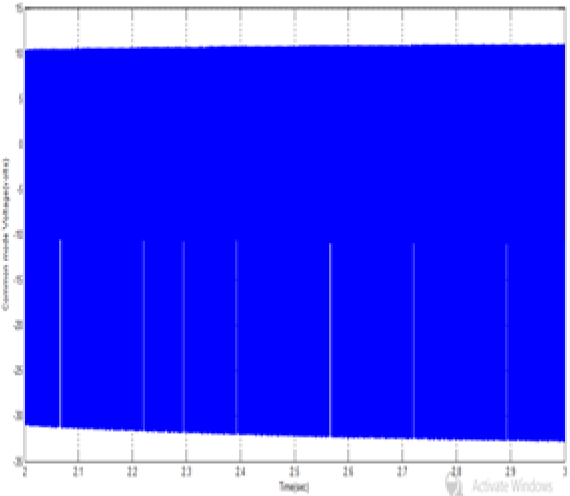


Figure 10: Common Mode Voltage (CMV) DSVPWM

6. Conclusion

By the parallel connection of two rectifiers at the input side, we can reduce the harmonic distortion, rectifier switch currents and improves the fault tolerance characteristics. From the results we can observe that the improvement in the Total harmonic distortion (THD), Power factor, Common-mode Voltage (CMV) and switching losses of the system by using DSVPWM technique compared to SVPWM technique.

References

[1] Cursino Brandao Jacobina, Euzeli Cipriano dos Santos, Nady Rocha and Edgard Luiz Lopes Fabr´ıcio "Single-Phase to Three-Phase Drive System Using Two Parallel Single-Phase Rectifiers" IEEE Transactions on Power Electronics, vol. 25, no. 5 , pp.1285-1295, May 2010.

[2] Euzeli Cipriano dos Santos, Cursino Brandao Jacobina, Jose Artur Alves Dias, and Nady Rocha "Single-Phase to Three-Phase Universal Active Power Filter" IEEE Transactions on Powe Delivery, vol. 26, no.3, pp.1361-1371, July 2011.

[3] Euzeli Cipriano dos Santos, Cursino Brand˜ao Jacobina, Edison Roberto Cabral da Silva, and Nady Rocha "Single-Phase to Three-Phase Power Converters: State of the Art" IEEE Transactions on Power Electronics, vol. 27, no. 5, pp.2437-2452, May 2012.

[4] Euzeli Cipriano dos Santos, Cursino Brandão Jacobina, Gregory Arthur de Almeida Carlos, and Isaac Soares de Freitas "Component Minimized AC–DC–AC Single-Phase to Three-Phase Four-Wire Converters" IEEE Transactions on Industrial Electronics, vol. 58, no. 10, pp.4624-4635, October 2011.

[5] Kazuya Inazuma, Hiroaki Utsugi, Kiyoshi Ohishi, and Hitoshi Haga "High-Power-Factor Single-Phase Diode Rectifier Driven by Repetitively Controlled IPM Motor" IEEE Transaction on Industrial Electronics, vol. 60, no. 10, pp.4427-4437, October 2013.

[6] Euzeli Cipriano dos Santos, Nady Rocha, and Cursino Brandao Jacobina "Suitable Single-Phase to Three-Phase AC–DC–AC Power Conversion System" IEEE Transaction on Power Electronics, vol.30, no. 2, pp.860-870, Feb 2015.

[7] K. Vinoth Kumar, Prawin Angel Michael, Joseph P. John and Dr. S.Suresh Kumar " Simulation and comparison of SPWM and SVPWM control for Three-Phase Inverter" ARPN Journal of Engineering and Applied Sciences, vol.5, no. 7, pp. 61-74, July 2010.

[8] Said Ahmed-Zaid, Elisa Barney Smith, and John Chiasson "MATLAB/Simulink Implementation and Analysis of Three Pulse Width-Modulation (PWM) Techniques" Master of Science in Electrical Engineering, May 2012.

[9] Ahmet M.Hava, and N. Onur Cetin "A Generalized Scalar PWM Approach With Easy Implementation Features for Three-Phase,Three-Wire Voltage-Source Inverters" IEEE Transactions on Power Electronics, vol. 26, no. 5, pp.1385-1395, May 2011.

[10] M. Kubeitari, A. Alhusayn, and M. Alnahar "Space Vector PWM Simulation for Three Phase DC/AC Inverter" World Academy of nScience, Engineering and Technology, vol. 6, pp. 644-649, Dec 2012.

[11] Atif Iqbal, Adoum Lamine, Imtiaz Ashraf, and Mohibullah "Matlab/Simulink model of Space Vector PWM for Three-phase voltage source Inverter".

[12] Mahammad Arif Khan, Atif Iqbal, and Abu Rub Haitham "Investigation of Discontinuous Space Vector PWM Techniques of a Three-Phase voltage source Inverter" i-managers journal on Electrical Engineering, vol. 2,no. 3, pp. 60-71, Jan-March 2009.

[13] Atif Iqball, Sk Moin Ahmed, Mohammad Arif Khan, and Haitham Abu-Rub "Generalised simulation and experimental implementation of space vector PWM technique of a three-phase voltage source inverter" International Journal of Engineering, Science and Technology, vol. 2, no. 1, pp.1-12, 2010.

[14] Atif Iqbal, Mohd. Arif Khan, Sk. Moin Ahmed, M. Rizwan Khan, and Haitham Abu-Rub "Analysis of Discontinuous Space Vector PWM Techniques for a Five-phase Voltage Source Inverter"International Journal of Recent Trends in Engineering, vol. 2, no. 5, pp.222-226, Nov 2009.

[15] Mahammad H.Rashid "Power Electronics Circuits, Devices, and Applications" Prentice Hall, 2.

[16] Chakrapong Charumit and Vijit Kinnares"Discontinuous SVPWM Techniques of Three-Leg VSI-Fed Balanced Two-Phase Loads for

ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Reduced Switching Losses and Current Ripple" IEEE Transaction on Power Electronics, vol. 30, no. 4, pp. 2194-2204, April 2015.
[17] Lundquist and Johan On Harmonic Distortion in Power Systems, Chalmers University of Technology: Department of Electrical Power Engineering, 2001.
[18] Mohan M. Renge and Hiralal M. Suryawanshi "Five-Level Diode Clamped Inverter to Eliminate Common Mode Voltage and Reduce dv/dt in Medium Voltage Rating Induction Motor Drives" IEEE Transactions on Power Electronics, vol. 23, no. 4, pp.1598-1607, July 2008.
[19] Dr.Dusan Graovac, Marco Purschel "IGBT Power Losses Calculation Using the Data-Sheet Parameters" Application Note, V 1. 1 , Jan 2009.
[20] John Ware "Power Factor Correction".