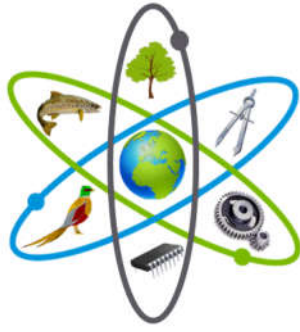TITLE: A Comparison Study of Sinusoidal PWM and Space Vector PWM Techniques for Voltage Source Inverter

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-RESEARCH ARTICLE-

A Comparison Study of Sinusoidal PWM and Space Vector PWM Techniques for Voltage Source Inverter

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Abstract

In this paper, the methods used to control voltage source inverters, which have been intensively investigated in recent years, are compared. Although the most efficient result is obtained with the least number of switching elements in the inverter topologies, the method used in the switching is at least as effective as the topology. Besides, the selected switching method to control the inverter will play an effective role in suppressing harmonic components while producing the ideal output voltage. There are many derivatives of pulse width modulation techniques that are commonly used to control voltage source inverters. Some of widespread methods are sinusoidal pulse width modulation and space vector pulse width modulation techniques. These modulation techniques used for generating variable frequency and amplitude output voltage in voltage source inverters, have been simulated by using MATLAB/SIMULINK. In addition, the total harmonic distortions of the output voltages are compared. As a result of simulation studies, sinusoidal pulse width modulation has been found to have more total harmonic distortion in output voltages of voltage source inverters in the simulation. Space vector pulse width modulation has been shown to produce a more efficient output voltage with less total harmonic distortion.

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Introduction

DC-AC converters are known as inverters. The function of an inverter is to convert the DC input voltage to a symmetrical AC output voltage of the desired amplitude and frequency. One of the most common problems in the power electronics industry is low-order harmonics, which cause distortions in voltage and current (Kumar, Michael, John, & Kumar, 2010). One solution to reduce low-level harmonics in high-power converters is to use PWM control techniques. There are many studies about PWM control techniques in the last decades (Ashish & Sanjiv, 2012; Colak & Kabalci, 2016; Durgasukumar & Pathak, 2012; Jesmin F. Khan, 2013; Vural, 2016; Guoqiang, Jianli, & Junwei, 2013; Wanchai, 2016; Gopalakrishnan & Narayanan, 2014; Oka & Matsuse, 2011). As can be seen from these studies; the point of density of the studies is low-order harmonics, which is a common problem. In this study, SPWM and SVPWM techniques, which are the most common PWM techniques, have been studied in detail and the six-pulse inverter circuit is simulated with the help of MATLAB / Simulink and the controls that are controlled by these two methods are examined for harmonics.

This paper is therefore organized as follows: An overview of inverter structure and its circuit are presented in the next section. The most common used PWM techniques which SPWM and SVPWM are presented in Section 2. The simulation results and discussions are presented in Section 3. Finally, the main concluding remarks of the paper are presented in the conclusions section.

Inverter Structure

The three-phase voltage source inverter (VSI) topology is presented in Figure 1. The output voltage can be obtained by changing the DC input voltage and holding the inverter gain constant. On the other hand, if the DC input voltage is fixed and cannot be controlled, the gain of the inverter can be varied to obtain a variable output voltage. This is accomplished by pulse width modulation (PWM) in the inverter (Bedford & Hoft, 1964; Rashid, 2003). Among PWM techniques, sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) are the most widely used techniques (Vural, 2016; Guoqiang, Jianli, & Junwei, 2013; Durgasukumar & Pathak, 2012; Wanchai, 2016; Colak & Kabalci, 2016; Gopalakrishnan & Narayanan, 2014; Jesmin F. Khan, 2013; Oka & Matsuse, 2011. However, in the SPWM technique, the peak voltage of the output voltage cannot exceed the DC supply voltage without operating in the over-modulation region. The SVPWM is more flexible and can be programmed to synthesize the output voltage with a numerical application.
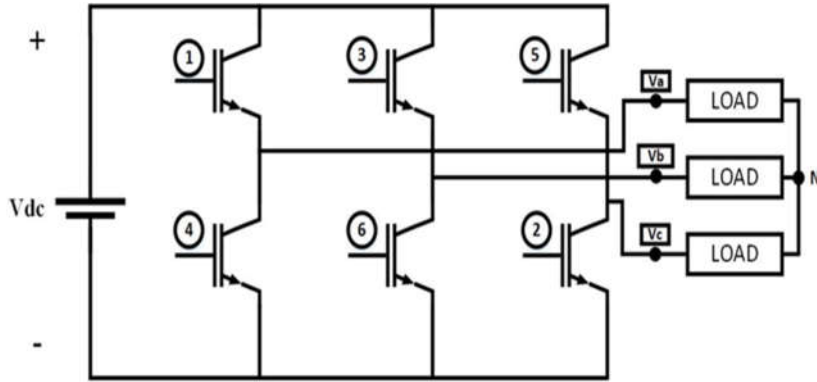
Figure 1. Three Phase VSI Topology

Sinusoidal PWM

The production of switching signals by sinusoidal PWM is shown in Figure 2. There are three sinusoidal reference waves (V_{ra}, V_{rb}, V_{rc}) each shifted by 120°. The carrier wave V_{cr} is compared to the corresponding reference signal to produce the switching signals of a phase (Nandhakumar & Jeevananthan, 2007). By comparing the carrier signal to the reference signals, the switch states G1, G2, G3, G4, G5 and G6 shown in Fig. 2. The switching elements G1 and G4, G3 and G6, G5 and G2 are not open or closed at the same time. To explain the Figure 2, if the Vcr>Vra, G1 is off and G4 is on state, Vcr<Vra, G1 is on and G4 off state, Vcr>Vrb, G3 is off and G6 is on state, Vcr<Vra, G3 is on and G6 off state, the other rule is Vcr>Vrc, G2 is off and G5 is on state, Vcr<Vrc, G2 is on and G5 off state. To determine the reference voltages, The signals can be regulated by the equation (1.1)

$$V_r = A.\sin\left(2\pi ft + \theta\right) \tag{1.1}$$

Where A is the magnitude of the signal, θ^o is the phase shift angle, $2\pi f = \omega$, angular velocity.

$$V_r = A.\sin\left(\omega t + \theta\right) \tag{1.1}$$

To determine the reference voltages for V(a-b-c) the following equations are used;

$$V_{ra} = A.sin\left(wt + 0^o\right) \tag{1.2}$$

$$V_{rb} = A.sin\left(wt - 120^o\right) \tag{1.3}$$

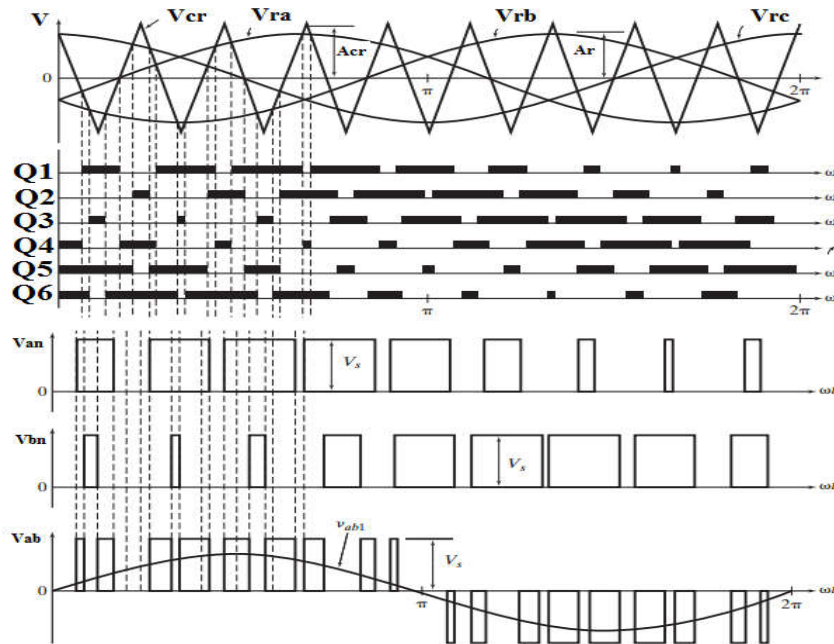$$V_{rc} = A.sin\left(wt + 120^o\right) \tag{1.4}$$

Figure 2. Sinusoidal PWM for three phase VSIs (Rashid, 2003)

The frequency of the output voltage is determined by the frequency of the reference signal. The amplitude of the reference signal determines the modulation index and in turn determines the rms value of the output voltage. The change of the rms value of the output voltage is possible by changing the modulation index (Zhenyu, Arefeen, & Issa, 1997).

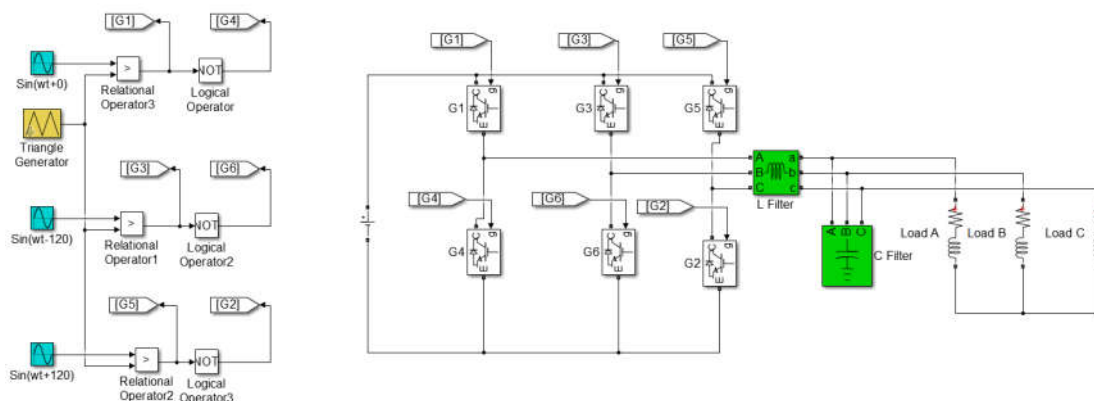The simulated SPWM circuit in MATLAB/Simulink is shown in below Figure 3.

Figure 3. Simulated Sinusoidal PWM circuit in Matlab/Simulink

Space Vector PWM

Space vector PWM avoids unnecessary switching. This leads to excellent output performance, high efficiency and reliability compared to similar inverters with conventional pulse width modulators

(Ashish & Sanjiv, 2012). In the SVPWM method, the reference signals in the abc coordinates are transformed to the normalized reference vector in the coordinates by the following transformation matrix, which is generated by the order of application and the application period of the vectors occurring in the switching states of the inverter.

Synthesis of voltage in Space Vector PWM applications; First, the transformation from a, b, c to α-β is done.

$$V_\alpha = V_{an} - \frac{1}{2}V_{bn} - \frac{1}{2}V_{cn}$$
$$V_\beta = V_{an} - \frac{\sqrt{3}}{2}V_{bn} - \frac{\sqrt{3}}{2}V_{cn}$$

(2.1)

The magnitude of the reference voltage

$$\left|V_{ref}\right| = \sqrt{\left(V_\alpha\right)^2 + \left(V_\beta\right)^2}$$

(2.2)

The angle between α-β is determined by the following equation.

$$\theta = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) = \omega t = 2\pi ft$$

(2.3)

The period of the vectors occurring in the switching states of the inverter is shown as a Clarke matrix ($T_{abc-\alpha\beta}$) which is determined by the given equations ((2.1) and (2.2)).

$$T_{abc-\alpha\beta} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}$$

(2.4)

In the inverter topology shown in Figure 1, if the switching elements G1 and G4, G3 and G6, G5 and G2 are not open or closed at the same time, eight different switching state vectors are generated. These switching vectors and the output voltages generated in these switching states are given in Table I at abc coordinates and normalized values in co-ordinates.

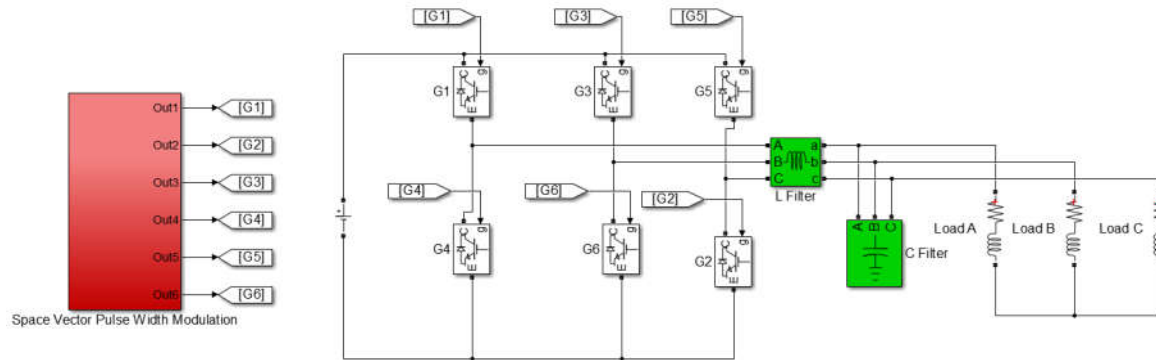The simulated SVPWM circuit in MATLAB/Simulink is shown in below Figure 4.

Figure 4. Simulated Space Vector PWM circuit in Matlab/Simulink

Table 1. Switching States of Space Vector Modulation

Vectors	Switching States			Normalized Output phase voltages			Normalized Output line voltages			Normalized $\alpha\beta 0$ Voltages		
	S_1	S_3	S_5	V_A/V_{DC}	V_B/V_{DC}	V_C/V_{DC}	V_{AB}/V_{DC}	V_{BC}/V_{DC}	V_{CA}/V_{DC}	V_α/V_{DC}	V_β/V_{DC}	V_0/V_{DC}
V0	0	0	0	0	0	0	0	0	0	0	0	0
V1	1	0	0	2/3	-1/3	-1/3	1	0	-1	2/3	0	0
V2	1	1	0	1/3	1/3	-2/3	0	1	-1	1/3	1/√3	0
V3	0	1	0	-1/3	2/3	-1/3	-1	1	0	-1/3	1/√3	0
V4	0	1	1	-2/3	1/3	1/3	-1	0	1	-2/3	0	0
V5	0	0	1	-1/3	-1/3	2/3	0	-1	1	-1/3	-1/√3	0
V6	1	0	1	1/3	-2/3	1/3	1	-1	0	1/3	-1/√3	0
V7	1	1	1	0	0	0	0	0	0	0	0	0

The representation of the vectors occurring in the switch cases at the   coordinates is shown in Figure 5. Among the space vectors that occur in switching states, there are six regions called sectors.
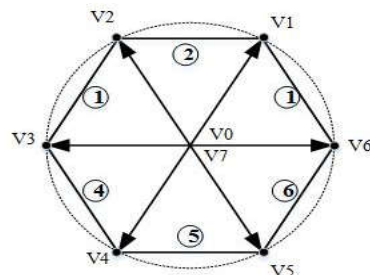

Figure 5. Three dimensional space vectors

The SVPWM method is applied in three basic steps;

Step I: The reference voltage in the abc coordinates is converted to the space vector normalized to the DC voltage in the alpha-beta coordinates and the rotation angle in the   coordinates of the reference vector is determined.

Step II: The sector in which the reference vector is located is determined and it is determined how long the vectors in the switching states must be applied in order to form the reference voltage.

Step III: Switching is performed according to the order in which the vectors in the switching states are applied.

Simulation Results

SPWM and SVPWM techniques have been applied to a three-phase VSI. Output voltage and current graphs of SPWM and SVPWM are given below in Figure 6-9.
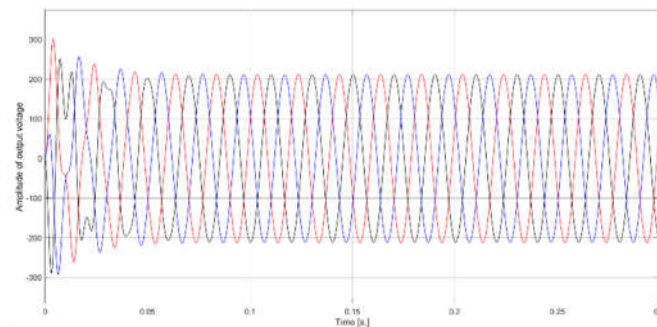

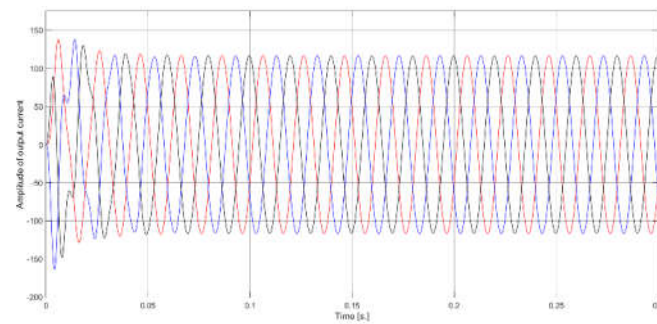**Figure 6.** Output voltage of VSI switched with SPWM

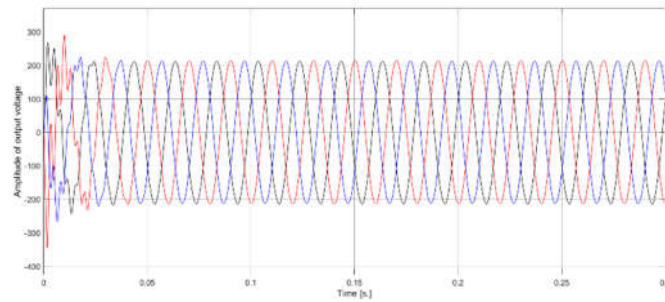**Figure 7.** Output current of VSI switched with SPWM

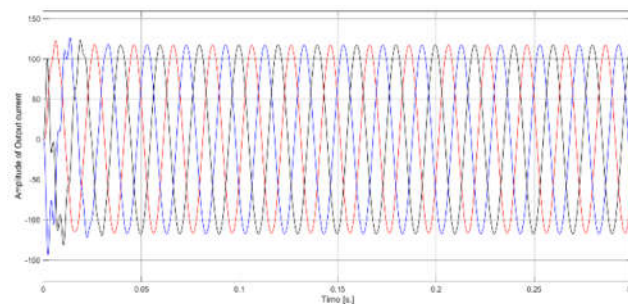**Figure 8.** Output voltage of VSI switched with SVPWM

Figure 9. Output current of VSI switched with SVPWM

As can be seen from the graphs, the output graphs of the SPWM controlled inverter show less degraded shapes.

Total harmonic distortion values of the output voltages and currents of VSI are given in Figure 10-13 and Table 2.
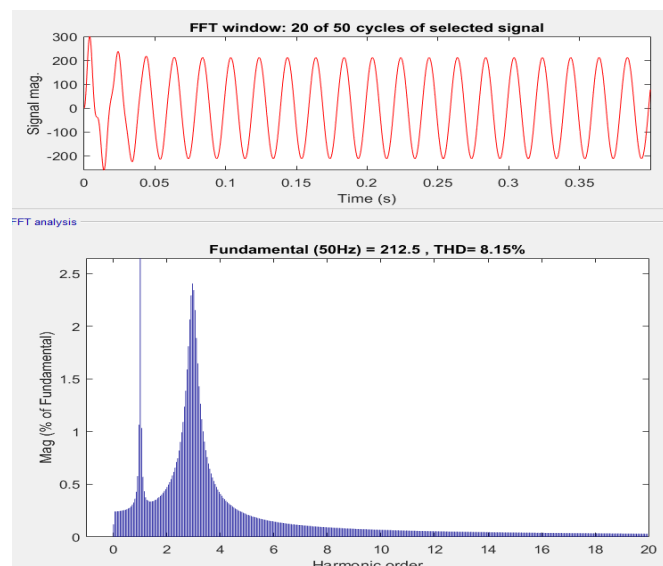

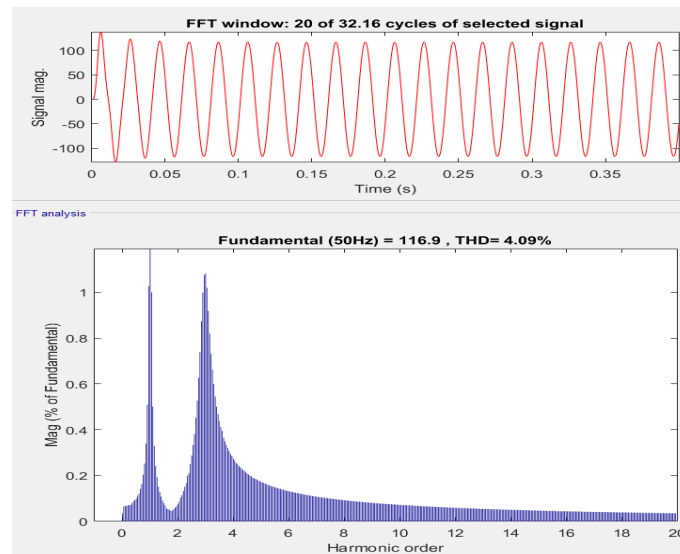**Figure 10.** Total Harmonic Distortion of Output Voltages of VSI switched SPWM

Figure 11. Total Harmonic Distortion of Output Current of VSI switched with SVPWM
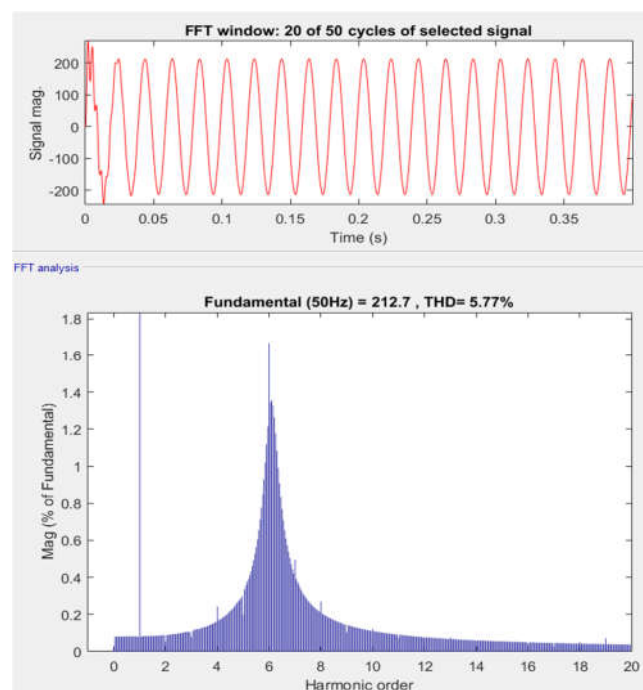

Figure 12. Total Harmonic Distortion of Output Voltages of VSI switched with SVPWM
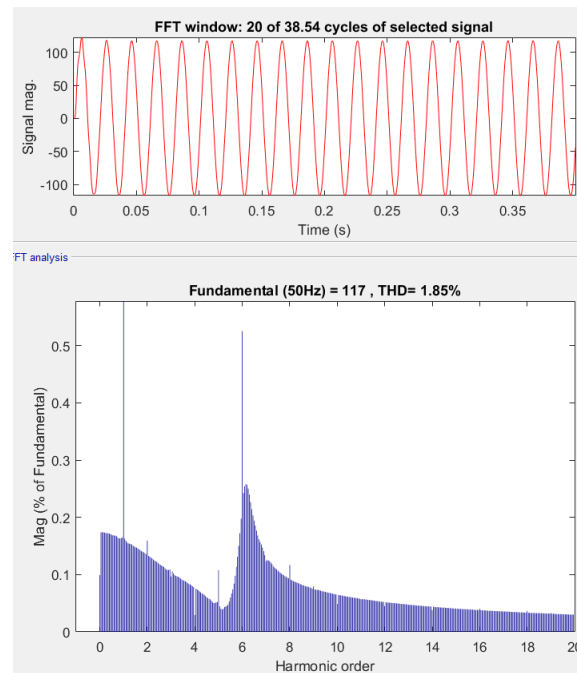
Figure 13. Total Harmonic Distortion of Output Current of VSI switched with SVPWM

Figures 10-13 show the THD plots for R = 1Ω and L = 1mh. As seen in the figures, there is less distortion in the output voltage and current of the inverter controlled by SVPWM. It is obvious that the controls made with SVPWM in the power electronics industry will cause less loss. Table 2 gives the THD values of the output voltage and current of inverters controlled by SPWM and SVPWM techniques for different load types.

Table 2. Total Harmonic Distortion(THD) for different type of load and switching technique

Switching Techniques	THD (%)							
	Voltage				Current			
	R=1Ω, L=1mH	R=10Ω, L=1mH	R=1Ω, L=3mH	R=10Ω, L=3mH	R=1Ω, L=1mH	R=10Ω, L=1mH	R=1Ω, L=3mH	R=10Ω, L=3mH
SPWM	8.15%	19.13%	17.15%	19.57%	4.09%	11.64%	6.39%	11.59%
SVPWM	5.77%	9.69%	15.19%	10.64%	1.85%	3.61%	4.48%	3.56%

In Table 2, the inductive load value for the same resistive load value is increased, the resistive load value for the same inductive load value is increased, the resistive and inductive load values are increased, and the THD values of the output voltage and current are examined. As a result, the

total harmonic distortion of the output current and voltage under different load conditions has been found to be higher in SVPWM than in SPWM switching technique.

Conclusion

In this study, SPWM and SVPWM techniques used to switch voltage source inverters have been simulated and compared under different types of load in MATLAB/SIMULINK. Figure 6, Figure 7, Figure 8 and Figure 9 show output voltage and current graphs of the voltage source inverter switched with SPWM and SVPWM. When the THD value of these voltages and currents are analyzed, THD value of the output voltage of the inverter which is controlled by SPWM is 8,15%, THD value of the current was 4.09%, THD value of the output voltage was 5.77% and the THD value of the current was 1.85% for the inverter controlled with SVPWM. In power systems, total harmonic distortion is an important factor in terms of power quality. In this study, the SPWM and SVPWM techniques used to switch voltage source inverters are compared in terms of THD. As a result of analysis, SVPWM technique has been found to be a more efficient switching method in terms of power quality. This study is a benchmarking in this respect. The aim of this study is to be able to transmit energy which obtain from renewable energy resources in the most efficient way possible and to choose the appropriate switching technique to minimize the harmonic rates to the lowest possible level. The next step of this study will be used the inverter controlled by the SVPWM technique with the renewable energy source for on-grid systems.

References

Ashish, G., & Sanjiv, K. (2012). Analysis of Three Phase Space Vector PWM Voltage Source Inverter for ASD's. *International Journal of Emerging Technology and Advanced Engineering, 2*(10), 163-168.

Bedford, B., & Hoft, R. (1964). *Principle of Inverter Circuits.* Newyork: John Wiley&Sons.

Colak, I., & Kabalci, E. (2016). Developing a novel sinusoidal pulse width modulation (SPWM) technique to eliminate side band harmonics. *International Journal of Electrical Power & Energy Systems, 44*, 861-871.

Durgasukumar, G., & Pathak, M. K. (2012). Comparison of adaptive Neuro-Fuzzy-based space-vector modulation for two-level inverter. *Electrical Power and Energy Systems, 38*, 9-19.

Gopalakrishnan, K. S., & Narayanan, G. (2014). Space vector based modulation scheme for reducing capacitor RMS current in three-level diode-clamped inverter. *Electric Power Systems Research, 117*, 1-3.

Guoqiang, C., Jianli, K., & Junwei, Z. (2013). Numeric analysis and simulation of space vector pulse width modulation. *Advances in Engineering Software, 65*, 60-65.

Jesmin F. Khan, S. M. (2013). Space vector PWM for a two-phase VSI. *Electrical Power and Energy Systems, 51*, 265-277.

Kumar, K. V., Michael, P. A., John, J. P., & Kumar, S. S. (2010). Simulation and Comparison of SPWM and SVPWM Control for Three Phase Inverter. *ARPN Journal of Engineering and Applied Sciences*, 61-74.

Nandhakumar, S., & Jeevananthan, S. (2007). Inverted Sine Carrier Pulse Width Modulation for Fundamental Fortification in DC-AC Converters. *7th International Conference on Power Electronics and Drive Systems* (s. 1028-1034). Bangkok, Thailand: IEEE.

Oka, K., & Matsuse, K. (2011). A novel PWM technique with switching-loss reduction for independent drive of two 3-phase AC motors fed by a five-leg inverter. *IEEJ Transactions on Electrical and Electronic Engineering, 6*, 260-265.

Rashid, M. H. (2003). *Power Electronics Devices, Circuits and Applications.* Upper Saddle River: NJ:Prentice Hall Inc.

Vural, A. M. (2016). PSCAD modelling of a two-level space vector pulse width modulation algorithm for power electronics education. *Journal of Electrical Systems and Information Technology, 3*(2), 333-347.

Wanchai, S. (2016). A Comparative Study of Sinusoidal PWM and Third Harmonic Injected PWM Reference Signal on Five Level Diode Clamp Inverter. *Energy Procedia, 89*, 137-148.

Zhenyu, Y., Arefeen, M., & Issa, P. (1997). A Review of Three PWM Techniques. *Proceedings of the 1997 American Control Conference* (s. 257-261). Albuquerque, NM, USA: IEEE.