SPACE VECTOR PWM CONTROL TECHNIQUE FOR THREE PHASE VOLTAGE SOURCE CONVERTER

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ABSTRACT

In this Space Vector PWM Control technique is designed for a three-phase voltage source converter (VSC) which act as a Static Synchronous Compensators to provide reactive power compensation. The VSC as STATCOM provide efficient damping for sub synchronous resonance that enhance the Power System Stability in addition to RPC. Among different Pulse width modulation techniques SVPWM technique is implemented as it is easy to achieve digital realization and DC bus Utilization. The space vector control algorithm in VSC provides different functions such as reactive power compensation for Power factor correction, Harmonic Elimination, Load balancing for both linear and non-linear loads. The proposed method relies on an approximate third-order nonlinear model of the VSC that accounts for uncertainty in three system parameters. The design ensures asymptotic tracking of q-axis current and dc-voltage reference trajectories. Simulation and experimental results verify the performance of the controller relative to an established vector control method.

Keywords : VSC as STATCOM, Space vector PWM, Space Vector- Z source

I INTRODUCTION

The advancement in Power Electronics Circuits led to the development of Power Converter circuits which finds application in controlling the power flow and to improve the power quality issues. In this the Voltage Source Converter (VSC) is provided to act as STATCOM which provides efficient damping for Sub synchronous resonance that enhance the power system Stability in addition to RPC. The Previous method incorporate Adaptive control along with PI Controller to generate PWM pulses for converter switches and to control the output voltage. The Adaptive control uses "Model Reference Adaptive Control" algorithm to control the output voltage where a reference voltage is kept as a base and the control is done based on the reference voltage. To maintain the stability of the system the controller is designed with Lyapunov function. PI controller is used which will not increase the speed of response and it is not possible to predict what will happen with the error in near future, Reaction time of the controller is more, As the output voltage level increases it is not possible to have a accurate control over the PWM technique. Due to imbalance load a small amplitude of high frequency harmonic exists. To overcome the above disadvantages Space Vector Modulation techniques is incorporated in the proposed method. The SVPWM technique is processed in άβ frame. There are different types of PWM techniques available like PWM, THIPWM, SVPWM among which SVPWM technique is preferred as it easy to achieve digital realization and better DC bus Utilization.

II VSC AS STATCOM

The Mathematical modeling of Converters is important for deriving its control or analyzing the behavior of the converters. The VSC is made to act as STATCOM which is used for RPC and is Connected across the 3 phase supply. When the voltage source converter is connected across the supply the DC Capacitor equalization Voltage at the output of the converter supplies the capacitive reactive component which cancels the Inductive reactive component of the supply so that the Power Factor is Improved.

2.1 Basic Method of Operation

The VSC Circuit Consists of 6 Switches which could either be IGBT, MOSFET or SCR having an anti parallel diode for the current to flow through it when the switches are in OFF State. Dead time is provided between the Switching of transistors in each leg. The VSC is connected between AC Source and Inductive load through Point of Common Coupling (PCC). The VSC gate pulses are g1, g2, g3, g4, g5, g6 and are binary value generated by SVPWM techniques. The Utilization rate of DC voltage in SPWM is 78.5% of DC voltage. The Problem of Under utilization is rectified by injecting third harmonic voltage in addition with the fundamental component. Thereby the Utilization factor is increased by 15.5% when compared to SPWM. Compared to other PWM techniques SVPWM technique is preferred because it is easy to achieve digital realization, lower the switching losses, reduce the harmonic content and maximize DC bus Utilization. Also the Modulation Index could be reached above 97%. With the use of SVPWM technique more precise control is achieved.

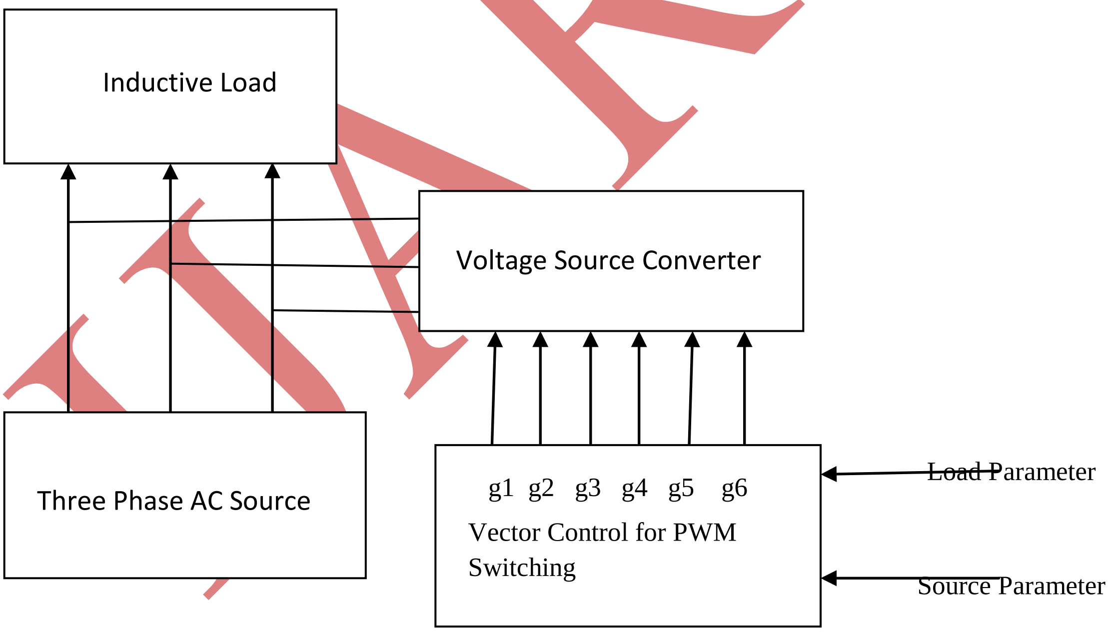

Fig 1: SC Control System Block Diagram

III SPACE VECTOR PWM

The Gate Pulse to Voltage Source Converter is designed using Space Vector PWM technique where the fundamental Component of Output voltage can be increased up to 27.39% as that of Sinusoidal PWM (SPWM) in which the modulation index could be reached up to Unity. SVPWM technique is accomplished by the rotating reference vector around the state diagram consisting of six basic non zero vector forming an Hexagon.

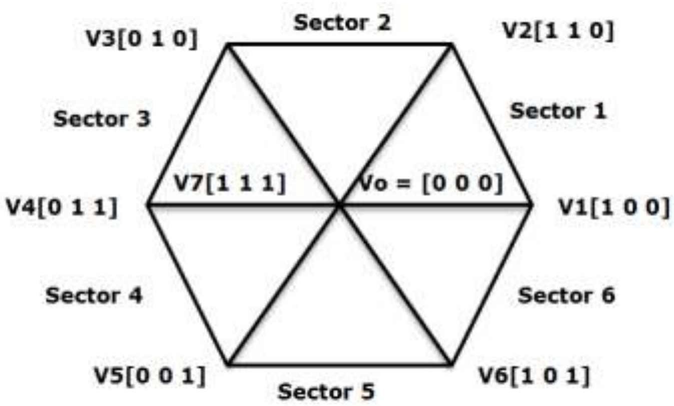

Fig.2: Space Vectors in 3 Phase VSC with three legs

$$: V_k = \left\{ \frac{2}{3} V_{dc}\, e^{j(k-1)\pi/3} \quad \text{for } k = 1,2,3,4,5,\ 6 \right.$$

$$:= \{0 \ for\ \ k = 0\ \&\ 7 \qquad (1)$$

V0 & V7 are called Zero Vectors. V1 to V6 are active vectors. The basic Principle of SVPWM is based on eight switching combinations of a three phase VSC. The Switching combinations are binary codes. Depending upon the binary code the switches are turned ON and its respective output voltage in a particular sector is tabulated as $V_{ά}$ & $V_{β}$ in "Table.1".

Voltage Vector	a	B	c	$V_{ά}$	$V_{β}$	Vector
V0	0	0	0	0	0	0
V1	1	0	0	2Vdc/3	0	$V_{0°}$
V2	1	1	0	Vdc/3	Vdc/√3	$V_{60°}$
V3	0	1	0	-Vdc/3	Vdc/√3	$V_{120°}$
V4	0	1	1	2Vdc/3	0	$V_{180°}$
V5	0	0	1	-Vdc/3	-Vdc/√3	$V_{240°}$
V6	1	0	1	Vdc/3	Vdc/√3	$V_{300°}$
V7	1	1	1	0	0	$V_{0°}$

"Table.1" Voltage vector corresponding to switching conditions

3.1 SVPWM Simulation System

The first block in "Fig.3" generates with three phase sinosoidal input voltage of fixed amplitude, frequency and DC bus voltage. The input voltages are delayed by 120° from each other.

The three phase ABC quantity is converted to two phase άβ Voltages in the second block and is given by equation (2) & (3)

$$V\alpha = \frac{2}{3}Va - \frac{1}{3}Vb - \frac{1}{3}Vc$$

$$V\beta = \frac{1}{\sqrt{3}}Vb - \frac{1}{\sqrt{3}}Vc \qquad (3)$$

The third block Calculate the Sector Phase angle and is represented in equation (4)

$$\theta = \tan^{-1}\left[\frac{V_\beta}{V_\alpha}\right] \qquad (4)$$

$$\theta \in [0.2\pi]$$

In the fourth block the timing of reference voltage vector is calculated and its active and zero vectors are calculated using equation (5). The Value of Ta & Tb is fixed for each T_{PWM} Period.

$$\begin{bmatrix} Ta \\ Tb \end{bmatrix} = \frac{MI\sqrt{3}Ts}{\pi}\begin{bmatrix} Sin\frac{K\pi}{3} & -Cos\frac{K\pi}{3} \\ -Sin\frac{(K-1)\pi}{3} & Cos\frac{(K-1)\pi}{3} \end{bmatrix}\begin{bmatrix} Cosn\ \omega Ts \\ Sinn\ \omega Ts \end{bmatrix} \qquad (5)$$

The triangular generator produces triangular wave which is then compared with the gate timing signals to produce output pulse for Six Switches.

The seventh block Simulate Voltage source Converter and its PWM phase to neutral voltages are given in equation (6).

$$Van = \frac{Vdc}{3}(2S1 - S3 - S5)$$

$$Vbn = \frac{Vdc}{3}(-S1 + 2S3 - S5) \qquad (6)$$

$$Vcn = \frac{Vdc}{3}(-S1 - S3 + 2S5)$$

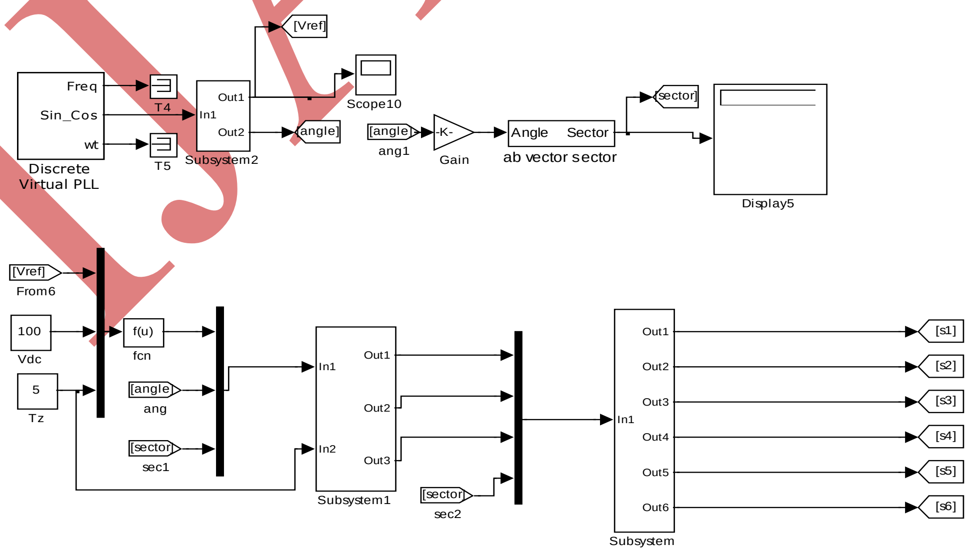

Fig.3: SVPWM System Simulation locks Diagram

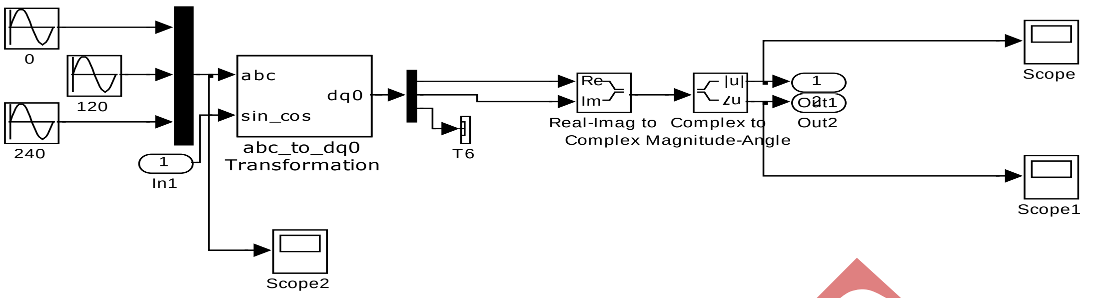

Fig.4: Reference Frame Transformation Theory

The Fig. 4 shows the Matlab simulink model of Reference frame transformation system in which the three phase abc quantity is converted to two phase d-q orthogonal quantity.

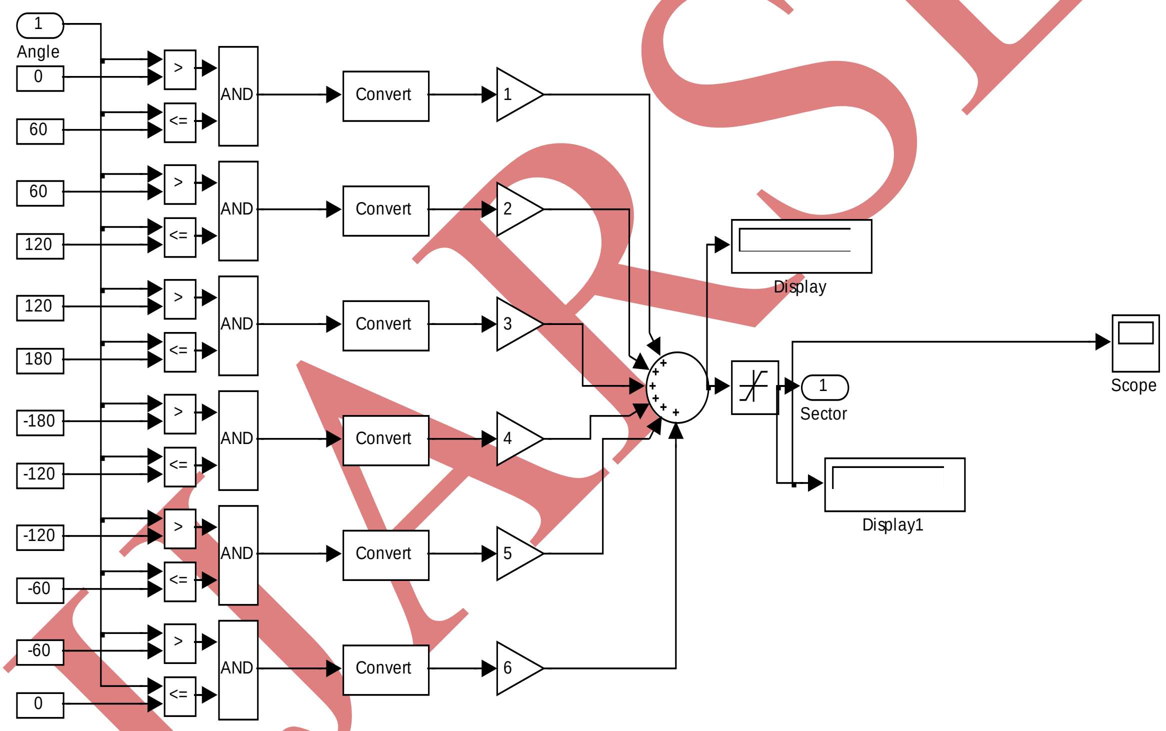

Fig.5: Sector Determination

The Fig. 5 shows the reference voltage sector determination system in simulink. The angle made by d-q quantity is compared with the reference angle which is between 0° to 360°. This concept is used to determine the angle of reference voltage vector which frames the different sector of the reference voltage. With this the reference voltage is made to work in different sectors with different angle which covers throughout the entire 360° of operation. This frames the Continuous Mode of Operation (CCM).

The Duty Cycle is defined as the ratio of ON time of the converter switches to that of total time. Therefore by controlling the time duration of the converter switches it is possible to obtain the controlled power at the load side.

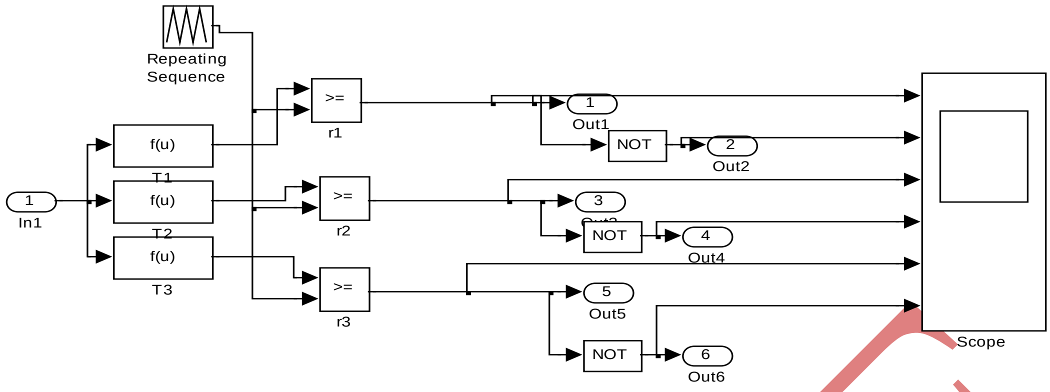

Fig.6: Gate Pulse Generation Circuit

3.1.1 SVPWM Simulation Output

SVPWM SIMULATION TEST RESULTS

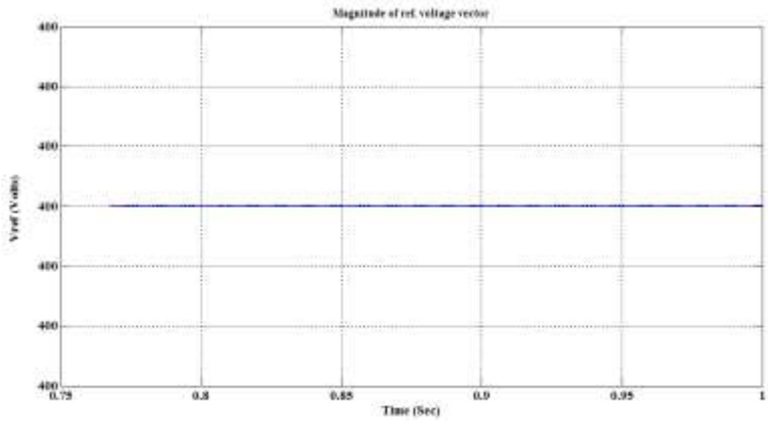

Fig.7: Magnitude of Reference voltage vector from Transformation Theory

The three phase stationary reference frame abc quantity is converted to d-q rotating reference frame quantity by Clark's transformation in which it is possible to obtain both the magnitude and the phase angle of the reference voltage vector and are as shown in Fig.7 and Fig.8.

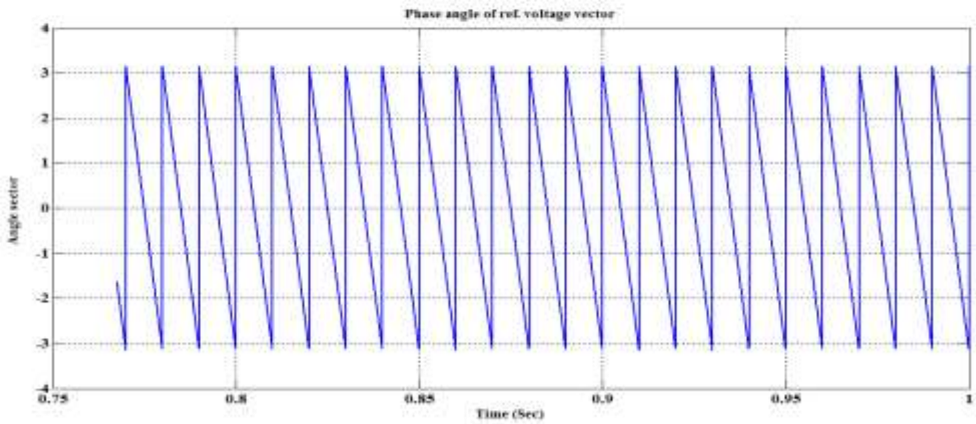

Fig.8: Phase angle of Reference voltage vector from Transformation Theory

The magnitude and Phase angle of the reference voltage vector is determined by using the following equation. The magnitude of the Orthogonal quantity (Reference Voltage) is calculated by using the below equation.

$$V_\alpha = \frac{2}{3}V_a - \frac{1}{3}V_b - \frac{1}{3}V_c$$

$$V_\beta = \frac{1}{\sqrt{3}}V_b - \frac{1}{\sqrt{3}}V_c$$

The phase angle of the reference voltage vector is calculated by

$$\theta = \tan^{-}\left[\frac{V_\beta}{V_\alpha}\right]$$

$$\theta \in [0.2\pi]$$

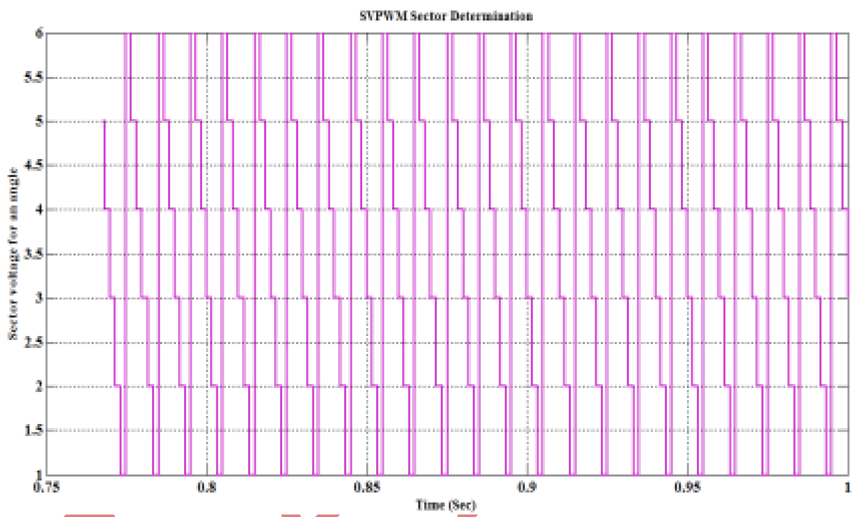

Fig.9: SVPWM Sector Determination

To achieve SVPWM technique it is necessary to obtain the length and angle of reference voltage vector. From the angle of the reference voltage vector the exact location of the reference voltage vector is derived so as to determine in which sector the reference voltage vector is located.

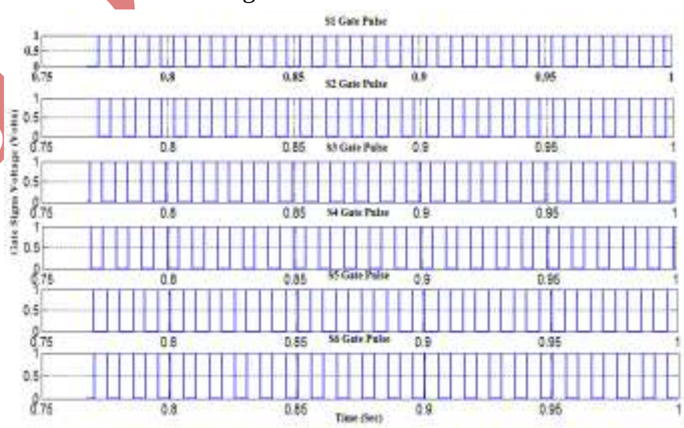

Fig.10 : SVPWM Gate Pulses to Converter Switches

The Fig. 10 gives the simulation output of SVPWM gate pulses to converter switches. The VSC has Positive Group Converters and negative group converters. The Positive group converter and the negative group converter are triggered with the phase difference of 60° each. Each positive group switches are triggered with a phase shift of 180° one after the other and the same has been repeated with negative group switches.

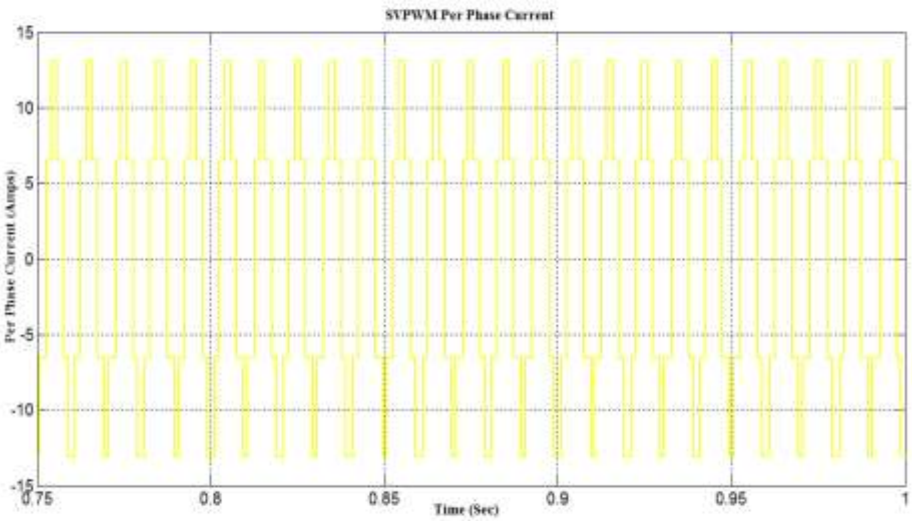

Fig.11: SVPWM Per Phase Switch Current

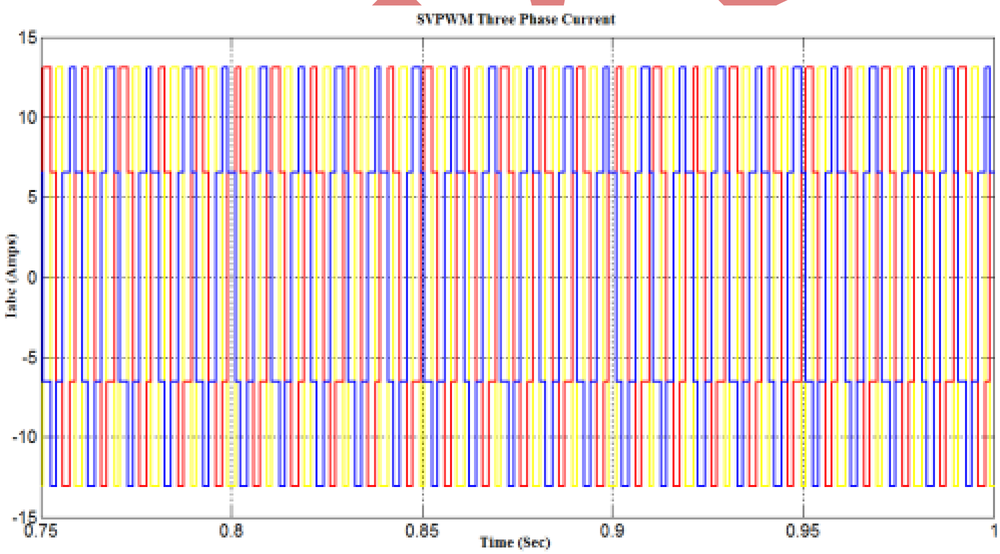

Fig.12: SVPWM Three Phase Switch Current

IV CONCLUSION

The SVPWM technique can only be applied to a three-phase VSC and it increases the overall system efficiency. The SVPWM is used for controlling the switching of the machine side converter. Advantages of this method include a higher modulation index, lower switching losses, and less harmonic distortion compared to SPWM [1]. SVPWM research has been widespread in recent years making it one of the most popular methods for three-phase inverters because it has a higher fundamental voltage output than SPWM for the same DC bus voltage. The SVPWM is significantly better than SPWM by approximately 15.5%. However, the SVPWM technique is complex in implementation, especially in the over-modulation region. The SVPWM technique has been deeply studied in the over-modulation region due to its performance benefits when compared to other modulation techniques. Numerous over-modulation algorithms have been proposed in the literature for the control of voltage source inverters [2,3,4]. The simulated results confirm that the over-modulation region 1 leads to a modulation index up to 0.952. This is an extension of around 5%, which is a significant improvement.

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