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Direct Vector Switching Control Technique for 3Φ VSC for PFC

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Abstract: ***In the present Scenario the Reactive power in Transmission System is more because of which the operating effeciency is very less. Therefore in the Proposed Concept the design of SVPWM Control for a three-phase voltage source converter (VSC) which act as a Static Synchronous Compensators to provide reactive power compensation. SVPWM technique is provided with άβ frame. The VSC as STATCOM provide efficient damping for sub synchronous resonance that enhances the Power System Stability in addition to RPC. The different Pulse width modulation techniques like SPWM, THIPWM and SVPWM. Among the different PWM techniques SVPWM is implemented so as to achieve better 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 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. Modeling, Simulation and experimental results are done in MATLAB to verify the performance of the controller with respect to the vector control method.***

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

1. Introduction

In the Present scenario with the tremendous development in Semiconductor industry the switching power converters finds ample of industrial applications at lower cost and are available at higher power levels. The advancement in semiconductor leads to the development of power electronic circuits which can also behave as an non-linear load. The Power Electronic circuit behaves like a non-linear load and when this has been connected to the power grid it injects a harmonic current which then leads to increase in total harmonic distortion. Therefore the system has to be designed to provide efficient and safe operation even when large amount of harmonics are present. With the availability of new semiconductors and control computers it is possible to design the controlled converters known as Voltage Source Converter (VSC). This VSC can be connected between the load and the source in the good to increase the dynamic response and to increase the power quality of the entire system. The mathematical modeling of VSC is important in deriving its control or analyzing its behavior. The Voltage Source Converter (VSC) finds ample applications in the area of Power Conversion, which can also be implemented as STATCOM to suppress the damping during Sub synchronous resonance that enhances the power system Stability in addition to RPC. The Proposed work investigates the Voltage Source Converter as STATCOM by using SVPWM (Direct Vector Control) Control method. Among different Pulse width modulation techniques SVPWM technique is implemented as it is easy to achieve digital realization and better DC bus Utilization.

2. Objective

1) The objective of the proposed work incorporates the modelling of voltage source converter in which the converter switch uses Space vector pulse width modulation techniques (SVPWM) for switching.
2) The Mathematical modelling of Converters is important for deriving its control or analyzing the behaviour of the converters.
3) The Voltage Source Converter act as STATCOM which is connected across the three phase supply and the Load.
4) 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.
5) SVPWM technique is processed in αβ frame. SVPWM technique is preferred as it easy to achieve digital realization and better DC bus Utilization.

3. VSC Modeling

3.1 VSC Operation

The three phase Voltage Source Converter is designed with Six MOSFET's, each having an anti-parallel diode to provide the path for the current when the MOSFET switch is in OFF condition. Three phase VSC have three leg with two switch in each leg operating in complementary fashion. If both the switch on the same leg conducts then a dead short circuit occurs in the DC link and therefore a dead time is included in the switches of the same leg. The VSC has Point of common coupling (PCC) between the AC source and the input filter. PCC is required to balance the three phase source and load. To PCC an inductive load can be connected. The point of common coupling voltages are represented as V_a, V_b, V_c and the current flowing through it is i_a, i_b, i_c and the VSC terminal voltages are e_a, e_b, e_c. The gate pulses to the voltage source converter switches are generated by using one the following control techniques and the analysis is made over SPWM and SVPWM techniques.

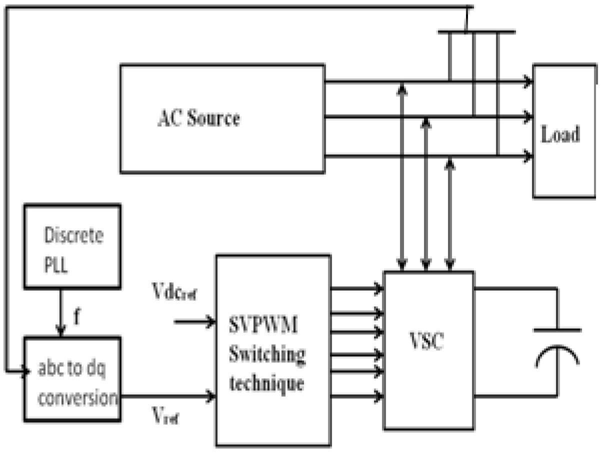

Figure 1: Basic Block Diagram

3.2 Modeling

The three phase input to voltage source Converter is given as (1)

$$V_a = V_m * Sin(\omega t)$$
$$V_b = V_m * Sin\left(\omega t - \frac{2\pi}{3}\right)$$
$$V_c = V_m * Sin\left(\omega t + \frac{2\pi}{3}\right)$$

When the driver circuit is designed with sinusoidal PWM technique or with an SVPWM technique a modulation index factor is added with the each phase of input voltage. Therefore the modulating signal is given as

$$V_{ma} = A_m * Sin(\omega t + \delta)$$
$$V_{mb} = A_m * Sin\left(\omega t - \frac{2\pi}{3} + \delta\right) \quad (2)$$
$$V_{mc} = A_m * Sin\left(\omega t + \frac{2\pi}{3} + \delta\right)$$

The voltage source converter output voltage and their relation with respect to modulation index and modulating angle is derived and analysed as follows. Under Balanced Condition the VSC terminal voltages are given as

$$e_a + e_b + e_c = 0. \quad (3)$$

$$e_a = \frac{V_{dc}}{6}\left[2V_{ma} - V_{mb} - V_{mc}\right]$$
$$e_b = \frac{V_{dc}}{6}\left[-V_{ma} + 2V_{mb} - V_{mc}\right] \quad (4)$$
$$e_c = \frac{V_{dc}}{6}\left[-V_{ma} - V_{mb} + 2V_{mc}\right]$$

4. PWM Control Technique

Switching Control technique in Voltage Source Converter is used for controlling the Output voltage of the converter circuit and also this is used to achieve the stability of the overall system. There are three different PWM Switching Control techniques that involves;

i. Sinusoidal PWM
ii. Third Harmonics injection PWM
iii. Space Vector PWM

The main objective of pulse width modulation technique in the converter circuit is to control the output voltage and to identify and manipulate the low frequency component of Converter output voltage via high frequency switching.

4.1 SPWM Technique

The Sinusoidal Pulse width Modulation produce output voltage in terms of pulses to provide gating signal for the converter circuit. The topology behind this SPWM technique is the normal frequency sine wave modulating signal is compared with the high frequency carrier wave (i.e.) triangular wave to produce an output pulse waveform with varying width. The required output voltage is achieved either by varying the amplitude or the frequency of the carrier (reference) or modulating voltage.

$$MI = \frac{OupputgeneratedbySPWM}{FundamentalPeakValue}$$

$$MI = \frac{V_{PWM}}{V_{max-Sixstep}} = \frac{Vdc/2}{\frac{2Vdc}{\pi}} = \pi/4 = 0.7855 = 78.55\%$$

4.2 SVPWM Technique

The Space Vector Pulse width Modulation is an alternative PWM technique available for controlling the three phase voltage source converters. In SVPWM technique the PWM duty cycle is computed rather by deriving from modulating wave and carrier wave comparison as discussed in SPWM technique. In SVPWM technique the three phase stationary reference frame voltages of each converter switching states are transformed to two phase orthogonal quantity in α - β Plane. The reference voltage is represented as vector in between the α - β Plane and the PWM duty cycle is computed for the selected switching state vector in proximity to the reference value. The fundamental component of output voltage in SVPWM technique is increased by 27.39% when compared to the fundamental component of output voltage in SPWM technique. The modulation Index could be increased to 92% when SVPWM technique is made to work in under modulation region and it could be reached approximate to Unity when it is working in Over Modulation region. Space vector modulation was derived from the concept that the set of three phase waveforms are represented by a single rotating reference vector around the State diagram. The State diagram is represented by means of state variable which consists of eight state vectors. Among the eight state vectors six state vectors are non-zero vectors forming a hexagon. The hexagon is inscribed inside the circle and the circle inscribed inside the state map corresponds to sinusoidal operation.

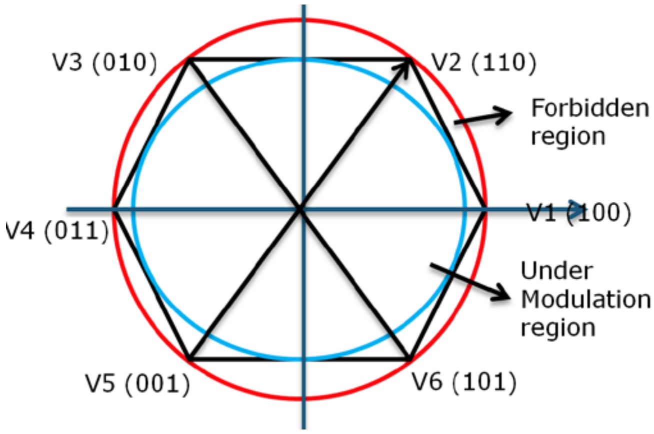

Figure 2: Sector Determination

4.3 Clark's Transformation

Reference frame transformation theory provides the concept of transforming three phase quantity in stationary reference frame to two phase quantity in orthogonal plane is known as Clarke or Park's transformation. The three phase System Voltages V_a, V_b, V_c in Stationary reference frame is mapped to a two phase orthogonal α - β Plane as V_α and V_β. Under balanced condition the three phase sinusoidal voltage vector is given as $V_{abc} = (V_a, V_b, V_c)^T$. Each phase voltage has a phase shift of 120° with respect other phase voltages.

$$V_a = V * Sin(\omega t+\varphi)$$
$$V_b = V * Sin(\omega t+\varphi-2\pi/3) \quad (5)$$
$$V_c = V * Sin(\omega t+\varphi+2\pi/3)$$

To Convert stationary reference frame abc quantity to two axis orthogonal αβ quantity Clarke's transformation or Park's transformation is used.

$$V_{\alpha\beta 0} = S*V_{abc} \quad (6)$$

where S is a Constant Matrix of Clarke's transformation

$$S = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \quad (7)$$

On similar analysis the successive row gives

$$= V * Cos(\omega t + \varphi) \quad (8)$$
$$= 0$$

$V_{\alpha\beta}$ in Phasor form is

$V_\alpha = V∟\varphi$

$$V_\beta = V∟(\varphi-\pi/2) \quad (9)$$

Vo = 0

Clarke's Transformation means converting Stationary reference frame to Rotating reference frame R(ωt).

$$R(\omega t) = \begin{bmatrix} Sin(\omega t+\varphi_0) & -Cos(\omega t+\varphi_0) & 0 \\ Cos(\omega t+\varphi_0) & Sin(\omega t+\varphi_0) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (10)$$

where R(ωt) is Rotation about third axis and this factor transforms αβ quantity to dq quantity.

$V_{dq0} = R(\omega t)*S*V_{abc}$

$$V_{\alpha\beta 0} = S*V_{abc} \quad (11)$$

$V_{dq0} = R(\omega t)*V_{\alpha\beta 0}$

$$K(t) = \frac{2}{3}\begin{bmatrix} Sin(\omega t+\varphi_o) & Sin(\omega t+\varphi_o-2\pi/3) & Sin(\omega t+\varphi_o+2\pi/3) \\ Cos(\omega t+\varphi_o) & Cos(\omega t+\varphi_o-2\pi/3) & Cos(\omega t+\varphi_o+2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

The three phase voltage source converter has eight possible switching states which can generate eight space vectors with the SVPWM Vector expression V_k and is given as

$$V_k = \begin{cases} \frac{2}{3}V_{dc}e^{j(k-1)\pi/3} \text{ for } k = 1,2,3,4,5,\ 6 \\ \to 0 \text{ for } k = 0\ \&\ 7 \end{cases} \quad (12)$$

4.4 SVPWM Duty Cycle

The equation given below determine the duty cycle of the Switching devices.

$$T1 = (u[4]==1)*(u[1]+u[2]+u[3])+(u[4]==6)*(u[1]+u[2]+u[3]) +(u[4]==2)*(u[1]+u[3])+(u[4]==3)*(u[1])+(u[4]==4) *(u[1])+(u[4]==5)*(u[1]+u[2]))$$

$$T_2 = ((u[4]==6)*(u[1])+(u[4]==1)*(u[1]+u[2])+(u[4]==2) *(u[1]+u[2]+u[3])+(u[4]==3)*(u[1]+u[2]+u[3])+(u[4]==4) *(u[1]+u[3])+(u[4]==5)*(u[1]))$$

$$T_3 = ((u[4]==6)*(u[1]+u[3])+(u[4]==1)*(u[1])+(u[4]==2) *(u[1])+(u[4]==3)*(u[1]+u[2])+(u[4]==4)*(u[1] +u[2]+u[3])+(u[4]==5)*(u[1]+u[2]+u[3]))$$

5. Simulation Diagram

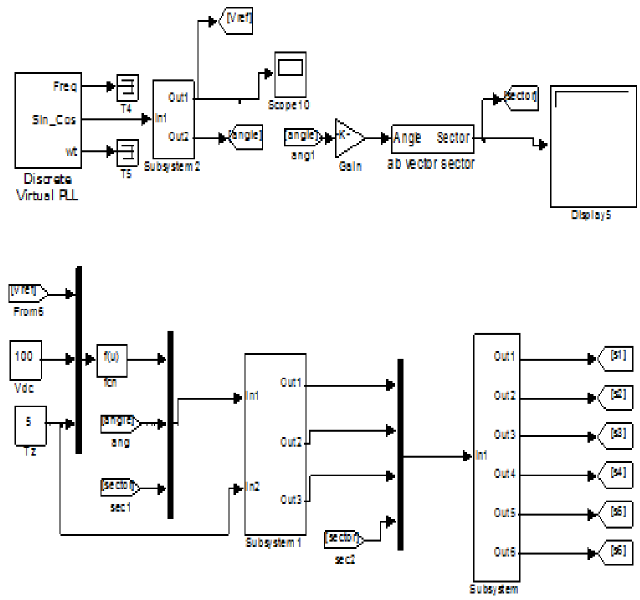

Figure 3: SVPWM Pulse Generation Circuit

The Fig. 5 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. The Pulse generated from SVPWM technique is used to trigger the MOSFET gate of VSC.

6. Simulation Test Results

The Simulation analysis is done with both SPWM technique and SVPWM technique and the results are compared.

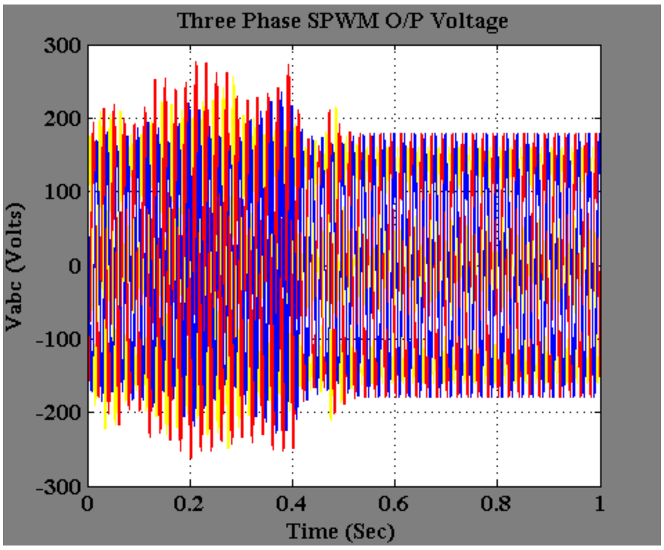

Figure 4: Three Phase VSC Output by SPWM technique

When the converter Switches are triggered with SPWM technique the output voltage generate harmonic distortion which increase the losses across the switches, active and passive devices. The harmonic distortion at the output reduce the overall efficiency of the entire circuit.

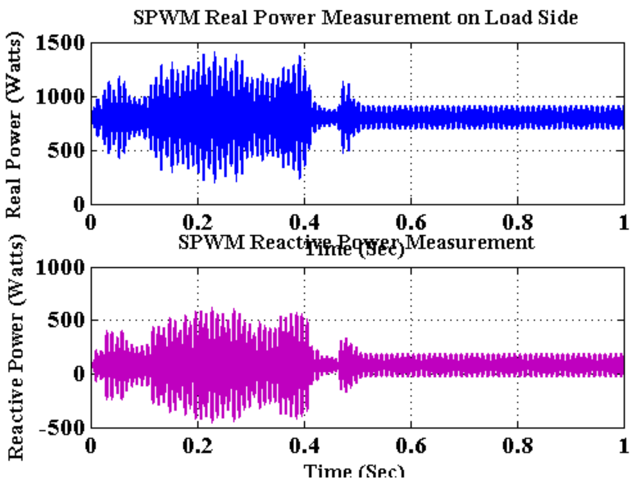

Figure 5: Real & Reactive Power Measurement by SPWM technique

When the VSC is switched by SPWM technique the real and reactive power measurement on load side is shown in Fig. 5. Due to the Converter switches working in Discontinuous Mode of Operation (DCM) the real and reactive power supplied to the load will be discontinuous and contains harmonic distortion which decreases the overall efficiency of the converter station.

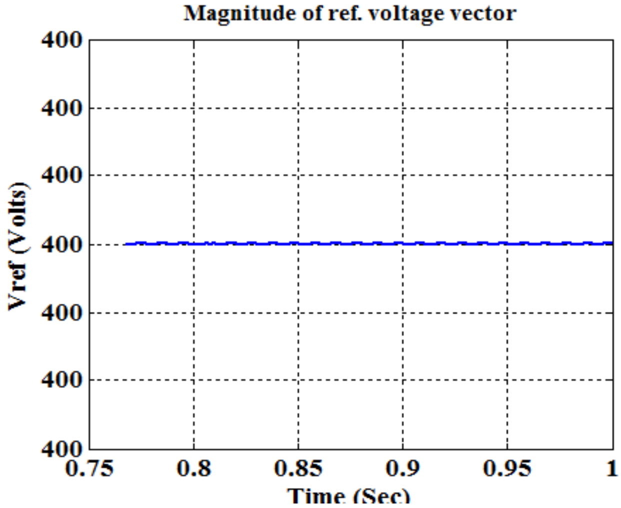

Figure 6: SVPWM Reference Voltage Vector

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. 6 and Fig. 7.

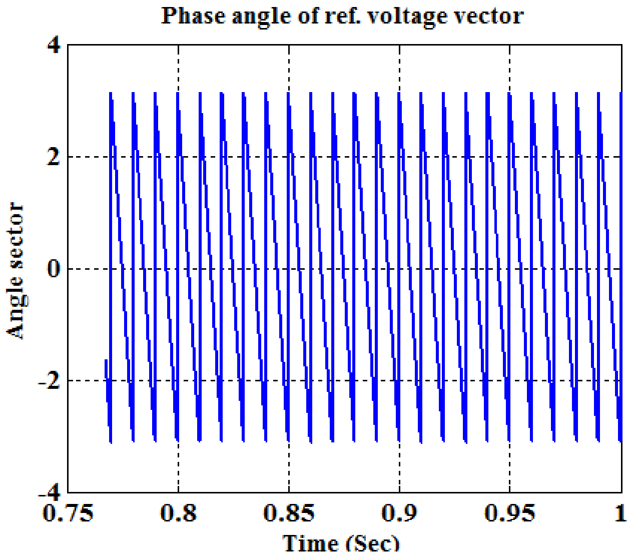

Figure 7: SVPWM Phase angle of Reference Voltage Vector

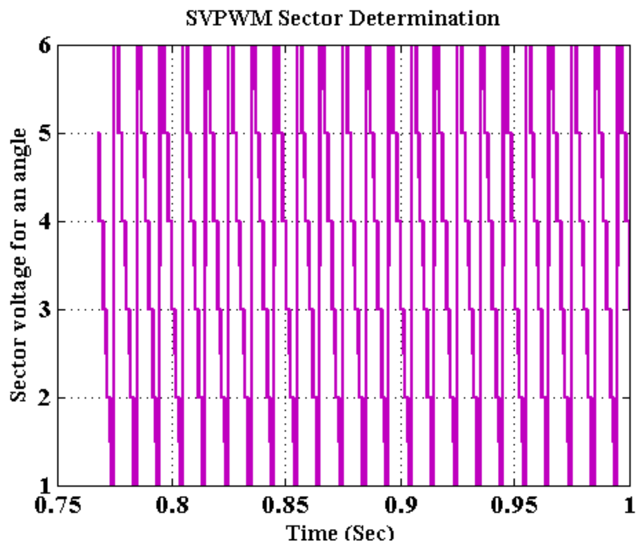

Figure 8: SVPWM Sector Determination

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.

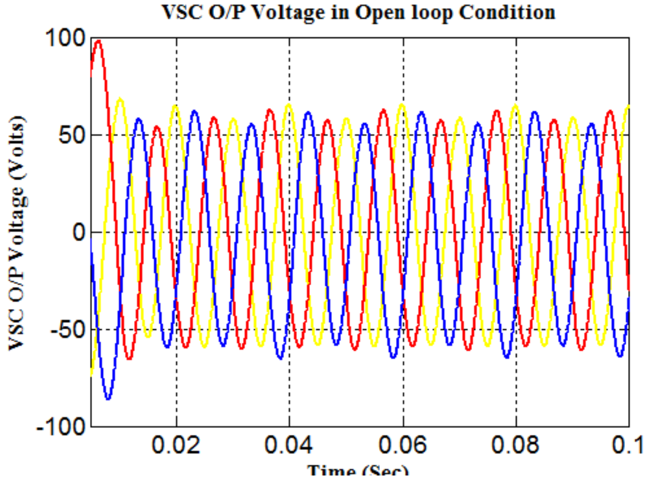

Figure 9: VSC Output in Open loop Condition

As shown in fig. 9. When the voltage source converter is switched by SVPWM technique it can work both in open loop condition and in closed loop condition. When the system is working in Open loop condition the entire system oscillates about the point of equilibrium from the reference value after time t=t0. To avoid such oscillations the system is made to work in closed loop system.

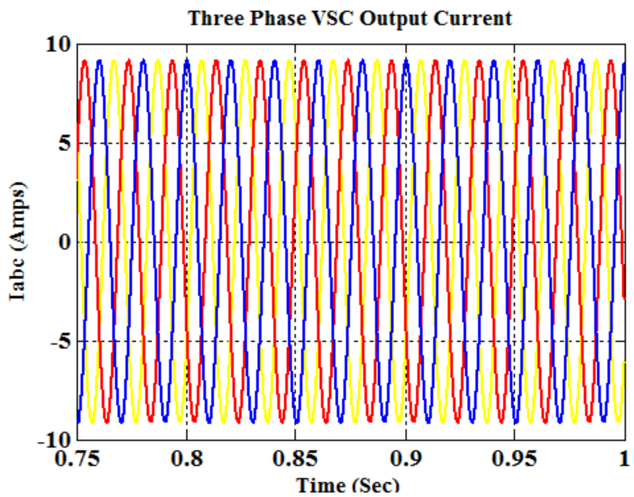

Figure 10: VSC Output in Open loop Condition

The Fig. 10. gives the simulation output of per phase and three phase current at the output of the VSC. When the System is made to work in Closed loop condition the oscillations at the output of the converter circuit is eliminated and the performance of the circuit is increased.

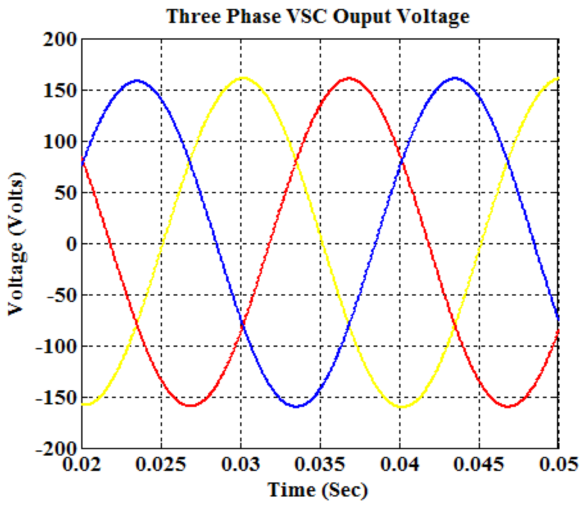

Figure 11: SVPWM - VSC Output Voltage

The Fig. 11. shows the output voltage of the voltage source converter. In this there is no distortion at the output and hence the efficiency of the system is increased. When this converter output voltage is connected in-between the load and source of the transmission or distribution system, the power factor is improved and hence the Voltage Source converter is made to work as STATCOM for Reactive Power Compensation.

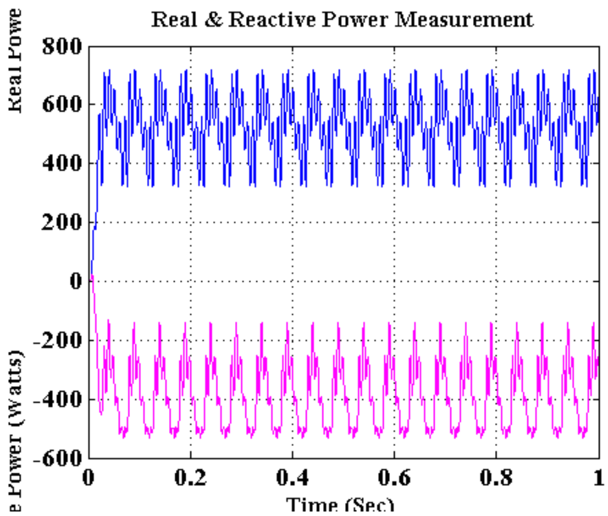

Figure 12: Real & Reactive Power On Converter Side

The Fig. 12. shows the Simulation result of Real and Reactive Power measurement on Converter side. On observing the result the reactive power is completely negative and hence it is compensated and only the real power has been transferred to the load side. As the reactive power is compensated the Power factor of the Voltage source converter is 0.91.

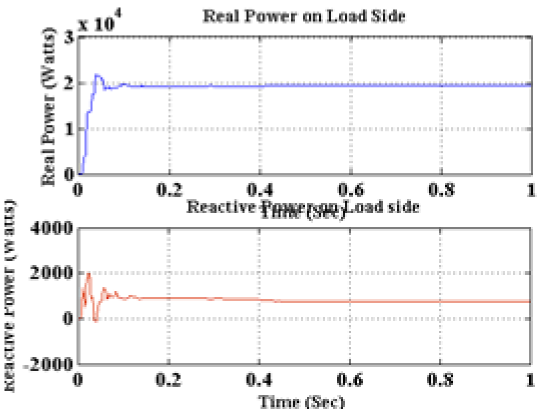

Figure 13: Real & Reactive Power On Load Side

The Fig. 13& 14 shows the Simulation result of Real and Reactive Power and V & I measurement on load side. On observing the result the real power on Load side is around 22KW whereas the reactive power is 2KW which is comparatively very less and it can be neglected and hence the Power factor on the load side is achieved approximately as Unity.

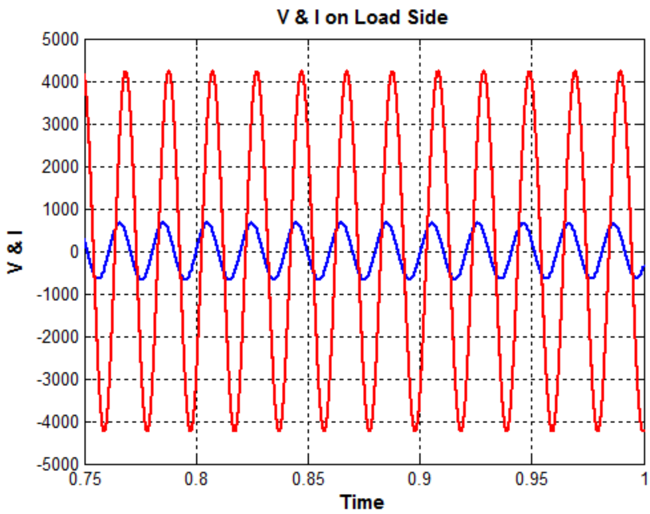

Figure 14: V & I on Load Side

7. Conclusion

The Pulse width Modulation is obtained either by analog technique or by digital techniques. The generation of pulses by SVPWM technique is a digital technique. The advantage of digital control technique over analog technique is that it is possible to achieve Stability, Precision (noise immunity) and Flexibility. With digital control the stability of the system is achieved as there is no drift, offset or aging effects. Digital technique is more flexible as it can be customized by changing the software. With the use of digital technique the DC bus utilization factor can be achieved fully.

Space Vector PWM technique in three phase Voltage Source Converter makes it possible to adapt the converter switching behavior to different loads like half load, full load, linear load, non-linear load, static load, pulsating load, etc. In combination with the Z-Source technique and grounding three phase transformer in the output this provides the following advantages:

i) Very low values can be reached for the output voltage THD (<2% for linear loads., <3% for non linear loads)
ii) Robust dynamic response (<3% deviation at 100% load step, recovery time to <1%: <20ms)
iii)In SVPWM technique the DC bus utilization factor can be increased by 15% more than the conventional PWM technique.
iv)With the use of SVPWM switching the peak switch current at the time of switching is reduced and hence looses in the switch is reduced. Therefore stress on the converter switches is less and hence the audible noise can also be influenced and therefore it can be minimized.
v) Space Vector Pulse width Modulation in Voltage source Converter provides excellent output performance, optimized efficiency, and high reliability compared to conventional Pulse Width Modulation.

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