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Power Quality Enhancement in Power System using STATCOM by Space Vector Modulation Techniques

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Abstract

Static Synchronous Compensator (STATCOM) is a Shunt active FACTS controller when connected at the mid-point of the transmission line; it can improve voltage regulation, power flow and stability of the transmission systems i.e. power quality of system. This paper demonstrates how the power flow sharing can be achieved in power system using programmable AC sources that is supplying linear and nonlinear loads. Space Vector Pulse Width Modulation (SVPWM) is used as a control algorithm in a three-phase Voltage Source Converter (VSC) which acts as a Static Synchronous Compensator (STATCOM) for providing reactive power compensation. Voltage Source Converter used as a Static Synchronous Compensator provides efficient damping for sub synchronous resonance that improves the power system stability in addition to reactive power correction. The Voltage Source Converter with space vector control algorithm is provided for compensating the reactive power flow to correct the power factor, eliminating harmonics and balancing both linear and non-linear loads. Among different Pulse Width Modulation (PWM) techniques space vector technique is proposed as it is easy to improve digital realization and AC bus utilization. The proposed control algorithm relies on an approximate third-order nonlinear model of the Voltage Source Converter that accounts for uncertainty in three phase system parameters. The control strategy for reliable power sharing between AC power sources in grid and loads is proposed by using Space Vector Pulse Width Modulation controller.

Keywords— Flexible AC Transmissions (FACTS), Static Compensator (STATCOM), Voltage Source Converter (VSC), Space Vector Pulse Width Modulation (SVPWM)

Introduction

The advancement in Power Electronics Circuits has led to the improvement of Converter circuits which finds application in controlling the power sharing and to achieve the power quality issues. In the proposed method, the Voltage Source Converter is provided to act as a STATCOM which provides efficient damping for sub synchronous reverberation that improve the power flow quality in power system. The method incorporates indirect vector control with PI controller to produce PWM pulses for converter switches and to control the output voltage. An 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 make the power quality of the system the controller design is proposed with pulse width modulation. 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, reaction time of the controller is more as the output voltage level improves it is not possible to have an accurate control over the PWM technique. Due to imbalance load small amplitude of high frequency harmonic exists.

To eliminate the above drawbacks Space Vector Modulation switching technique is implemented in the proposed method. The SVPWM switching technique is processed in αß frame. There are different types of PWM techniques available like PWM, 48 pulse inverter, and SVPWM among which SVPWM switching technique is suggested as it simple to improve stability as shown in Fig.1. In this Paper coordination control algorithm is proposed for

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all converters to smooth power transfer between source and load links when the grid is switched from one operating condition to another under various load and resource conditions which is verified by Matlab/Simulink.

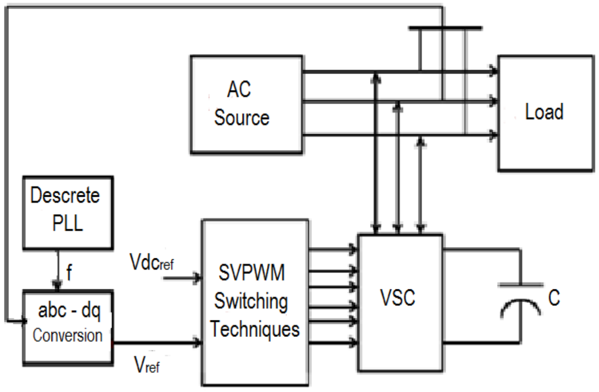

Fig. I. Block Diagram of Proposed Model

CONVERTER DESIGN

A. Static Synchronous Compensator: The converter is interfaced with power system through voltage source converter. The modeling of converter is important for deriving its control or analyzing the behavior of the converters. The VSC is made to provide for power system and is connected across three phase AC power 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 which is proved by using Fig. 2.

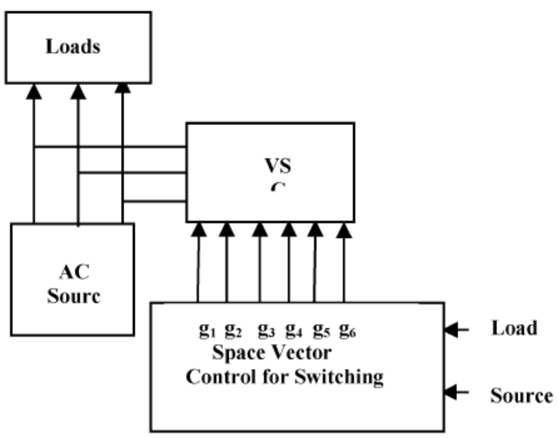

Fig.2. Control Circuit of Voltage Source Converter

B. Voltage Source Converter Structure: 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 as shown in Fig. 3. Three stages VSC have three leg with two switch in every leg working in integral manner. In the event that both the switch on the same leg directs then a dead short out happens in the DC join and along these lines a dead time is incorporated in the switches of the same leg. The VSC has Point of basic coupling (PCC) between the AC source and the information channel. 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 Va, Vb, Ve and the current flowing through it is ia, ib, ie and the VSC terminal voltages are ea, eb, ee. The gate pulses to the voltage source converter switches are generated by using SVPWM technique.

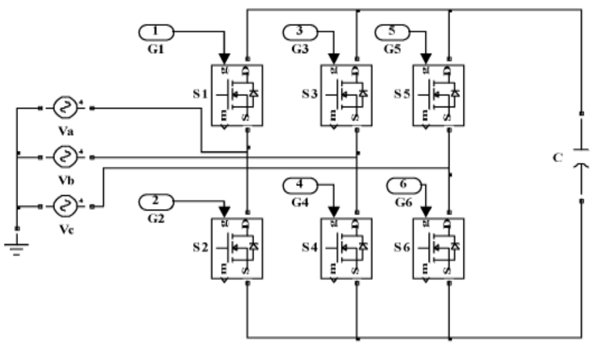

Fig.3. Simulation Model of Voltage Source Converter

C. Voltage Source Converter Modeling

Three phase input to the voltage source Converter is given as

$V_a = V_m \sin(\omega t)$..1

$V_b = V_m \sin(\omega t - 2\pi/3)$...............................2

$V_c = V_m \sin(\omega t + 2\pi/3)$..............................3

At the point when the driver circuit is designed with sinusoidal PWM method or with a SVPWM switching technique a modulation index factor is added with the each period of input voltage. Therefore the modulating signal is given as

V_{ma} = A_m sin (ωt + δ)....................................4

V_{mb} = A_m sin (ωt - 2 π/3 + δ)..........................5

V_{mc} = A_m sin (ωt + 2 π/3 + δ).........................6

Table 1. Voltage vector corresponding to switching conditions using SVPWM

Voltage Vector	a	b	c	$V_{\acute{a}}$	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	$V_{0°}$

The voltage source converter output voltage and their relation based on the modulation index and modulating angle is derived and analyzed as follows. Under Balanced Condition the VSC terminal voltages are given as

ea + eb+ ec= 0...7

Substituting the value of V_{ma}, V_{mb}, V_{mc} from above equations

We get,

e_a = (1/2) Vdc *m_a sin (ωt + δ)........................8

e_b = (1/2) Vdc * m_b sin (ωt - 2 π/3 + δ)...............9

e_c = (1/2) Vdc * m_c sin (ωt + 2 π/3 + δ).............10

CONTROL TECHNIQUE DESIGN

Introduction: Switching Control method in Voltage Source Converter is used to control the output voltage of the converter circuit and also this is used to improve the stability of the overall system. There are three dissimilar PWM Switching Control techniques that involve Sinusoidal PWM, Third Harmonics injection PWM and 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 control the low frequency module of Converter output voltage via high frequency switching. The Space vector modulation is a direct vector Control method in which the control technique is directly adopted by Reference frame transformation theory. Reference frame transformation theory means the motionless frame ABC reference quantity is converted to two axes orthogonal quantity αß which is a rotating reference frame quantity. In this type of modulation the duty cycle is computed in spite of comparing the modulating and carrier wave.

Space Vector Pulse Width Modulation Technique: The topology of a three stage VSC is shown in Fig.4 because of imperative that the data lines should never be shorted and the yield current must dependably be constant a VSC can accept just eight unmistakable topologies. Six out of these eight topologies create a nonzero yield voltage and are known as nonzero exchanging states and the staying two topologies deliver zero yield voltage and are known as zero exchanging states.

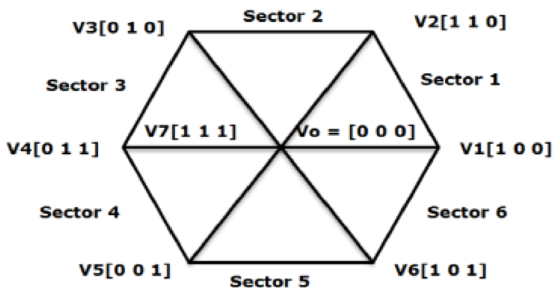

Fig.4. Principle of Space Vector used in VSC

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% 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. The angle made by d-q quantity is compared with the reference angle which lies between 0° to 360°. This concept is implemented to find 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).

SIMULATION TEST RESULTS

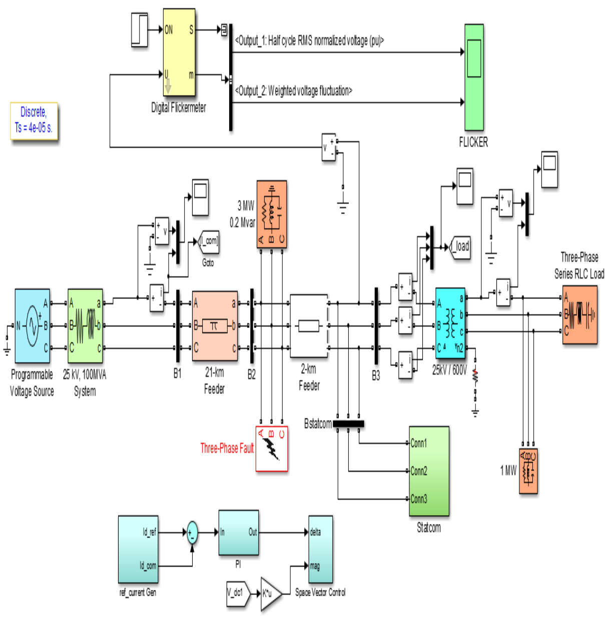

Fig.5. Simulation Model for SVPWM Controller

The three phase abc quantity is converted to two phase αß Voltages which is represented in "equations"

$V\alpha = (2/3)Va - (1/3)Vb - (1/3)Vc$..................11

$V\beta = (1/\sqrt{3})\, Vb - (1/\sqrt{3})\, Vc$........................12

The Sector Phase angle which is represented in "below equation"

$\theta = \tan^{-1}(V\beta / V\alpha)$.....................................13

$\theta\ \varepsilon\ [0.2\Pi]$..14

The timing of reference voltage vector is calculated and its active and zero vectors are calculated by using below equations.

The Value of Ta & Tb is fixed for each T_{PWM} Period.

$$\begin{bmatrix} Ta \\ Tb \end{bmatrix} = \frac{MI\sqrt{3}Ts}{\pi}\begin{bmatrix} Sin\frac{n\pi}{3} & -Cos\frac{n\pi}{3} \\ -Sin\frac{(n-1)\pi}{3} & Cos\frac{(n-1)\pi}{3} \end{bmatrix}\begin{bmatrix} Cos\,wTs \\ Sin\,wTs \end{bmatrix} \quad ....15$$

The following assumptions have been considered in simulation:

- Unity power factor and power sharing at point of common coupling bus
- Real and reactive powers transfer is supported by batteries and super capacitor to load.

The Case Study

Result obtained without fault while using SVPWM STATCOM

We studied the performance of Space vector pulse width modulation STATCOM with a power system connected without fault condition in MATLAB the output waveform of the proposed method are as follow;

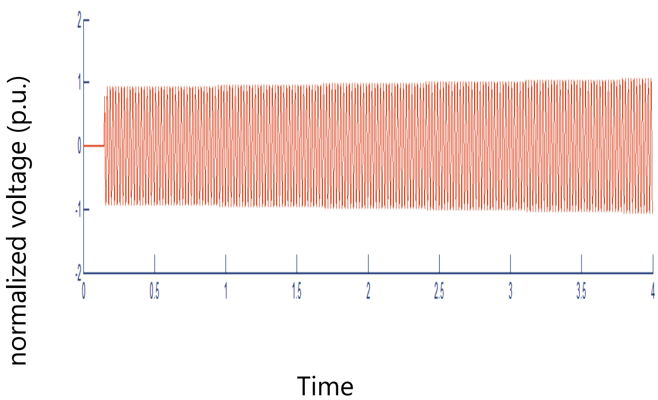

Fig. 6 Half cycle normalized voltage without fault (SVPWM STATCOM)

Figure 6 shows the transient voltage fluctuation of the SVPWM STATCOM (Space Vector Pulse Width Modulation STATCOM) system connected with normal load under balance condition.

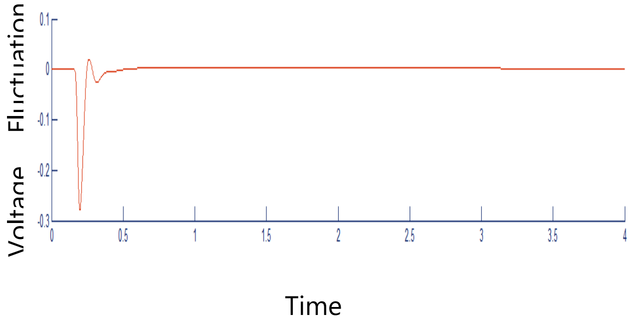

Fig.7. Fluctuation voltage without fault (SVPWM STATCOM)

As we see from the figure the value of transient voltage fluctuation varies up to -0.2 p.u. value which is the very negligible deviation as other VSC based STATCOM and the duration of fluctuation settling time is approximately within 0.5 seconds. Also the instantaneous flicker sensation wave is very smooth.

Result obtained with fault while using SVPWM STATCOM

We studied the performance of Space vector pulse width modulation STATCOM with a power system connected with fault condition in MATLAB the output waveform of the proposed method are as follow;

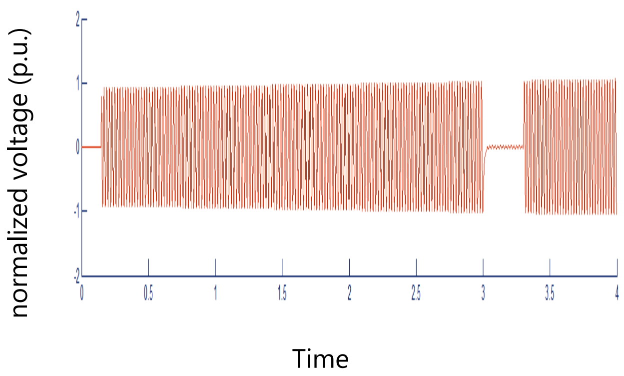

Fig. 8. Half cycle normalized voltage with fault (SVPWM STATCOM)

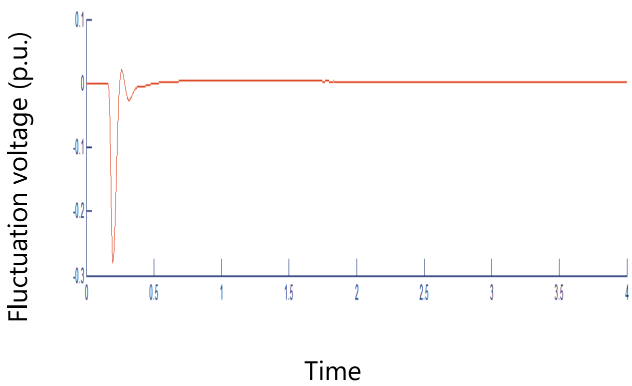

Fig. 9. Fluctuation voltage with fault (SVPWM STATCOM)

Figure 8 shows the voltage fluctuation of the system connected with fault or abnormal unbalance condition using SVPWM STATCOM as the compensator. As we can see in the waveform, the value voltage fluctuation is up to - 0.2 p.u. values which is very negligible and the instantaneous voltage fluctuation wave have negligible spikes which is very smooth.

Figure 9 shows the voltage fluctuation of the system connected under fault condition the voltage fluctuation duration is smooth is both cases transient and fault. And the instantaneous flicker sensation wave has been no disturbed within fault condition.

CONCLUSION

The proposed work shows the reduction in transient period and also the magnitude of fluctuating voltage. From the simulation study it shows that the Space Vector PWM STATCOM has advantage over other during fault condition. And has advantage over others in normal operation with load condition in amplitude only. This thesis has described a synchronous reference control, strategy to regulate and balance the voltage at a weak bus in six bus system using a SVPWM STATCOM device. This control strategy was developed specifically for a PWM controlled voltage source inverter connected to the weak bus network through AC filter. Simulation results have demonstrated that the controller achieves balanced voltages at the weak bus while maintaining a fast transient response. It has also been shown that the interaction between a SVPWM STATCOM device and a weak bus network is sensitive to non-ideal supply conditions and load variation. Therefore, tuning of the controller to achieve a fast and stable response under varying system conditions requires careful design and investigation for each specific installation. It has also been shown that the interaction between a SVPWM STATCOM device and a supply system makes the rural consumers healthy and wealthy.

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