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A Review on Static Synchronous Compensator and Its Modulation Techniques

Ms. Rucha P. Khadatkar[1], Mr. D. B. Waghmare[2]
[1](*P.G. Scholar Of Fourth Semester, Department Of Electrical Power System, Shri Sai College Of Engineering And Technology, Bhadrawati, Maharashtra, India*)
[2](*Assistant Professor, Department of Electrical Engineering, Shri Sai College Of Engineering And Technology, Bhadrawati, Maharashtra, India*)

Abstract:
This paper enlightens the one of the flexible ac transmission devices (FACTS) i.e. static synchronous compensator which is also abbreviated as STATCOM. The power system consists of number of various generators, loads, voltage sources, current sources, electrical machines, motor, etc. If any fault occurs on the power system, it will cause disturbances in the power system. These disturbances will cause harm not only to the power system but also to the equipments and machines we are using in the power system if proper controllable measures are not taken. STATCOM is shunt connected in the power system which can absorb or inject reactive power from or into the power system respectively during faults as well as normal conditions. Various modulation techniques are present in the literature which is used for controlling the gate pulses of the thyristor switches of the compensator. The working of STATCOM and the modulation techniques required or controlling its pulses are reviewed in this paper.

Keywords: *STATCOM, reactive power, shunt compensation, power system stability, energy storage, power system disturbances, reactive power injection.*

I. INTRODUCTION

Electrical power is being used by all for operating various machines and loads. It is used for domestic purposes, industrial purposes, etc. In India, new industries are emerging day by day. Urbanization is taking place on wide range. Whenever there is locality or industry, there is need of electrical power for sure. There is one way of providing electrical supply to the consumers and industries is that to build new electrical power transmission lines which will carry power to the required areas. However, building new transmission lines is not economical. Cost of transmission lines is not affordable. It is very expensive. Moreover, even if we build transmission lines to supply the power over large distances, the various losses occurring along the transmission line are dangerous which will affect the performance of the power system. Power system is one huge network which consists of various generators, linear loads as well as non-linear loads, current transformers, voltage transformers, circuit breakers, filters, etc. If any disturbance occurs in it, it will adversely effects the equipments connected in the system. Therefore, another way to fulfill the electrical demand of the consumers and industries is by installing facts devices near the utilities. To enhance the power transfer capability and stability of the network, Flexible AC Transmission systems (FACTS) controllers are emerging as an effective and promising alternative method which is redistributing the line flow and regulating the bus voltages [1]. There is continuous developments in the field of power electronics, particularly the development of Gate Turn-off (GTO) based devices, which have introduced a new family of versatile FACTS controllers, namely static synchronous compensator (STATCOM) [1],[2]. The STATCOM is one of the custom power devices that improve system stability, with the development of power electronics technology. It has received much attention. These devices play important role in bringing unprecedented efficiency improvement and cost effectiveness in modern electrical power system. The STATCOM based on voltage source converter which is abbreviated as VSC is used for voltage regulation in transmission systems as well as distribution systems [1]. A review on working of STATCOM and modulation techniques for operating gate pulses is given in this paper.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM is a flexible ac transmission device which is connected in shunt configuration with the power system. It can absorb or inject reactive power into the power system whenever the system needs it. However, it cannot inject active power or can inject very small active power. Ability to inject or absorb active power is acquired by the STATCOM by integration with energy storage device.

Figure 1 shows the equivalent circuit diagram of STATCOM. It is connected to the power system at PCC. PCC stands for point of common coupling. Va, Vb, Vc are the PCC voltages. Vdc and Idc are the dc voltage and dc current respectively at the input of the STATCOM and ea, eb, ec are the ac output voltages of STATCOM and ia, ib, ic are the corresponding currents. A dc link capacitor is provided to maintain constant dc voltage at the input of the STATCOM. A transformer is provided, for coupling the STATCOM to the power system, which is represented by resistance rs and inductance ls.

Comparison of conventional method of PI control with various feedback control strategies is explained in the paper [1]. It shows how PI control method contrast with other feedback control strategies. A Static Compensator (STATCOM) is a device that can provide reactive support to a bus which consists of voltage sourced converters. These converters are connected to an energy storage device on one side whereas on the other side they are connected to power system.

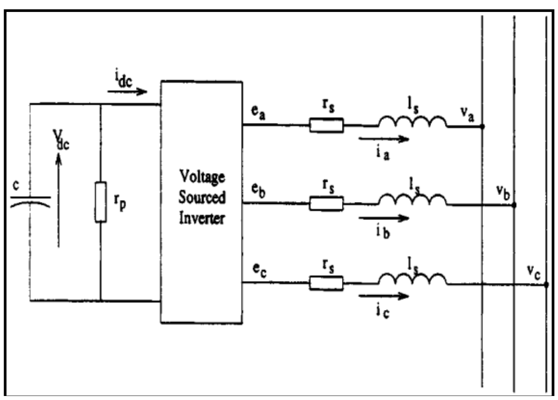

Fig.1: Equivalent Circuit Of STATCOM

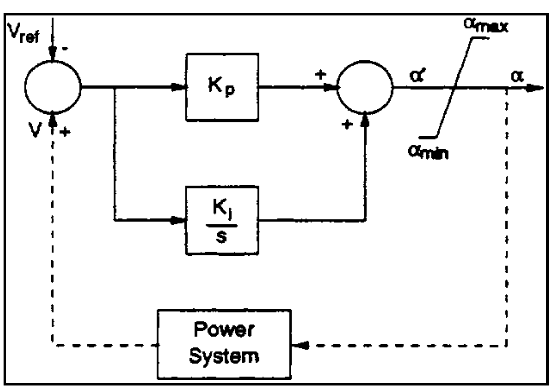

Fig.2: Block Diagram Of PI Control Scheme

The modeling of a STATCOM for power system is presented in the paper[1]. Three types of state feedback controllers i.e. proportional–integral (PI) control, pole-placement methods and linear quadratic regulator (LQR) are developed and compared in the paper [1]. Nearly linear behavior of the STATCOM response enables linear control methods to be effectively employed. This is one of the main advantages of these approaches. This control method allows a wide range of design strategies to be explored with linear tools. On the other hand, a nonlinear simulation need only be applied during the final stages of design to substantiate the control.

Limitations of the present mechanically controlled transmission systems can be overcome by use of FACTS devices. This is one of the advantages of using facts devices. There are many more advantages given further. It eliminates or minimize the need to enlarge power plants and enables neighboring utilities and regions to exchange power[1]. Due to increasing prevalence of power wheeling, utilization of power electronic devices will be more frequent to insure system reliability and stability and to increase maximum power transmission along various transmission corridors. In practice, automatic voltage regulation can be achieved by conventional proportional-integral (PI) control[1].

Pole placement control stabilizes an unstable system by moving one or more poles from the right-half complex plane to the left, which increases damping of system response by increasing the magnitude of certain poles, or changing oscillatory frequency which is done by manipulating the complex part of poles[1].

The linear quadratic regulator i.e. LQR approach is also a pole-placement method. However, in this method, the poles of the system are placed indirectly by reducing a given performance index.

Modeling of STATCOM using above mentioned state feedback controllers involves some disadvantages too. If capacitor banks alone are used in a weak voltage area, then it causes one difficulty of decrease in amount of injected reactive power from the capacitor bank with decrease in voltage profile thus exasperating the voltage problem [1]. However, if we use capacitor banks in conjunction with a STATCOM, the latter will hold the local voltage profile at the reference voltage setpoint, and therefore will maintain the effectiveness of the capacitor banks.

Without DC power source, such as a battery or SMES across the DC capacitor, only reactive power can be injected into the power system by STATCOM [1]. Reactive power injection has only localized effects on power flow and power system dynamics, thus effective control of active power problems, such as transient stability, interarea oscillations, and subsynchronous resonance cannot be obtained. In the future we can apply proposed control methodologies to the system with more than one STATCOM by considering each device individually.

The static synchronous compensator (STATCOM) and its integration with an energy storage system in damping power oscillations is discussed in paper [2]. STATCOM is a self-commutated solid-state voltage inverter whose performance can be improved with the addition of energy storage [2]. An electromagnetic transient program PSCAD/EMTDC can be used to study the dynamics of real and reactive power responses of the integrated system to system oscillations. The results show that, depending on the location of the STATCOM-SMES combination, the performance of the combined compensator can be significantly improved by simultaneous modulation of real and reactive power. Some of the control aspects in the integrated system are also discussed [2]. The real power capability of STATCOM can be very useful in effective damping of power system oscillations. The performance of a STATCOM can be enhanced by adding energy storage and it possibly reduces the MVA ratings requirements of the STATCOM operating alone[2]. This can play an important role as it involves cost effective analysis of installing flexible ac transmission system controllers on utility systems [2].

Rapid response (mili-second), high power (multi-MW), high efficiency, and four-quadrant control are various characteristics of SMES system which has gained SMES systems considerable attention for power utility applications. Improved system reliability, dynamic stability, enhanced power quality and area protection are the advantages obtained by energy storage of SMES systems [1],[2]. STATCOM-SMES at the reduced rating can be as effective as a STATCOM at the full rating in damping oscillations. Connecting SMES to ac system through a series connected VSI (Static Synchronous Series Compensator) instead of shunt connected VSI provides better damping dynamic performance. However, it is not cost effective. STATCOM can be integrated with other battery storages like BESS, large dc storage, flywheel, battery, etc[2].

The enhancement of damping the power system oscillation via coordinated design of the Power System Stabilizer (PSS) and STATCOM controllers is investigated in paper [4]. The particle swarm optimization (PSO) algorithm is employed, using the developed linearized model of a power system equipped with STATCOM-based stabilizer & PSS, to search for optimal controllers parameters in paper [4],[7]. In addition, singular value decomposition (SVD) based approach is presented in this paper to asses and measures the controllability of the poorly damped electromechanical modes by different controllers' inputs. The effectiveness of the coordinated design in damping the power system oscillation can be seen by nonlinear time domain simulation and Eigen value analysis results [4].

A STATCOM power oscillation damping is improved by adding supplementary damping controller to the STATCOM AC voltage control loop [4]. The coordination between STATCOM damping stabilizer and internal PI voltage controllers is taken into consideration in the design stage [4],[7]. It has ability to provide good damping of low frequency oscillation and improve greatly the system voltage profile. The power system stabilizers greatly enhanced system stability [4]. Also the coordinated design outperforms the individual design. The damping ratios of the electromechanical modes at all points are greatly improved. Coordinated design approach greatly reduced the control effort [4].

Even being capable of providing supplementary feedback stabilizing signals, PSSs suffer a drawback of being responsible to cause great variations in the voltage profile [4]. Same co-ordination technique can be extended for large multi machine system [4] in future.

An increasing interest in the enhancement of system stability using FACTS controllers has been extensively investigated in the literature [5]. A comprehensive review on the research and developments taking place in the power system stability enhancement using FACTS damping controllers is observed [7]. The essential feature of FACTS controllers is their potential to enhance system. The location and feedback signals are used for design of FACTS-based damping controllers. FACTS devices solve various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement [7]. As supplementary functions, it performs damping of the inter area modes and enhancement of power system stability. Expensive cost is the main disadvantage of FACTS devices to provide smooth and fast response to secure power system during normal and steady state operations [5],[7]. FACTS devices can be employed in emerging deregulated power system so that it will provide several benefits at existing or enhanced levels of reliability such as balancing the power flow in parallel networks over a wide range of operating conditions, alleviating unwanted loop flow, mitigating inter area power oscillations, and enhancing the power-transfer capacity of existing transmission corridors [5],[7]. By increasing the switching frequencies to the low kHz range, pulse width modulation techniques can be more effectively used for control of output magnitude and thus harmonic distortion can be achieved [4],[5].

III. COMPARISON BETWEEN STATCOM AND SVC

An assessment study of two different shunt FACTS-based controllers for damping power system oscillation is proposed in paper [3]. These controllers are named as static synchronous compensator (STATCOM) and static var compensator (SVC). The study of effect of energy storage based STATCOM is also analyzed for controlling power system dynamics [3]. Weakly interconnected power system which employs FACTS-based controllers are evaluated with STATCOM/SVC installed at the mid line [3]. To examine the system response, Eigen value analysis and nonlinear time domain simulations under a severe disturbance are carried out [3]. A schematic diagram of SVC and STATCOM is shown in figure 3.

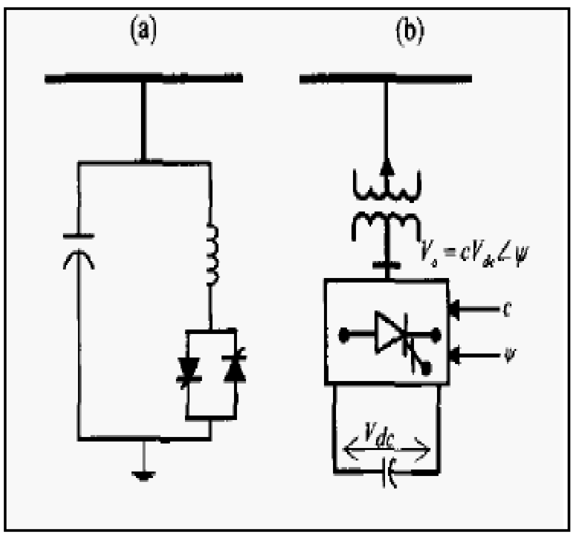

Fig.3: Schematic Diagram Of (A) SVC And (B) STATCOM

A supplementary lead-lag controller in STATCOM DC voltage loop is compared with SVC-based stabilizer in term of damping power system oscillation [3]. On the basis of eigen value analysis and the nonlinear time domain simulation results, it is proved that the STATCOM-based controller has a better performance compared to that of SVC-based stabilizer [3],[4]. Significant size reduction, reduced number of passive elements due to the development of super capacitor technology, and the ability to supply required reactive power even at low bus voltages are the major advantages of STATCOM over the conventional SVC [3].

IV. PULSE WIDTH MODULATION (PWM)

Pulse-width modulation (PWM) delivers energy through a succession of pulses instead of continuously varying signal such as analog signal [6]. The controller can increase or decrease the energy flow to the motor shaft by increasing or decreasing the pulse width.

A PWM signal is not a constant signal but it is a varying signal. The signal is ON for part of its period, and OFF for the remaining period [6]. The duty cycle, D, is expressed as the percentage of the period for which the signal is on. The duty cycle will lie anywhere from 0 to 1, or in other words, from the state when the signal is always off to the state when the signal is constantly on. A 50% duty cycle always results in a perfect square wave[6].

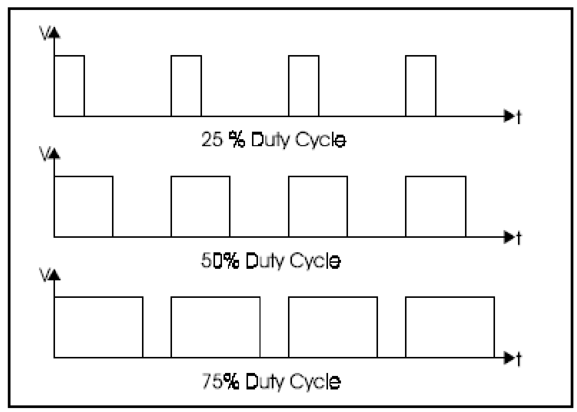

Fig.4: Duty Cycles

The two PWM schemes which are most widely and commonly used for multi-level inverters are the sine-triangle PWM or SPWM or carrier based PWM techniques and the space vector based PWM techniques.

Figure 5 shows the arrangement of sinusoidal pulse width modulation technique for three phase inverter using triggering circuit and low pass filter. The corresponding waveforms for sinusoidal pulse width modulation technique are shown in figure 6 [8]. Two signals i.e. modulating signal and carrier signal are given to the input terminals of comparator. Modulating signal is given at non-inverting terminal i.e. +ve terminal whereas carrier signal is given at inverting terminal i.e. –ve terminal of comparator. +Vcc and –Vcc are the output magnitudes of comparator for high and low level respectively. It can be seen from figure 6 that when modulating signal is lower than carrier signal, output is low i.e. –Vcc and when modulating signal is higher than carrier signal, output is high i.e. +Vcc [8].

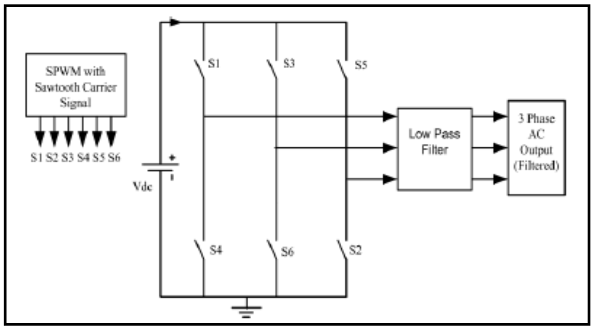

Fig.5: Block Diagram Of SPWM Based Three Phase Inverter Using Triggering Circuit And Low Pass Filter

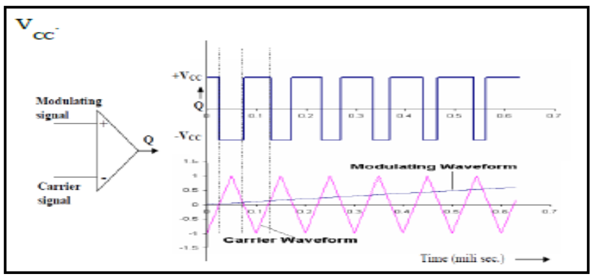

Fig. 6: Waveforms For Comparison Of Modulating And Carrier Signals

SPWM perfectly eliminates low frequency voltage harmonics generating almost perfect sinusoidal waveforms, with a THD lower than 5%. Each converter operating at low switching frequency reduces the semiconductor stresses, and therefore also reduces switching losses. Carrier frequency is increased which leads to shifting of lower order harmonics to higher order [6]. Control of magnitude and the frequency of the output voltage is achieved by sinusoidal PWM (SPWM) switching scheme [8]. However, without using output filter circuit, it is impossible to improve the total harmonic distortion. Switching losses are high as switching frequency in SPWM is equal to carrier frequency [6]. When sinusoidal PWM waveform is considered, the pulse width does not change significantly with the variation of modulation index due to the characteristics of the sine wave [9]. Space vector pulse width modulation technique is the unique solution to solve the problems [8].

The duty cycles are computed in the Space Vector Pulse Width Modulation (SVPWM) technique unlike in Sine Pulse Width Modulation (SPWM) where the duty cycles are derived through comparison [9]. The SVPWM technique can improve the fundamental component by up to 27.39% than SPWM. Figure 7 shows the two-level SVPWM controlled STATCOM.

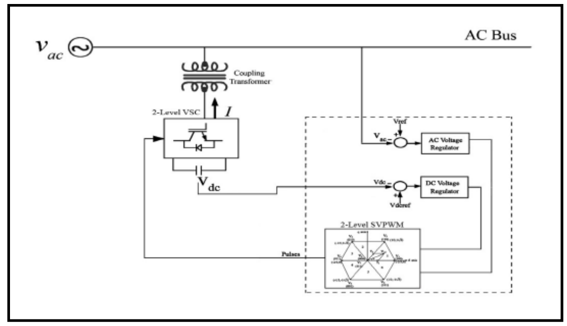

Fig.7: Two-Level Svpwm Controlled Statcom

Each sector is represented by four vectors which are denoted by Vi, Vi+1 where i can take any value between 1 to 5. These vectors are called active vectors [10]. This is so because output voltage of the power module will be greater than zero when these vectors are applied to the power module, i.e. one of the switches in each leg of the inverter will not be off[10]. The other two vectors V0 and V7 are called inactive vector, because during that time, all switches will be off or on. The basic principle of Space Vector Pulse Width Modulation depends on the basis of the combinations of eight switches of a three phase inverter. The switch combinations can be represented as binary codes i.e. in form of 0 and 1 only. These combinations correspond to the top switches of the 3 phase voltage source inverter. Three independent pole voltages are generated by each switching circuit [10]. Six switches and eight inverter configurations are therefore used to control the three phase inverter. The eight inverter states are then transformed into eight corresponding space vectors. The vector identification uses 0 to indicate -ve phase voltage level and 1 to represent +ve phase voltage level in each configuration. In addition to the above, the switches in one inverter leg operate in asuch a manner that it gives 1 if the switch is on and 0 if it is off. Thus, Space Vector Pulse Width Modulation Technique (SVPWM) is used to improve the performance of Power System equipments as the harmonics is reduced by SVPWM model.

The behaviour of STATCOM and the two common and widely used pulse width modulation techniques are sorted out in the form of following table 1.

Sr. No.	Name of Author & Year	Title of paper	Advantages	Limitation	Future scope
1	Rao, Pranesh, M. L. Crow, and Zhiping Yang (2000)	STATCOM control for power system voltage control applications	Limitations of the present mechanically controlled transmission systems can be overcome by use of FACTS devices. It helps to minimize the need to enlarge power plants and enable neighboring utilities and regions to exchange power.	Without DC power source, only reactive power can be injected into the power system by statcom. It has only localized effects on power flow and power system dynamics, thus control of active power problems, such as transient stability, interarea oscillations, and subsynchronous resonance cannot be obtained.	In the future we can apply proposed control methodologies to the system with more than one statcom by considering each device individually
2	Arsoy, Aysen, et al. (2001)	Dynamic performance of a static synchronous compensator with energy storage	Improved system reliability, dynamic stability, enhanced power quality and area protection are the advantages obtained by energy storage of SMES systems.	Connecting SMES to ac system through a series connected VSI instead of shunt connected VSI provides better damping dynamic performance.	Statcom can be integrated with other battery storages like BESS, dc storage, etc.
3	Bamasak, S. M., and M. A. Abido (2004)	Assessment study of shunt facts-based controllers effectiveness on power system stability enhancement	Significant size reduction, reduced number of passive elements due to the development of super capacitor technology, and the ability to supply required reactive power even at low bus voltages are the major advantages of STATCOM over the conventional SVC.	Stacom without energy storage can absorb or supply reactive power only. It supplies active power also but it is very small in magnitude.	In order to make it possible to absorb or supply active power, statcom must be integrated with energy storage.
4	Bamasak, Saleh M., and M. A. Abido (2005)	Robust coordinated design of PSS & STATCOM controllers for damping power system oscillation	The proposed stabilizers greatly enhanced system stability. The damping ratio of the electromechanical modes at all points are greatly improved. Coordinated design approach greatly reduced control effort.	Even being capable of providing supplementary feedback stabilizing signals, PSS suffer a drawback of being liable to cause great variations in the voltage profile.	Same co-ordination technique can be extended for large multi machine system.
5	Abido, M. A. (2009)	Power system stability enhancement using FACTS controllers: A review	FACTS devices solve various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement. As supplementary functions, it performs damping of the interarea modes and enhancement of power system stability.	Expensive cost is the main disadvantage of FACTS devices to provide smooth and fast response to secure power system during normal and steady state operations.	FACTS devices can be employed in emerging deregulated power system so that it will provide several benefits at existing or enhanced levels of reliability.
6	Aspalli, M. S., and Anil Wamanrao (2009)	Sinusoidal pulse width modulation (SPWM) with variable carrier synchronization for multilevel inverter controllers	SPWM perfectly eliminates low frequency voltage harmonics generating almost perfect sinusoidal waveforms, with a THD lower than 5%. Each converter reduces the semiconductor stresses, and therefore switching losses.	Without using output filter circuit, it is impossible to improve the total harmonic distortion. Switching losses are high as switching frequency in SPWM is equal to carrier frequency .	Not only PWM techniques but also Space Vector Control (SVC) can be used for multi-level inverters improving significantly the quality of the output voltage waveform.
7	Shahgholian, Ghazanfar, and Jawad Faiz (2010)	Static synchronous compensator for improving performance of power system: A review	Static synchronous compensator has the ability to improve the damping and voltage profiles of the system. Integration of statcom with energy storage provides more flexible power system operation.	Statcom does not employ capacitor or reactor banks to produce reactive power unlike static var compensator. Major disadvantage of a traditional statcom (with no energy storage) is that it has only two possible steady-state operating modes, namely, inductive (lagging) and capacitive (leading).	Various control techniques can be applied for desired flow of power transfer from source to load.
8	Shete, Pranay S., Rohit G. Kanojiya, and Nirajkumar S. Maurya (2012)	Performance of sinusoidal pulse width modulation based three phase inverter	Control of magnitude and the frequency of the output voltage is achieved by sinusoidal PWM (SPWM) switching scheme.	Disadvantages of SPWM are difficulty in manipulation, less flexibility, lower modulation index, higher harmonics, lesser utilization of DC supply voltage.	Space vector pulse width modulation technique is the unique solution to solve the problems. .

9	Ahuja, Rajesh Kumar, and Amit Kumar (2014)	Analysis, Design and Control of Sinusoidal PWM Three Phase Voltage Source Inverter Feeding Balanced Loads at different carrier frequencies Using MATLAB	Common applications of SPWM are motor speed control, converters, audio amplifiers, etc	When sinusoidal PWM waveform is considered, the pulse width does not change significantly with the variation of modulation index due to the characteristics of the sine wave.	The project can be extended to the twelve pulse VSI and its implementation in the Matlab/Simulink.
10	Doraya, Himanshu, et al.	Performance Comparison between PWM Based Inverter and SVPWM Based Inverter	Reduce total harmonic distortion in the power system and make fully utilization of sine wave.	The matlab model designed for SVPWM is somewhat cumbersome.	The project can be carried out with multilevel inverters.

Table.1: Summery of STATCOM and its Behaviour and the Modulation Techniques used

V. CONCLUSION

A static synchronous compensator and its principle of operation is explained in this paper. Comparison between svc and statcom is made from which the conclusion can be made that statcom performs better than svc. Controller techniques used for statcom in the past are also discussed. Modulation techniques of PWM for producing pulses are reviewed. SVPWM gives better results as compared to SPWM at high switching frequencies. Overall, it is concluded that SVPWM technique provides better performance and has good efficiency as compared to SPWM technique.

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