Comparative Analysis of 6 and 12 Pulse STATCOM

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Abstract - *This paper presents the performance and comparative analysis of Static Synchronous Compensator (STATCOM) based on 6 and 12 pulses VSC configuration. STATCOM is implemented for regulation of the voltage at the Point of Common Coupling (PCC) bus which has time-variable loads. The d-q decoupled current control strategy is used for implementation of STATCOM, where modulation index M and phase angle phi are varied for achieving voltage regulation at the PCC bus. The 6 and 12 pulses configurations are compared and analyzed on the basis of Total Harmonic Distortion (THD) and time response parameters such as rise time, maximum overshoot and settling time. The simulation of various configurations of STATCOM is carried out using power system block-set in MATLAB/Simulink platform.*

Key Words: Decoupled Current Control System, Voltage Sourced Converter, Total Harmonic Distortion, FACTS and STATCOM.

1. INTRODUCTION

This Reactive power is an important aspect of electrical power systems. Reactive power in the system needs to be effectively controlled as it may lead to many problems such as voltage instability, voltage fluctuations, power quality problems, poor system power factor and reduce the power transfer compatibility. Thus, reactive power compensation is necessary to improve the performance and stability of the power systems by maintaining a flat voltage profile [1]. Traditionally, reactive power compensation was done using capacitor banks, synchronous condensers and mechanically switched capacitors or inductors. The invention of Flexible AC transmission System (FACTS) devices has overcome the limitations of the traditional methods of reactive power compensation [2]. FACTS devices have the capability to accommodate changes in operating conditions of transmission systems while maintaining sufficient steady state and transient margins [3]

The Static Synchronous Compensator (STATCOM) is a shunt connected FACTS device, which is capable of providing both capacitive and inductive compensation [4]. It can maintain maximum output current which is not dependent on the AC system voltage. STATCOM is mainly used for controlling voltage of the transmission line, increasing power flow, improving the power system stability and damping power oscillations [5].There are various topologies of implementing a STATCOM. A detailed explanation of STATCOM configurations, controller and its uses are given in [6]. It has been observed that the use of multi-pulse configuration for STATCOM has helped in achieving a pure sine waveform [7], [8]. These configurations have eliminated the need of filters for harmonic reduction. The Type I inverter allows the instantaneous values of both (phase angle between PCC bus voltage and STATCOM voltage) and M (modulation index) to be varied for control purposes. In Type II inverters M (modulation index) is a constant factor, and the only available control input is the phase angle, [9]. The phase angle between the ac voltages produced by two sets of three-level 24-pulse VSCs is varied for controlling the magnitude of the converter ac voltage which in turn controls the reactive power of the STATCOM [10].The decoupled current control scheme is used to control the real power (to maintain the dc-link voltage) and reactive power independently [11]. This paper presents the implementation of two level 48- pulse 100 MVA STATCOM using decoupled current control strategy for regulation of voltage at the PCC bus. Section II explains the operating principle of STATCOM. Section III describes control strategy of STATCOM. Section IV explains different STATCOM configurations. Section V gives the results of the MATLAB simulation of 6 and 12 pulses STATCOM. Section VI presents the comparison of results of 6 and 12 pulses STATCOM. Conclusions are explained in Section VII.

2. OPERATING PRINCIPLE OF STATCOM

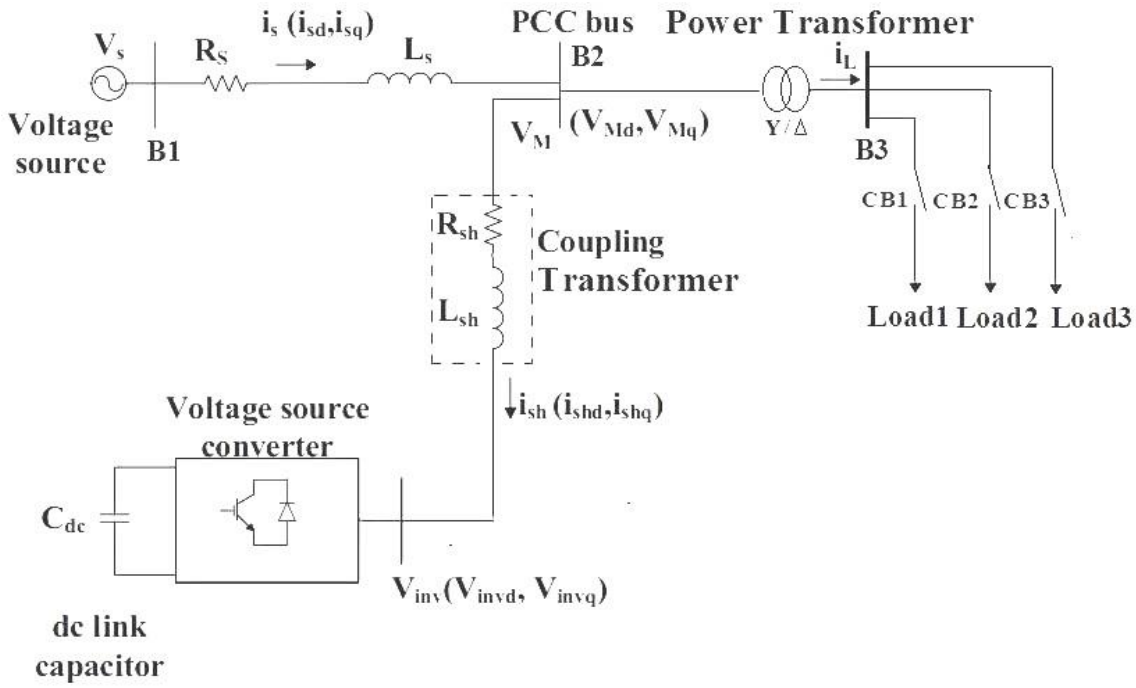

Fig -1: Single Line Diagram of STATCOM

The operation of STATCOM for voltage regulation is depicted schematically in Fig. 1. DC voltage is provided by the charged capacitor CDC and using this voltage, the converter produces a controllable three phase output voltage which has frequency same as that of the frequency of AC power system. The converter output voltage is in phase with AC system voltage.

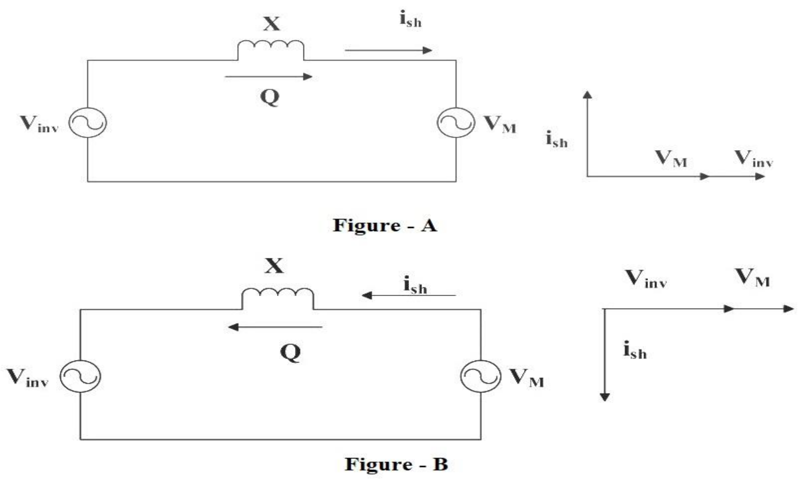

Fig -2: (A) Phasor diagram for capacitive operation of STATCOM
(B) Phasor diagram for Inductive operation of STATCOM

The converter and the AC system are coupled through a very small (0.1-0.15p.u.) reactance which consists of shunt inductance of the coupling transformer. By changing the magnitude of the output STATCOM and the ac system can be controlled. If the magnitude of the output voltage is greater than the AC system voltage, then the direction of current flow is from STATCOM to the AC system and the STATCOM inject reactive power into the AC system. This mode of operation is known as capacitive mode of STATCOM. Fig. 2-A shows the phasor diagram of capacitive mode of STATCOM. When the magnitude of the output voltage is lesser than the AC system voltage, then the current flows from the AC system to the STATCOM, and the STATCOM absorbs reactive power from the AC system. This mode is termed as inductive mode of STATCOM. Fig.2-B shows the phasor diagram of inductive mode of STATCOM. When STATCOM voltage is equal to the PCC bus voltage, the reactive power transfer is zero. During such a condition, STATCOM operates in floating mode. Generally, in converter due to semiconductor switching losses are occurred, and hence the energy stored in the DC capacitor is utilized for internal losses. Therefore, in order to maintain the DC link voltage at a constant value, the output voltages of the converter are made to lag the AC system voltages by a small angle. In this way the converter absorbs a small amount of real power from the AC system to maintain the capacitor voltage at it required value and replenish its internal losses.

3. DECOUPLED CURRENT CONTROL STRATEGY

The d-q decoupled current control strategy [10], [11] can be divided in the following sections.

1) AC Voltage controller.
2) DC Voltage controller.
3) Current controller.

3.1: AC terminal voltage regulator

When STATCOM is used in voltage regulation mode, it regulates the PCC bus voltage and maintains its magnitude V_{Mag} equal to its reference value $V_M{}^*$ given in equation below. For this purpose a PI controller is used. The reference value of PCC bus voltage $V_M{}^*$ and actual PCC bus voltage magnitude V_{Mag} are compared and then the error is given to the PI controller. From this error signal we get reference quadrature axis STATCOM current $I_{shq}{}^*$ which is applied to the inner current loop. When the value of $V_M{}^*$ is more than V_{Mag}, STATCOM injects reactive power so as to increase the value of V_{Mag}. When the value of VM * is less than V_{Mag}, STATCOM absorbs reactive power so as to decrease the value of V_{Mag}.

$$V_{Mag} = \sqrt{V_{MD}^2 + V_{MQ}^2}$$

3.2: DC voltage regulator

The function of the DC voltage regulator is to maintain the DC voltage, V_{dc} of the STATCOM equal to its reference value, V_{dc}^* A PI (proportional and integral) controller is chosen for DC voltage regulation. The reference value of V_{dc}^*, and the actual value, V_{dc} are compared and then the error is given to the PI controller. From this error signal we get reference value of d-axis STATCOM current $I_{shd}{}^*$ which is applied to the inner regulation loop. When value of V_{dc} is less than V_{dc}^*, $I_{shd}{}^*$ rises and a less quantity of active power transfer from the power system to the dc side and V_{dc} rises; and when the value of V_{dc} is more than V_{dc}^*, $I_{shd}{}^*$ reduces and the active power transfer from the power system to the dc side reduces and V_{dc} decreases [10]. This process is continues unless V_{dc} becomes equal to V_{dc}^* hence regulating the dc link voltage V_{dc} at its reference magnitude V_{dc}^*.

3.3: Current Controller

The reference values of direct and quadrature axis component of STATCOM current i.e. $I_{shd}{}^*$ and $I_{shq}{}^*$ from external AC Voltage Controller and DC voltage Controller are the two inputs for this controller. The direct axis current component ishd maintains the voltage of the dc capacitor to its reference value and the quadrature axis current component ishq plays role in controlling the reactive power of STATCOM or for controlling the PCC bus voltage. Using following equation we get, V_{invd} and V_{invq} ,

$$I_{invd} = V_{Md} - K_I\left(I_{shd}^* - I_{shd}\right) - K_i\int\left(I_{shd}^* - I_{shd}\right)dt + \omega I_{shq} \quad \dots (1)$$

$$I_{invq} = V_{Mq} - K_I\left(I_{shq}^* - I_{shq}\right) - K_i\int\left(I_{shq}^* - I_{shq}\right)dt + \omega I_{shd} \quad \dots (2)$$

From above equations, we get phase angle and modulation index (M.I) between terminal voltage of the system and STATCOM voltage which are given below equation 3 and equation 4. Using modulation index (M) and phase angle (∅), controller generates pulses which are given to the inverter. The d-q decoupled current Control Strategy and Firing Pulses Logic circuit is shown in fig.3

$$M = MI = \sqrt{\frac{(V_{invd})^2 + (V_{invq})^2}{V_{dc}}} \quad \dots (3)$$

$$\emptyset = tan^{-1}\left({V_{invq}}/{v_{invd}}\right) \quad \dots (4)$$

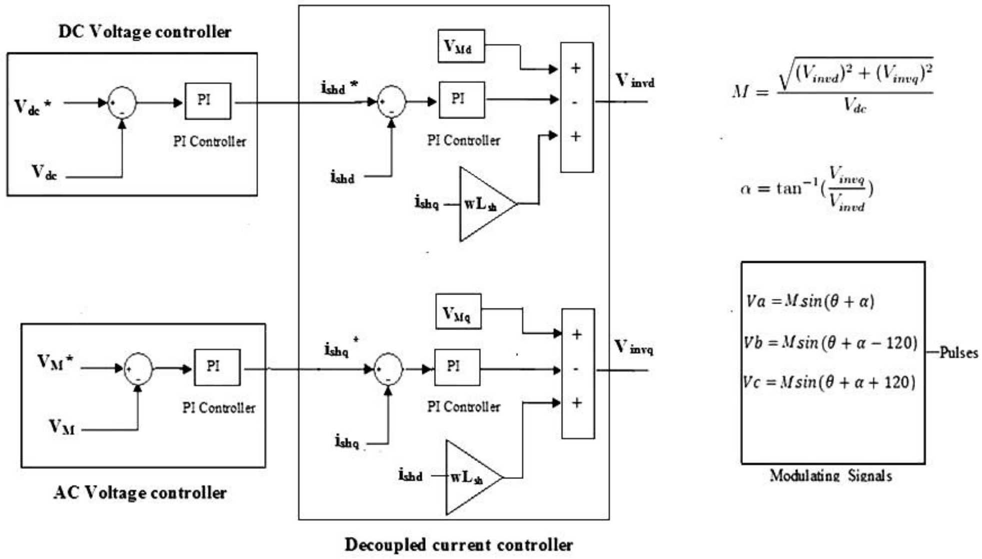

Fig -3: d-q decoupled current control strategy with firing pulses logic

4. DIFFERENT STATCOM CONFIGURATIONS

Different types of STATCOM configurations are detailed described in below.

4.1: 6 Pulses STATCOM

A 6 pulse STATCOM is basic STATCOM model. This configuration requires only one bridge for obtaining 6 Pulses voltage waveform as output. The output of this bride Inverter is applied to 3 phase transformer, which gives the required system voltage. In 6 pulses STATCOM the output voltage is not sinusoidal because it contains large number of harmonics. The generated output voltage has the harmonics of the order 6n±1 i.e. 5th, 7th, 11th, 13th etc. The percentage THD of the STATCOM output voltage is around 15% shown in Fig.4, which does not satisfy the IEEE 519 standard.

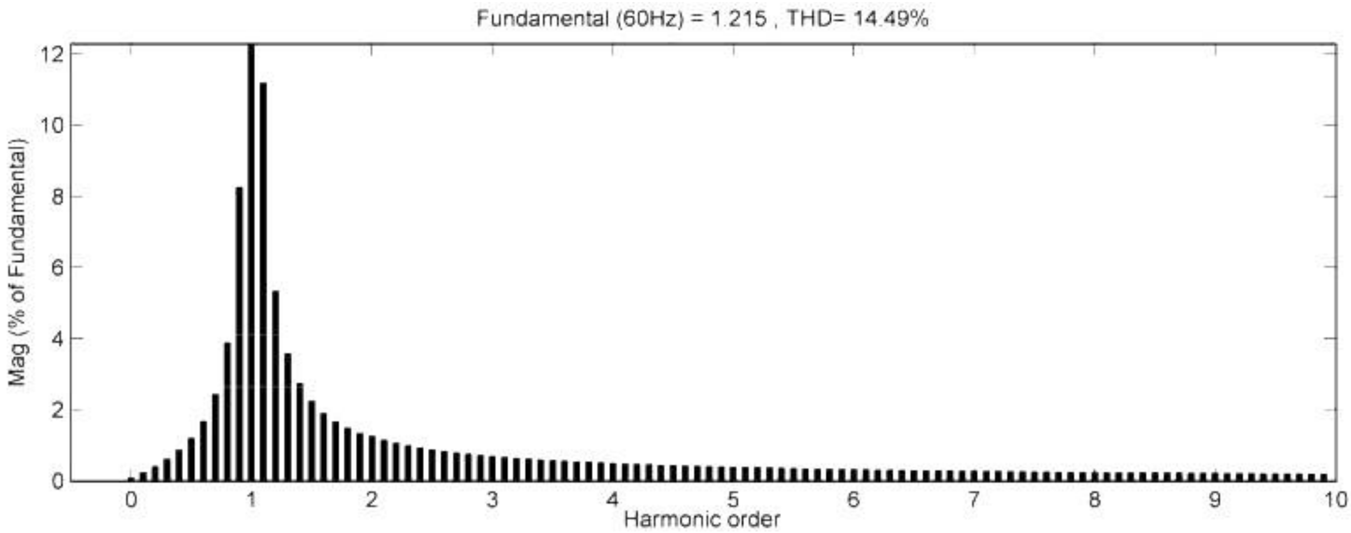

Fig -4: Harmonic spectrum of system voltage, V_M for 6 pulses STATCOM obtained from simulation results.

4.2: 12 Pulses STATCOM

In the 12 pulse STATCOM, two six-pulse converters, having total of six phase-legs are connected in parallel on the same DC bus, and work together as a 12-pulse converter [5]. The two voltages generated by the converters, which have a Phase shift of 30º, are applied to the Y-Y and Δ -Y transformers. The combined output voltage has the harmonics of the order12n±1 i.e. 11th, 13th, 23th, 25th etc. The percentage THD in the STATCOM voltage is around 9%, which is shown in fig.5

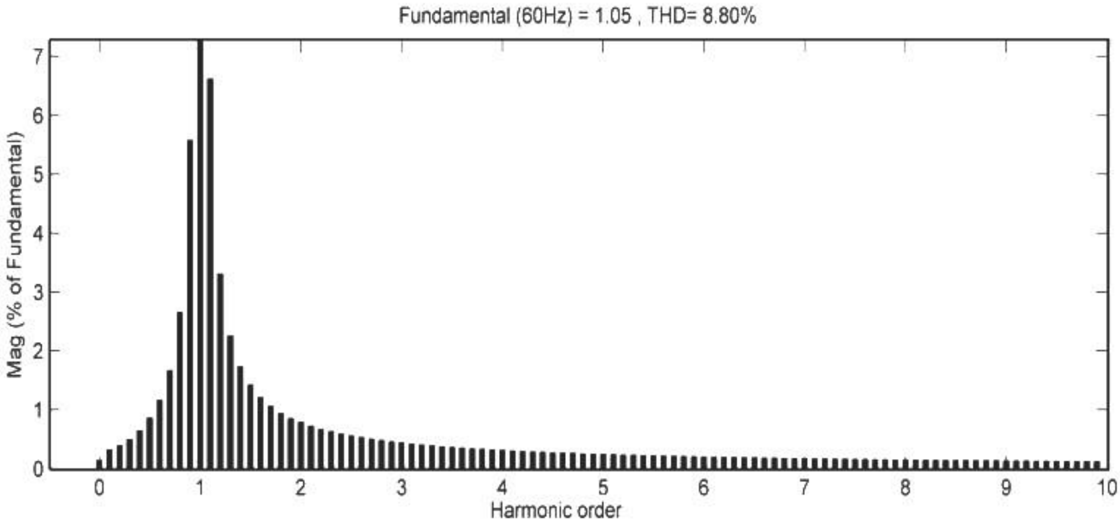

Fig -5: Harmonic spectrum of system voltage, V_M for 12 pulses STATCOM obtained from simulation results

5. COMPARISION OF RESULTS OBTAINED FROM DIFFERENT STATCOM CONFIGURATIONS

For THD analysis FFT tool is used. From table 1 and 2, it is seen that for 12 pulses STATCOM have less THD, peak overshoot and settling time than 6 pulses STATCOM. Hence we conclude that 12 pulse STATCOM having better performance than 6 pulses STATCOM. As the number of pulses of STATCOM increases its cost also increases. So, cost of 12 pulses STATCOM is higher than 6 pulses configuration.

Table -1: 6 Pulse STATCOM Results

System Parameters		6 pulse STATCOM			
		Load changes at time(sec)			
		0	2	4	6
STATCOM Voltage (V_{inv})	THD	14.48	7.63	8.58	12.67
	Peak Overshoot	0.106	0.014	0.0048	0.234
	Settling time	0.6	0.67	0.66	0.733
STATCOM current (i_{sh})	THD	13.85	12.9	9.95	14.19

Table -2: 12 Pulse STATCOM Results

System Parameters		12 pulse STATCOM			
		Load changes at time(sec)			
		0	2	4	6
STATCOM Voltage (V_{inv})	THD	8.8	6.62	6.3	8.03
	Peak Overshoot	0.068	0.012	0.0045	0.245
	Settling time	0.33	0.512	0.577	0.545

6. CONCLUSIONS

This work is carried out for finding out best configuration of STATCOM that provides THD less than 5%, which satisfies the IEEE 519 standard hence 6 and 12 pulses STATCOM configurations are considered for the for study and compare output parameter such as Total Harmonics Distortion (THD), Peek Overshoot and Setting Time of STATCOM Voltage such as THD of STATCOM, By varying the modulation index (M) and phase angle (ϕ) between PCC bus voltage and STATCOM voltage, voltage regulation at the PCC bus is achieved. The THD and various time response parameters of 6 and 12 pulses STATCOM are compared. The results show that THD of output voltage of 12 pulses STATCOM is greater than 5%, which does not satisfies the IEEE 519 standard. Hence, from above work it is concluded that there is need of active filter. Also, greater than 12 pulse STATCOM such as 24 pulses and 48 pulses STATCOM has better transient response as compared to 6, 12 pulse STATCOM.

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