REDUCTION OF THD IN POWER SYSTEMS USING STATCOM

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Abstract

In this paper, an operation methodology of a STATCOM (Static Synchronous Compensator) is proposed for reduction in Total Harmonic Distortion (THD) in power systems. For achieving this objective a comparison is made between two different configurations of Statcom.One is made up of two sets of three-level 12-pulse converter considering magnetic saturation and other is made up of two sets of three-level 12-pulse converter without magnetic saturation .The reactive power is controlled by the phase angle difference between the two sets of three-level 12-pulse VSC's. The magnetic saturation of transformers used in VSC topology results in increased THD. As per IEEE standard, in new configuration THD is reduced .The proposed model of the STATCOM is connected to a 33kV, 50Hz system and Fast Fourier Transform (FFT) results are presented for demonstrating its performance.

Index Terms:
Static Synchronous Compensator (STATCOM),
Voltage Source Converter (VSC),
Flexible AC Transmission System (FACTS),
Total Harmonic Distortion (THD),
Fast Fourier Transform (FFT).

1. Introduction

In recent year's energy, environment, right-of-way, and cost problems have delayed the construction of both power stations and new transmission lines, while the demand for electric power has continued to grow in many countries. This situation has spurred interest in providing already existing power systems with greater operating flexibility and better utilization, thus having led to the concept of flexible ac transmission systems (FACTS). The main purpose of introducing FACTS devices to power systems is to increase stability and transmission capability [1].

The static synchronous compensator (STATCOM) belonging to the family of flexible alternating current transmission system (FACTS) devices based on the voltage source converter (VSC) is a regulating device used in alternating current transmission systems[1-6]. The circulating power in the grid that does no useful work which results from energy storage elements in the power grid (mainly inductor and capacitors) has a strong effect on system voltages. Harmonic distortion is found with both the voltage and the current waveform.

Most current distortion is generated by electronic loads, also called non-linear loads. Current distortion affects the power system and distribution equipment. The Statcom is implemented by 6pulse converter comprising GTO Thyristors fed from a dc capacitor. Multi-pulse circuit configurations are employed to reduce the harmonic generation and to produce practically sinusoidal current [3].

In this paper, a STATCOM is proposed using two-sets of three-level 12-pulse VSC's. The phase angle difference between the two-sets of the three-level 12-pulse VSC's is varied to control the system reactive power and hence THD. The objective is to reduce the harmonics generated by the converter when magnetic saturation of the core is not considered [4]. The proposed STATCOM is modeled using MATLAB/ SimPowerSystems (SPS) tool boxes and the developed model is used to simulate its performance.

2. Working Principle of Statcom

The main objective of STATCOM is to control reactive current by generation and absorption of controllable reactive power. The essential components in a VSCbased STATCOM are GTO-VSC bridge(s), DC capacitor(C) working as an energy storage device, interfacingmagnetics forming the electrical coupling between theVSC bridge circuits, AC mains system,and controllers generating gating signals [5].
A controllable three-phase AC output voltage waveform is obtained at the point of common

coupling (PCC). AC output voltage of VSC bridge circuits (V_c) is governed by DC capacitor voltage which is controlled by varying phase difference between V_c, and V_s (system voltage at PCC).

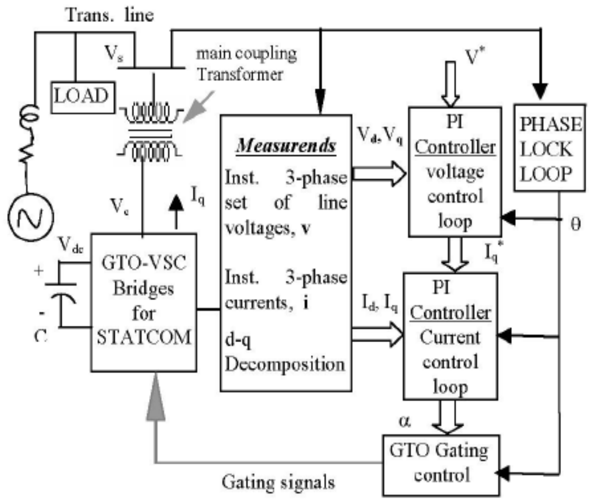

Fig .1.VSC based STATCOM Architecture.

The magnitude and phase difference of I_q determine the magnitude and phase difference between V_c and V_s across the transformer leakage inductance, which in turn controls reactive power flow [5].

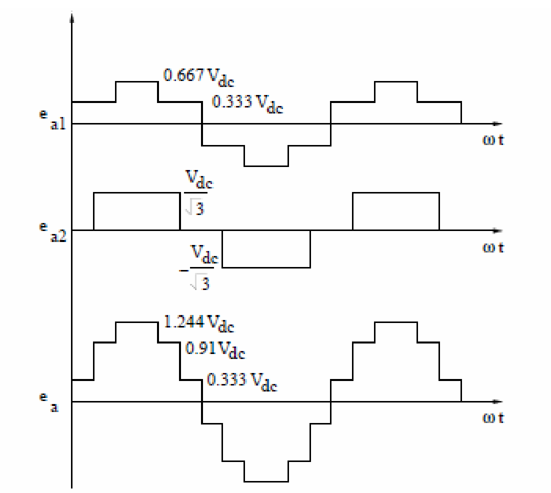

Fig.2.Output voltage waveforms of a 12 pulse converter

3. System Description

A. Transformer connections

When the power rating justifies the use of more than one bridge, the need for external filtering can be reduced by appropriate phase shifting of the individual converter transformers, which can be achieved by the use of different transformer connections.

The most common transformer connections are the star and delta types. A transformer consisting of star-connected primary and secondary windings does not alter the phase relationship of the input and output line-to-line voltages. However, the use of either delta–star or star–delta primary to secondary connections introduces a 30º phase shift between the input and output line-to-line voltages [6].

A 12 pulse converter circuit consists of two 6 pulse bridges connected in series on the AC side with an intermediate (summing) transformer [2].The two bridges are connected in parallel on the DC side. The summing transformer adds the phase to neutral voltage of bridge 1 to the phase to phase voltage of bridge 2. The transformer requires a 1:$\sqrt{3}$ turns ratio so that the magnitude of the current flowing into each bridge is equal.

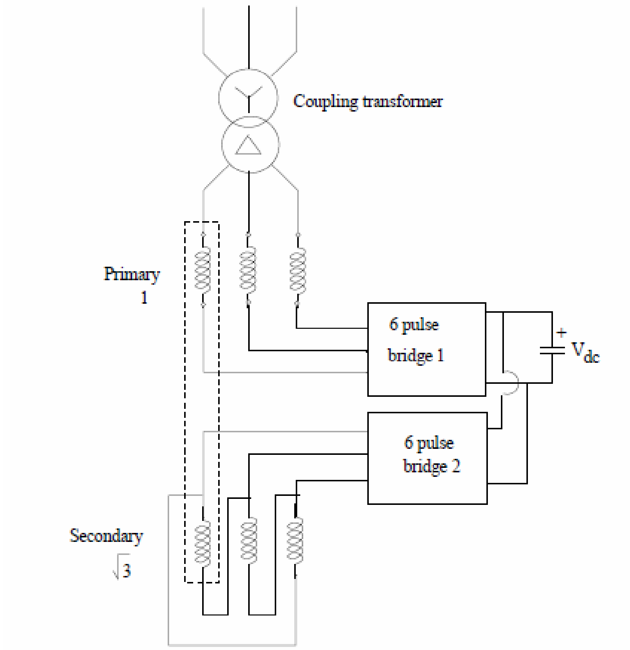

Fig.3.A Twelve pulse STATCOM

Transformers are also constrained in their performance by the magnetic flux limitations of the core. When a transformer's primary winding is overloaded from excessive applied voltage, the core flux may reach saturation levels during peak moments of the AC sine wave cycle. The overloaded transformer will distort the wave shape from primary to secondary windings, creating harmonics in the secondary winding's output. Reactive power flow [5].

Another cause of abnormal transformer core saturation is operation at frequencies lower than normal. For example, if a power transformer designed to operate at 60 Hz is forced to operate at 50 Hz instead, the flux must reach greater peak levels than before in order to produce the same opposing voltage needed to balance against the source voltage. Finally THD of the converter is also based upon the transformer core saturation.

The following equation allows determination of the characteristic harmonics for a given pulse number

$h = k_q \pm 1$

Where, h is the harmonic number (integer multiple of the fundamental) k is any positive integer, q is the pulse number of the converter. This means that a 6-pulse (or 3-phase) rectifier will exhibit harmonics at the 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc. multiples of the fundamental.

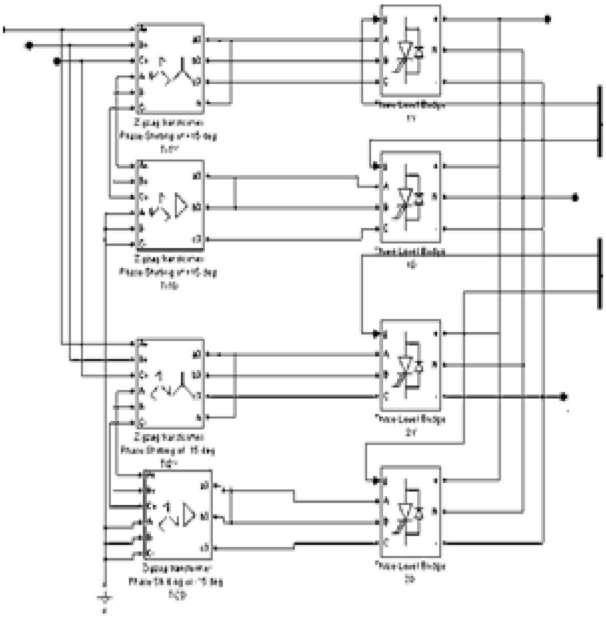

Fig.4.Proposed two sets of 3level 12 pulse statcom

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A frequently used measure of harmonic levels is total harmonic distortion (or distortion factor), which is the ratio of the rms value of the harmonics (above fundamental) to the rms value of the fundamental, times 100%.

$$THD_V = \frac{\sqrt{\sum_{k=2}^{\infty} V_{krms}^2}}{V_{1rms}} \cdot 100\%$$

The power factor of the system is affected with THD and hence if THD is controlled power factor of the system is controlled.

B.Control of statcom

Basically two controlling methods can be implemented for statcom:

They are:

1. Indirect Control: Reactive output current can be controlled indirectly via controlling the DC capacitor voltage.

2. Direct Control: Internal voltage control mechanism of the converter in which the DC voltage is kept constant

In the proposed statcom, indirect vector control method is used. In the vector control strategy, the three-phase currents are transformed to d and q axes, which are then synchronized with the AC system three phase voltage via a phase-locked loop (PLL). The d and q voltages generated by vector control are transformed to three-phase quantities and converted into line voltages by the VSC.The control system task is to increase or decrease the capacitor DC voltage, so that the generated AC voltage has the correct amplitude for the required reactive power.

The control system must also keep the AC generated voltage in phase with the system voltage at the STATCOM connection bus to generate or absorb reactive power. The vector control strategy uses the following inner blocks to control reactive power and hence the THD.

Various inner blocks in vector control are:

The Phase-Locked Loop (PLL) block is a feedback control system that automatically adjusts the phase of a locally generated signal to match the phase of an input signal. Also it synchronizes GTO pulses to the system voltage and provides a reference angle to the measurement system.

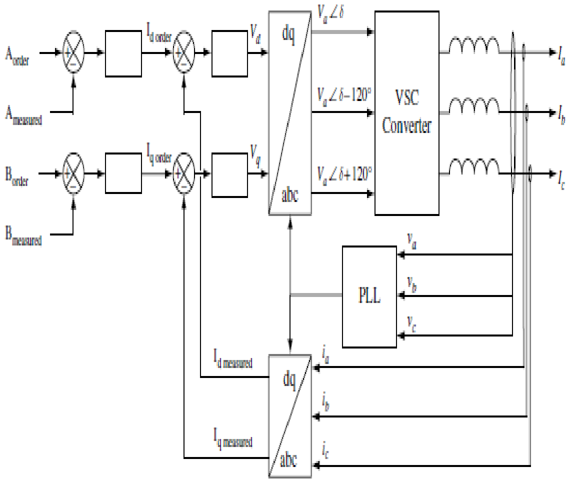

Fig.5.Vector control strategy implemented for proposed STATCOM

ABC-DQO transformation computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal.

Voltage regulation is performed by two PI regulators: from the measured voltage v_{meas} the reference voltage V_{ref}, the Voltage Regulator block (outer loop) computes the reactive current reference I_{qref} used by the Current Regulator block (inner loop). The output of the current regulator is the α angle which is the phase shift of the VSC voltage with respect to the system voltage.

Firing Pulses Generator generates pulses for the four VSC's from the PLL output and the current regulator output (α angle).

4. Simulation Results

The proposed STATCOM is modeled using MATLAB/Simulink SimPower Systems (SPS) toolboxes and simulated results are shown:

Table.1.THD results for various configurations

Input quantity	Single 12 pulse converter	2 sets of 12 pulse converter with core saturation	Proposed 2 sets of 12 pulse converter without core saturation
$V_{statcom}$(va_{sec},va ia_{prim})	7.75%	11.19%	1.78%
I_q-I_{qref}	80.19%	17.50%	20.98%
Q(Mvar)	67.58%	67.58%	63.42%

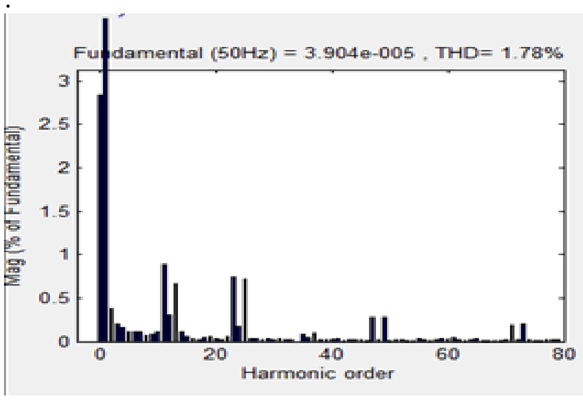

Fig.6.Harmonic spectrum of phase-a current

From Table.1 THD results,the proposed statcom consisting of two sets of 3 level 12 pulse statcom with out core saturation results in improved THD which inturn improves the system powerfactor.

5. Conclusion

Two sets of three level 12 pulse statcom strategy is proposed and its performance has been validated using developed model in MATLAB/Simulink.Proposed statcom without core saturation results in better THD compared with single three level 12 pulse statcom or proposed statcom with core saturation. The harmonic content of the STATCOM current is found well within specified IEEE 519 standard [9].

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