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"A Smulation Based On 12-Pulse Vsc Statcom With Harmonic Filter Reduced Harmonics And Voltage Flickers "

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ABSTRACT: *Voltage flicker is considered as one of the most severe power quality problems (especially in loads like electrical arc furnaces), voltage flicker effect on the voltage quality. Due to the latest achievements in the semiconductors industry and consequently the emergence of the compensators based on voltage source converters, FACTS devices have been gradually noticed to be used for voltage flicker compensation. In this thesis voltage flicker mitigation has been investigated for static synchronous compensator (STATCOM). For this purpose a two-bus system connected with STATCOM is used. Initially a 6-pulse voltage source converter STATCOM is used to compensate for the voltage flicker. In this case injection of harmonics into the system caused some problems which are later overcome by using 12-pulse voltage source converter STATCOM and harmonic filter. All the simulations have been performed on the MATLAB SIMULINK software. The obtained results show that STATCOM is very efficient and effective for the flicker compensation.*

INTRODUCTION: Power quality is the combination of voltage quality and current quality, thus power quality is concerned with deviations of voltage and or current from ideal. Power quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment and Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance.

All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality problems.

Power quality problems:

The term power frequency disturbance describes events that are slower and longer lasting compared to electrical transients. Power frequency disturbances can last anywhere from one complete cycle to several seconds or even minutes. While the disturbance can be nothing more than an inconvenience manifesting itself as a flickering of lights or bumpy ride in an elevator, in other instances the effects can be harmful to electrical equipment. Typically, the deleterious effects of power frequency disturbances are predominantly felt in the long run and such disturbances do not result in immediate failure of electrical devices. The effects of power frequency disturbances vary from one piece of equipment to another and with the age of the equipment. Equipment that is old and has been subjected to harmful disturbances over a prolonged period is more susceptible to failure than new equipment. Fortunately, because power frequency disturbances are slower and longer lasting events, they are easily measured using instrumentation that is simple in construction .

Most common power quality problems are :

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1. Voltage sag (dip)
2. Voltage swell
3. Harmonics
4. Interruptions
5. Voltage spike
6. Noise
7. Voltage unbalance
8. Distortions
9. Transients
10. Voltage flicker

FLEXIBLE AC TRANSMISSION SYSTEM:

Flexible AC Transmission Systems, called FACTS, got in the recent years a well-known term for higher controllability in power systems by means of power electronic devices. Several FACTS devices, have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice.

In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. The basic applications of FACTS devices are:

- Power flow control,
- Increase of transmission capability,
- Voltage control,
- Reactive power compensation,
- Stability improvement,
- Power quality improvement,
- Flicker mitigation,

Classification of FACTS devices:

The development of FACTS devices has started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for high and even highest voltage levels. The overall starting points are network elements influencing the reactive power or the impedance of a part of the power system. Figure 2.1 shows a number of basic devices separated into the conventional ones and the FACTS devices.

For the FACTS side the taxonomy in terms of 'dynamic' and 'static' needs some explanation. The term 'dynamic' is used to express the fast controllability of FACTS-devices provided by the power electronics. This is one of the main differentiation factors from the conventional devices. The term 'static' means that the devices have no moving parts like mechanical switches to perform the dynamic controllability. Therefore most of the FACTS devices can equally be static and dynamic.

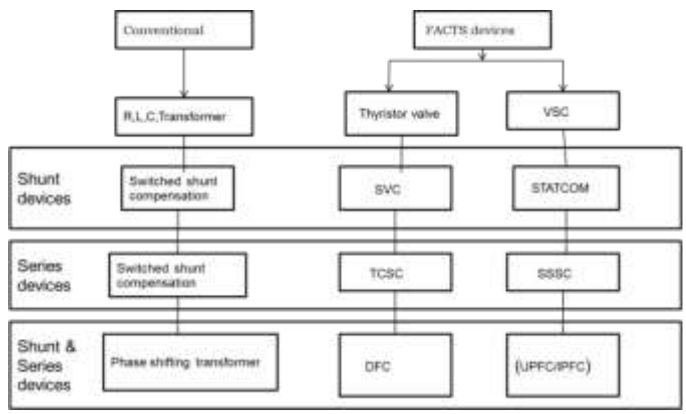

Fig. 2.1 Overview of major FACTS devices

PRINCIPLE OF STATCOM OPERATION

The STATCOM consists of two basic components: 1) a three-phase voltage source inverter (VSI) and 2) a step-down adaptive transformer. The latter component is interface between the power system and inverter. It is noted that this transformer, which connected in parallel with the bus, creates a limitation due to the elimination of harmonic by STATCOM. Since the transformer is not able to pass the harmonic currents. This compensator is connected in parallel with the furnace (or other non-linear load) to the furnace bus (for instance the system proposed in), or PCC bus (the proposed system in). A general scheme of a STATCOM connected to an AC system has been presented in Fig. 1. If the primary voltage of the transformer

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(inverter side) becomes larger than that of the secondary voltage (system side), the current passes the AC power system through the leakage reactance (X) of the transformer, and inverter generates reactive power for the power system (capacitive case). If the secondary voltage of the transformer (inverter side) becomes larger than the primary voltage (system side), the reactive current passes from AC system to the inverter and inverter observes reactive power (inductive case).This current is calculated as follows: X U U I acs− vsi = (1) where Uacs and Uvsi are the ac power system and VSI voltages, respectively and X is the leakage reactance of the transformer. In the case of equal secondary and primary voltage, interchange of the reactive power is equal to zero.

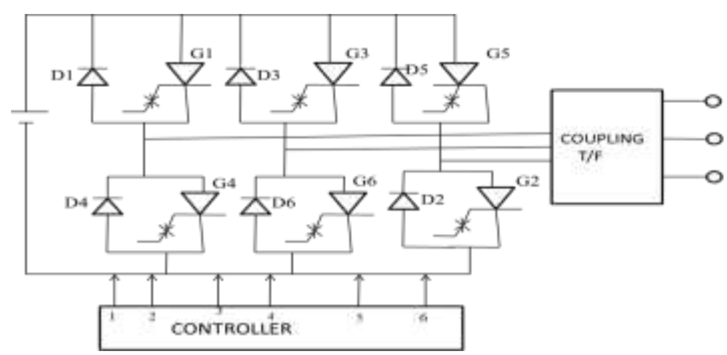
COMPENSATION SYSTEM:

1. A two bus power system connected with STATCOM: In this project a two bus system is considered to investigate the voltage flicker compensation using STATCOM. This configuration block diagram is illustrated in fig: 3.2 which consist of 3Ø programmable voltage source [1-23] and STATCOM. The voltage oscillation is produced by the programmable voltage source which is connected to the main bus-bar, by specifying the amplitude of modulation the signal increments and decrements with respect to unit value. Operating conditions and parameters are represented in the Appendix.

2. 2.6-pulse voltage-source converter STATCOM: The block diagram of a three-phase 6-pulse voltage source converter STATCOM is shown in figure 3.3. Six valves compose the converter and each valve is made up of a GTO with a diode connected in anti-parallel [21]. In this type of STATCOM, each GTO is fired and blocked one time per line voltage cycle. In this case, each GTO in a single branch is conducted during a half-cycle (180 degree) of the fundamental period. The combined pulses of each leg have 120 degrees Phase difference to produce a balanced set of voltages. By adjusting the conducting angle of the GTOs, the generated voltage and then the injected or absorbed power of the STATCOM are controlled [3]. The instantaneous output line-to-line voltage (Vab) of the 6-pulse voltage-source converter is as follows:

$$V_{ab} = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi} \cos\frac{n\pi}{6}\, sinn\left(wt + \frac{\pi}{6}\right)$$

It is clearly perceptible from the above equation that, the even harmonics in the instantaneous line-to-line voltage has zero value and does not enter the network voltage. The six pulse bridge produces harmonics at 6N +/- 1, i.e. at one more and one less than each multiple of six. In theory, the magnitude of each harmonic is the reciprocal of the harmonic number.



Block diagram of 6-pulse voltage source converter STATCOM

3. 12-pulse voltage-source converter STATCOM

Two 6-pulse bridges are connected in parallel, forming a 12-pulse converter for a complete voltage flicker compensation design . These are linked together using a three winding transformer. Moreover, the delta-connected secondary of the second transformer must have $\sqrt{3}$ times the turns compared to the wye-connected secondary and the pulse train to one converter is shifted by

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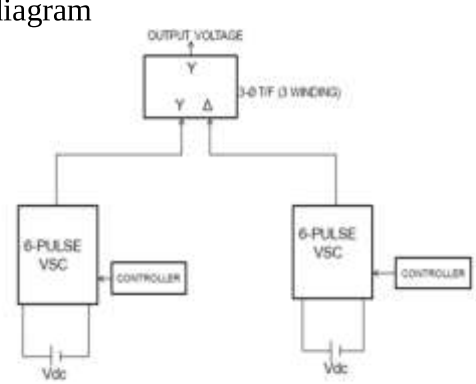
30 degrees with respect to the other . The 12-pulse voltage-source converter STATCOM circuit diagram



Block diagram of 12-pulse voltage source converter STATCOM

4. 12-pulse voltage-source converter STATCOM with 3Ø harmonic filter: Three-phase harmonic filters are shunt elements that are used in power systems for decreasing voltage distortion. Nonlinear elements such as power electronic converters generate harmonic currents or harmonic voltages, which are injected into power system. The resulting distorted currents flowing through system impedance produce harmonic voltage distortion. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths [24]. Harmonic filters are designed to be capacitive at fundamental frequency, so that they are also used for producing reactive power required by converters and for power factor correction.

In order to achieve an acceptable distortion, several banks of filters of different types are usually connected in parallel. The most commonly used filter types are band-pass filters, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th, etc.

Band-pass filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).In this project double tuned 3Ø harmonic filter is used[23], it is connected across the 12-pulse voltage source converter as shown in fig3.6 double-tuned type filters that can be modeled with the three-phase harmonic filter block are shown in fig.3.5.

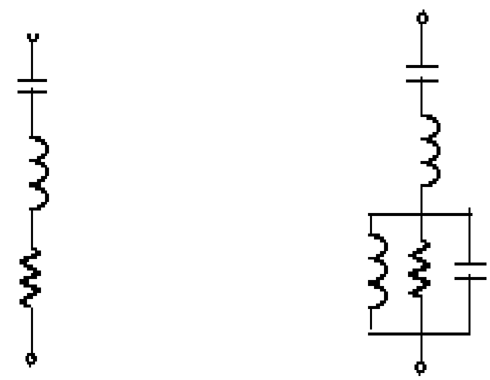


Fig.3.5 Band-pass filters.

The double-tuned filter consists of a series LC circuit and a parallel RLC circuit. If f1 and f2 are the two tuning frequencies, both the series circuit and parallel circuit are tuned to approximately the mean geometric frequency $f_m = \sqrt{f_1 f_2}$.The quality factor Q of the double-tuned filter is defined as the quality factor of the parallel L, R elements at the mean frequency f_m:

$$Q = \frac{R}{L * 2\pi F_n}$$

Total Harmonic Distortion (THD): Total Harmonic Distortion (THD) is the ration of the RMS value of the sum of the individual harmonic amplitudes to the RMS value of the fundamental frequency .

For a periodic wave, THD is defined as:

i = order of harmonics,

V (i) = Amplitude of ith harmonic component of voltage

THD

THD has the following properties:

• THD is zero for a perfectly sinusoidal waveform

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• As the distortion, increases THD becomes very large
• A commonly used THD level in distribution system in 5%.THD of either current or voltage may be calculated.
• Quick measure of distortion as it can be calculated easily.

CONTROL CIRCUIT

A new technique based on a novel control algorithm, which extracts the voltage disturbance to suppress the voltage flicker, is presented in this thesis. The concept of instantaneous reactive power is used for the controlling system. Following this 3Ø flicker voltage has been transformed to synchronous reference frame by the use of abc to dqo transformation (Park's transformation). To implement the synchronous reference frame some kind of synchronizing system (phased looked loop) should be used [24-6].

3Ø AC system load voltage is the input to the phase locked loop (PLL), this PLL can be used to synchronize on a set of variable frequency, and 3Ø sinusoidal signals.3Ø PLL block provides three outputs [21-23].

Output 1: Measured frequency (Hz) = $\frac{\omega}{2\pi}$

Output 2: Ramp ωt varying between 0 and 2π Synchronized on zero crossing of the fundamental (positive – sequence) of phase A.

Output 3: Vector (Sinωt, Cosωt)

From the output of PLL sinωt and cosωt value are given to abc to dqo transformation, this transformation leads to the appearances of three instantaneous space vectors: v_d on the d-axis (real or direct axis), v_q on the q-axis (imaginary or quadrature axis) and v_0, from 3 – Ø phase flicker voltage of v_a, v_b and v_c. The related equations of this transformation, expressed in the MATLAB Simulink software [23], are as follows:

$$V_d = \frac{2}{3}\,(V_a \sin(wt) + V_b \sin\left(wt - \frac{2\pi}{3}\right) + V_c \sin(wt + \frac{2\pi}{3}))$$

$$V_q = \frac{2}{3}\left(v_a \cos(wt) + V_b \cos\left(wt - \frac{2\pi}{3}\right) + V_c \cos\left(wt + \frac{2\pi}{3}\right)\right)$$

$$V_0 = \frac{1}{3}(V_a + V_b + V_c)$$

Park's Transformation of 3-phase flicker voltage to the instantaneous vector's is given to demux block, it extract the component of an input signal and output's the components as separate signals Vd, Vq and V0.The active and reactive components of the system are represented by the direct and quadrature component, respectively, the decrease of the voltage flicker of the network and the compensating control to decrease the voltage flicker can be limited only based on the amount of the imaginary component of the instantaneous voltage (Vq), so to decrease the voltage flicker controlling system uses only Vq to control the STATCOM, the obtained Vq is entered as an input to the sum block and other input to the sum block is constant value zero, it indicates the Vq per unit reference value[6].

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In sum block plus and minus signs indicate the subtraction or comparison operation to be performed on the inputs, resultant is the sum block output as the error signal is given to PI controller. PI controller output signal is firing angle component in radians, it is multiple by the gain of to get in degrees, and this firing signal is given to the input of pulse generator to control the pulses of the generator. The inputs AB, BC, CA are the phase – phase voltages these are given from the 3Ø flicker voltage. Step value is block reference value. Pulse generator output contains the pulse signal (pulse width 10 degree is specified) are to be sent to the voltage source converter to trigger the power switching devices (GTO's) of the STATCOM, to produce required magnitude of voltage and injection or absorption of reactive power.

SIMULATION AND ANALYSIS OF THE RESULTS: In order to investigate the influence of the STATCOM as an effective mitigating device for voltage flicker, first a 6 pulse VSC STATCOM then a 12pulse VSC STATCOM and 12 pulses VSC STATCOM with 3Ø harmonic filter are simulated in MATLAB SIMULINK. The compensation technique and their results are presented in this thesis.

Simulation of a two bus power system without STATCOM: In this project 69 kv 3Ø voltage source, 100 km 3-Ø ∏ section power system line are used and are connected to the step-down 3Ø transformer, which supplies a 3Ø parallel RL load. 3Ø programmable Voltage source is used to produce voltage flicker or voltage fluctuation into the system. Block parameters of 3Ø programmable voltage source are as follows, amplitude of modulation is 0.3 pu, frequency of the modulation is 10 HZ, Variation timing is 0 to 0.4 sec. with these specified parameter values, the variation in the output load voltage is shown in the fig 5.2 SIMULINK diagram of a two bus power system without STATCOM .

Simulation of 6-pulse voltage source converter STATCOM connected to the power system: The load voltage and the flicker source voltage are given to phase locked loop (PLL) and abc to dq transformation blocks respectively. From the control circuit trigger pulse are given to the corresponding GTO's, by adjusting the conducting angle of the GTO's the generated voltage and then the injected or absorbed reactive power of the STATCOM are controlled. Fig 5.3 shows SIMULINK diagram of 6 pulse voltage source converter STATCOM connected to the power system.

Fig 5.4 and fig 5.5 shows the compensated output load voltage and harmonic spectrum respectively by 6 pulse voltage source converter STATCOM. It can be observed that the compensated output load voltage is 1.15pu (maximum value), the voltage flicker existing in the output load voltage is 0.15pu (15%), the considerable existing characteristic harmonics in the output load voltage wave form in addition to the fundamental component are 5^{th}, 7^{th}, 11^{th}, 13^{th} and higher. It can be observed from the harmonic spectrum that THD is 8.95%. 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonic should be eliminated from the output load voltage.

Simulation of 12-pulse voltage source converter STATCOM connected to the power system: In this compensation, pulse generator outputs 1and 2 are two vectors of six pulses, are given to the two 6-pulse converters connected respectively to the Y

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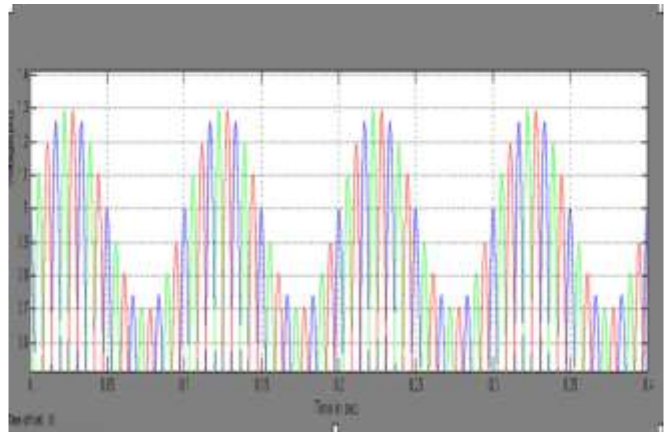
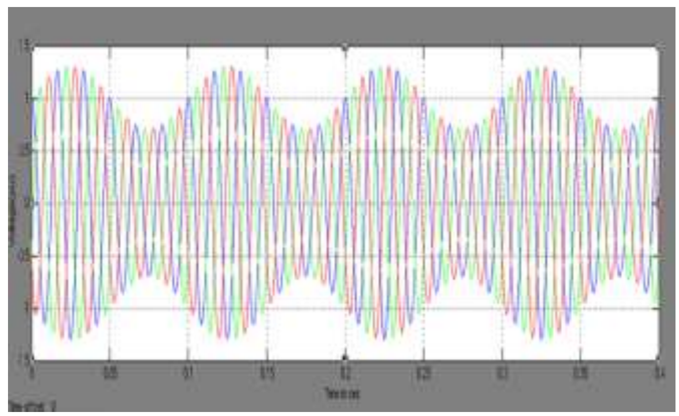
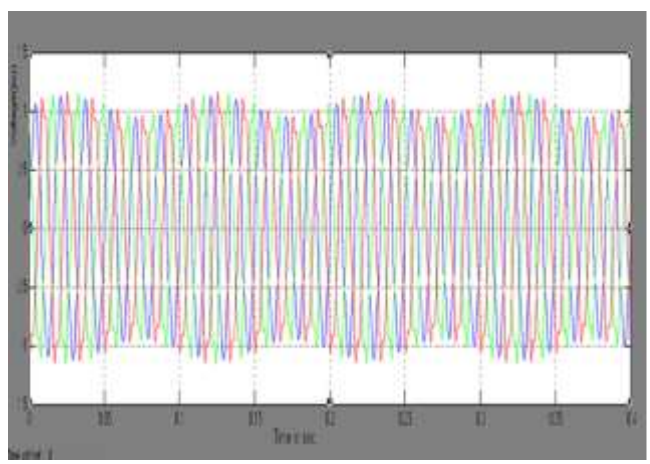
winding and Δ connected windings of 3Ø transformer (three windings). The pulse train to one converter is shifted by 30 degrees with respect to the other. Fig 5.6 shows SIMULINK diagram of 12 pulse voltage source converters STATCOM connected to the power system. The output load voltage mitigated by 12-pulse voltage-source converter STATCOM and its harmonic spectrum are shown in figures 5.7 and 5.8 respectively. In this respect, the voltage flicker is completely removed from the output load voltage. It can be observed from the harmonic spectrum that THD is 4.47%.

Simulation of 12-pulse voltage source converter STATCOM with 3Ø harmonic filter connected to the power system: To eliminate lowest order harmonics such as 11th and 13th harmonic, double tuned band pass filter is connected across the 12 pulse voltage source converter output. Fig 5.9 shows SIMULINK diagram of 12 pulse voltage source converters STATCOM with 3Ø harmonic filter connected to the power system. The output load voltage mitigated by 12-pulse voltage-source converter STATCOM with 3Ø harmonic filter and its harmonic spectrum is shown in figures 5.10 and 5.11 respectively. In this respect, the voltage flicker is completely removed from the output load voltage and a sinusoidal waveform is obtained. It can be observed from the harmonic spectrum that THD is 2.30%.





Output load voltage without STATCOM.



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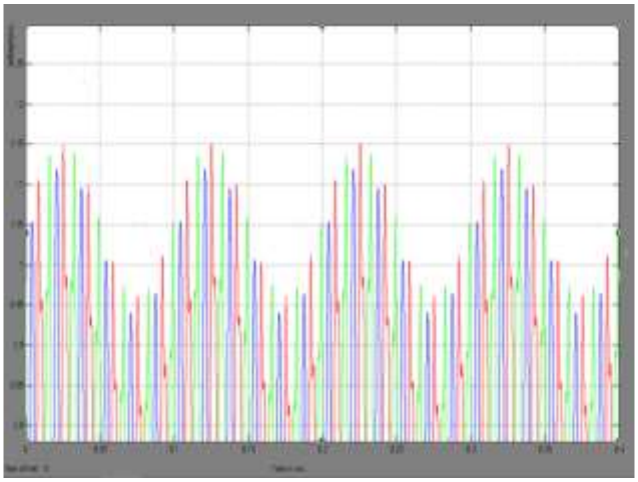
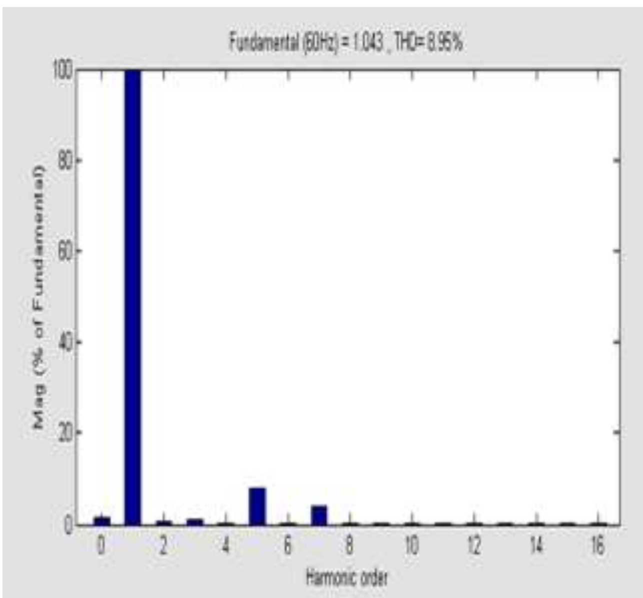
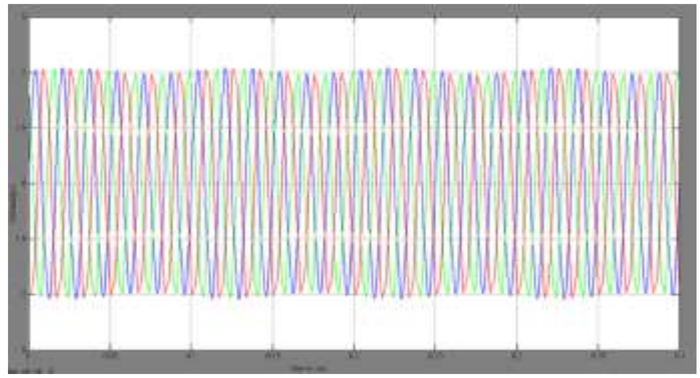


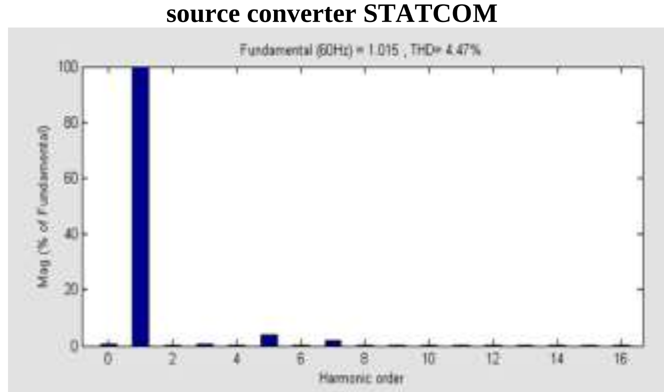
Compensated output load voltage by 6-pulse voltage source converter STATCOM



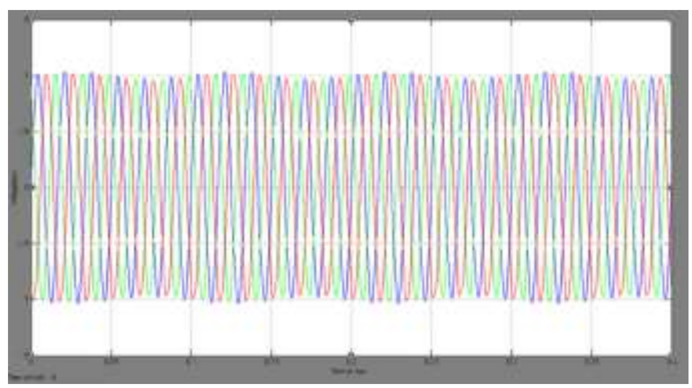
Harmonic spectrum of the compensated output load voltage by 6-pulse voltage-source converter STATCOM.



7 Output load voltage mitigated by 12-pulse voltage source converter STATCOM



Harmonic spectrum of the output load voltage mitigated by 12-pulse voltage-source converter STATCOM.



Output load voltage mitigated by 12-pulse voltage source converter STATCOM with 3Ø harmonic filter

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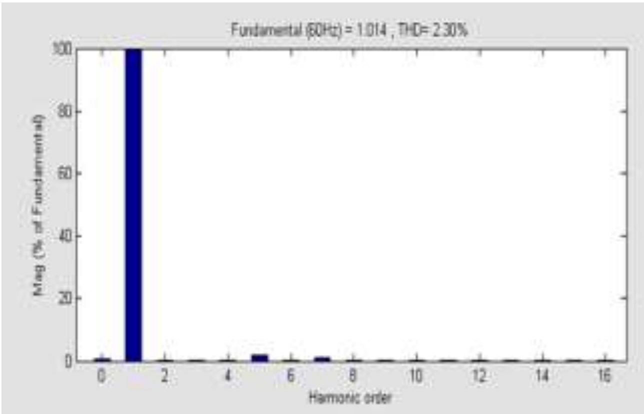

Harmonic spectrum of the output load voltage mitigated by 12-pulse voltage-source converter STATCOM equipped with a harmonic filter.

Results analysis: Voltage flicker mitigation using 6 pulse voltage source converter STATCOM, 12 pulse voltage source converter STATCOM, and 12 pulse VSC STATCOM with 3Ø harmonic filter are simulated. The output load voltage without STATCOM and with STATCOM is obtained and compared. The results obtained are as follows:

I. Without STATCOM:

The output load voltage is 1.3 Pu (maximum value).The voltage flicker existing in the output load voltage (exerted to the system) is 0.3 Pu (30%).

II. With STATCOM:

TABLE 5.1 Comparison of voltage flicker mitigation and THD value of STATCOM compensators.

Compensator	**Compensated output load voltage (maximum value)**	**Voltage Flicker**	**THD**
6 pulse VSC STATCOM	1.15 pu	Existing is 0.15 pu (15%) (or) Mitigated by 50%	8.95 %
12 pulse VSC STATCOM	1.0 pu	Completely mitigated	4.47 %
12 pulse VSC STATCOM with 3Ø harmonic filter	1.0 pu	Completely mitigated	2.30 %

CONCLUSION: In this thesis, the application of STATCOM technology based on voltage-source converters for voltage flicker mitigation has been investigated and simulation results emphasized its significant effect. A 6-pulse STATCOM is decreasing the voltage flicker by 50%. However, there is injection of the harmonic from 6-pulse STATCOM into the system which can be improved with the increase of the voltage source converters of STATCOM using a 12-pulse STATCOM equipped with a harmonic filter. The obtained results clearly demonstrate that 12-pulse STATCOM equipped with a harmonic filter can reduce the voltage flicker completely and the output is obtained with minimum THD Value.

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