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A 24 Pulse Multilevel Statcom for Harmonics Elimination in Power System

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ABSTRACT

This paper present shunt connected 24 Pulses STATCOM for particular harmonics elimination (5^{th}, 7^{th}, 11^{th}, 13^{th}) generated by non-linear load in a simulated environment using MATLAB software with Simulink Sim Power System(SPS) toolbox . It is a multilevel STATCOM using Gate Turn Off Transistor (GTO) as switch and having VSC topology. For reducing the Total Harmonics Distortion (THD) in power system, Magnetic interfacing of Phase shifting Transformers is being used. This paper present the comparative analysis of 24 pulse STATCOM and 12 Pulse STATCOM in terms of THD, in the system with and without the effect of Transformer core saturation in system.

Keywords: Static Synchronous Compensator (STATCOM), Voltage source converter (VSC), Fast Fourier Transform (FFT), Phase Shifting (PST), Total harmonics Distortion (THD), Sim Power System (SPS), Point of Common Coupling (PCC), Gate Turn Off Transistor (GTO).

1. INTRODUCTION

STATCOM is a Flexible A.C. Transmission device (FACTS) device having similarities with synchronous condenser. It is used for voltage regulation and to control Reactive as well as Active power flow for voltage fluctuation and stability conditions. STATCOM having VSC topologybasically consist of DC voltage source, a capacitor and variable voltage self-commutated converter using different type of switches like SCR, IGBT, GTO, GCT etc. [1]. The selection of switching device is based upon its characteristics derived from potential applications like Traction, Industry, Energy storage systems and Energy systems like low and medium voltage drives [4]. Gate Turn Off Thyristor is well suited for Voltage source converter applications.

Proposed STATCOM is of 24 pulses multilevel shunt compensation device, which is fired with fundamental frequency switching method. PI controlling strategy is being used for inner current and Outer voltage control loop. Voltage control loop will determine the reference reactive current, which is in quadrature with supply current. At the point of common coupling GTO-VSC supply voltage and current to reduce the harmonics content in power supply, generated by the Non-Linear load, as per IEEE standards [5]. So that the effect of harmonics on Power source will be reduced to greater extent. Magnetic Interfacing is provided in two stages, where first stage consist of four three phase Phase Shifting Transformers (PST) to provide phase shift of +7.5 and -7.5 Degree and in second stage Star-Delta configuration of Transformers to provide displacement angle of 0 and +30 degree. Star-Delta Transformer ensuring the elimination of 3^{rd} harmonics completely leaving only 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonics which is to be handled by PSTs. Charging of Capacitor in VSC configuration is maintained at fundamental frequency of operation. With capacitance voltage more than Supply voltage ($V_c > V_s$) ensure the capacitive operation of STATCOM and when ($V_c < V_s$) then operation will be inductive and with both the voltage equal ($V_c = V_s$) system will result into no exchange of reactive power as shown in fig.1.

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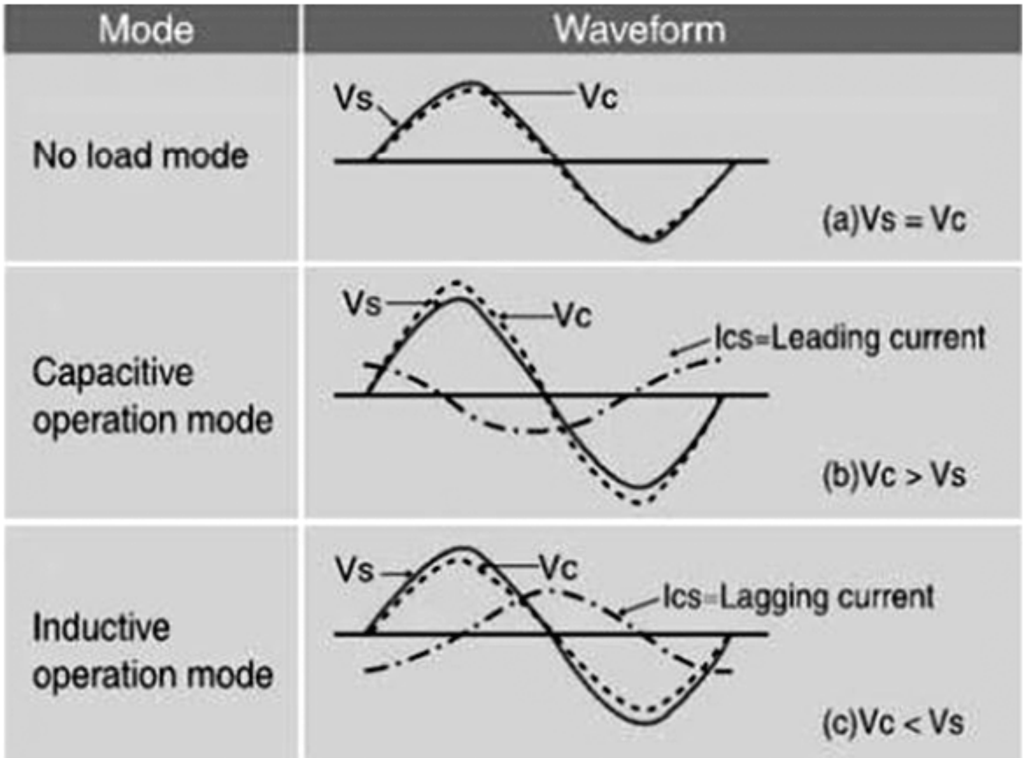

Figure 1: Operation Mode

2. PRINCIPAL OF STATCOM

The essential components in a VSC based STATCOM are GTO-VSC bridge(s), DC capacitor(C) working as an energy storage device, inter-facing magnetic forming the electrical. coupling between the VSC bridge circuits, AC mains system and controllers generating gating signals.

STATCOM is a shunt connected device which is represented as synchronous voltage source for the purpose of positive sequence analysis. STATCOM bus is represented as a PV bus in diagram which may change into PQ bus in case of violation of voltage limit of power system [2]. During this case it will absorb reactive power from power system and source voltage will be higher than the Capacitor voltage in this case ($V_c < V_s$) and vice versa is also possible. STATCOM works as a Voltage source for whole operation.

Power flow equations for STATCOM are as follows

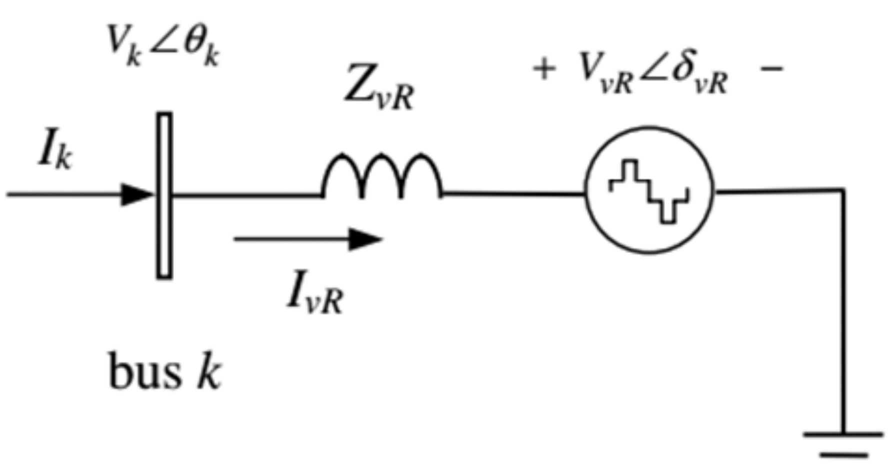

Figure 2: Power Flow model of STATCOM

$$E_{vR} = V_{vR}\left(\cos\delta_{vR} + j\sin\delta_{vR}\right) \tag{1}$$

Power equation will be

$$S_{vR} = V_{vR} I_{vR}^{*} = V_{vR} Y_{vR}^{*}\left(V_{vR}^{*} - V_{K}^{*}\right) \tag{2}$$

Along with the Voltage control operation another important function of STATCOM is to eliminate harmonics generated by Dynamic, Variable or Non-Linear load of power system. For which Magnetic interfacing of transformers has been incorporated in simulation environment in two different stages. By providing the adequate phase shift by PSTs and Star-Delta transformer voltage and current phasor generated in such a way to eliminate the effect of 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonics in simulated system. In high power FACTS devices it is not advisable to have very high switching frequency. while keeping the switching frequency equal to fundamental frequency Multilevel convertor or double converter configuration can provide solution[6]. In this paper Multi level converter configuration has been discussed for harmonics elimination. As we keep on increasing the level of inverter, output filter circuit size reduces and Capacitance requirement increases with the reduction in voltage required charging of the same capacitor. Switching voltage also reduces with increase in level of Inverter.

3. CONTROLLER DESIGN

The controller design have started without proper transfer function of system, so the control compensation selected randomly and Proportional and integral gain are achieved by trial and error. Current Control and Voltage control loop were designed separately [7].

In Current Control Loop Phase lock loop is providing necessary θ angle for d-q0 transformation. D-Q0 transformation provides the direct and quadrature axis of the three phase current I_{ABC}. Low pass filter is

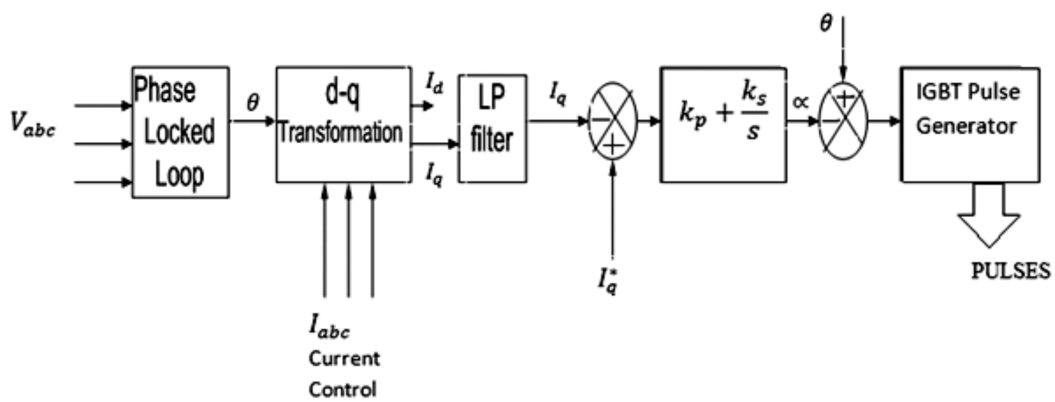

Figure 3: Block Diagram of Current Control Loop

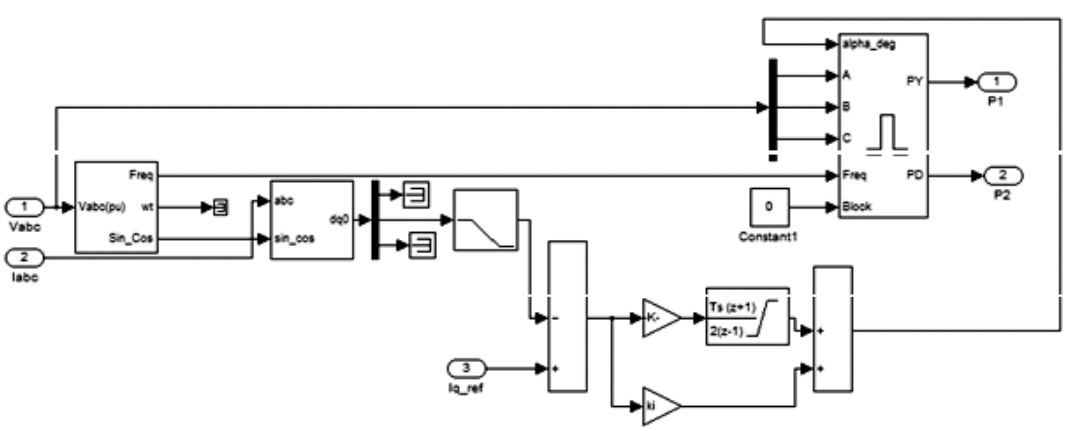

Figure 4: Simulation diagram of Current Control loop

provided to reduce the non-linearity of the I_q^* signal. After the comparison of I_q and I_q^* are subjected towards the P-I controller and generating the output signal $\propto$.

The θ signal from Phase locked loop is further compared with the $\propto$. The difference of the two signals is used as input to twelve pulse synchronous generator for producing the required pulses.

The voltage controller analyzed in this work is exhibited in Fig. 5, Which employs the dq0 rotating reference frames because it offers higher accuracy than stationary frame based techniques. Phase Locked loop is providing the operation of d-q0 transformation. In this figure 5, V_{ABC} are the three-phase terminal voltages, V* is the reference voltage, V_d and V_q are the Direct and Quadrature axis of the Three phase Voltage. Low pass filter is used to reduce the non-linearity of the V_{dq}. Reactive current I_q^* is the current output which is compared with I_q in the current control loop. Further V_{dq} is compared with the reference voltage to maintain the accuracy of the system [8].

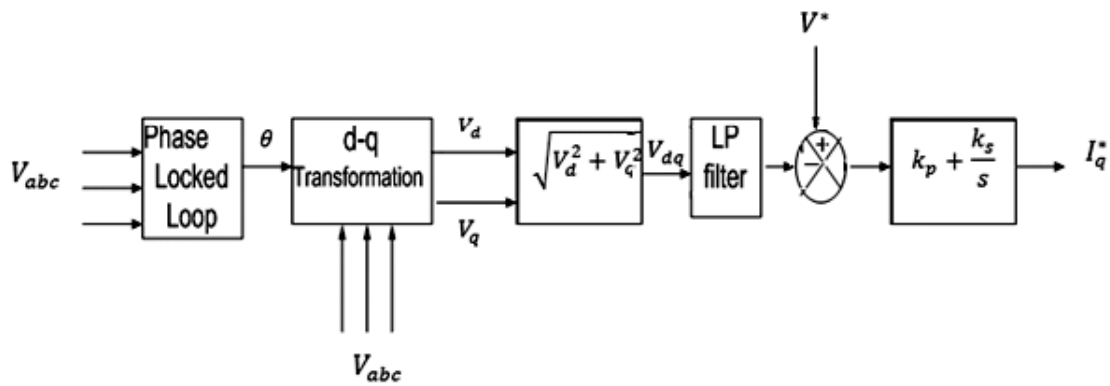

Figure 5: Block Diagram of Voltage Control Loop

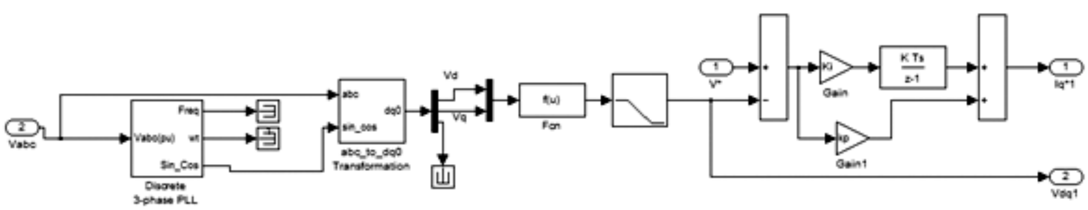

Figure 6: Simulation diagram of Voltage Control loop

4. SIMULATION MODEL OF STATCOM

The following fig. 7 shows the Simulation model of 24 pulse multilevel STATCOM with rating of +100Mvar connected to the system of 132KV voltage at the point of common coupling. The 24 pulse model is simulated by connecting four 6 pulse GTO-VSC in parallel to the DC side [3]. The Capacitor is used for energy storing source at the DC side of 20000µF and kept initially charged at 8.3 KV. GTO-VSC bridges connected to the DC source are provided with the Gating signals generated by the voltage and current controlling units for producing the reactive power accordingly to the demand by observing the AC system side voltage for particular harmonics elimination. The two control loop strategy, First is Inner current control loop and second is outer voltage control loop are employed. Voltage control loop provide the that is input to the other current control loop. Current control loop generates the á i.e. used to produce the Gating pulses for the GTO-VSC Bridges. Varity of Non-Linear load in parallel to system is supplied to the STATCOM in simulation model to check the useful ness of model in dynamic conditions. The secondary sides of the two PSTs are parallel connected to the stage-I primary. The primaries of the stage-I and stage-II transformers are connected in series [3].

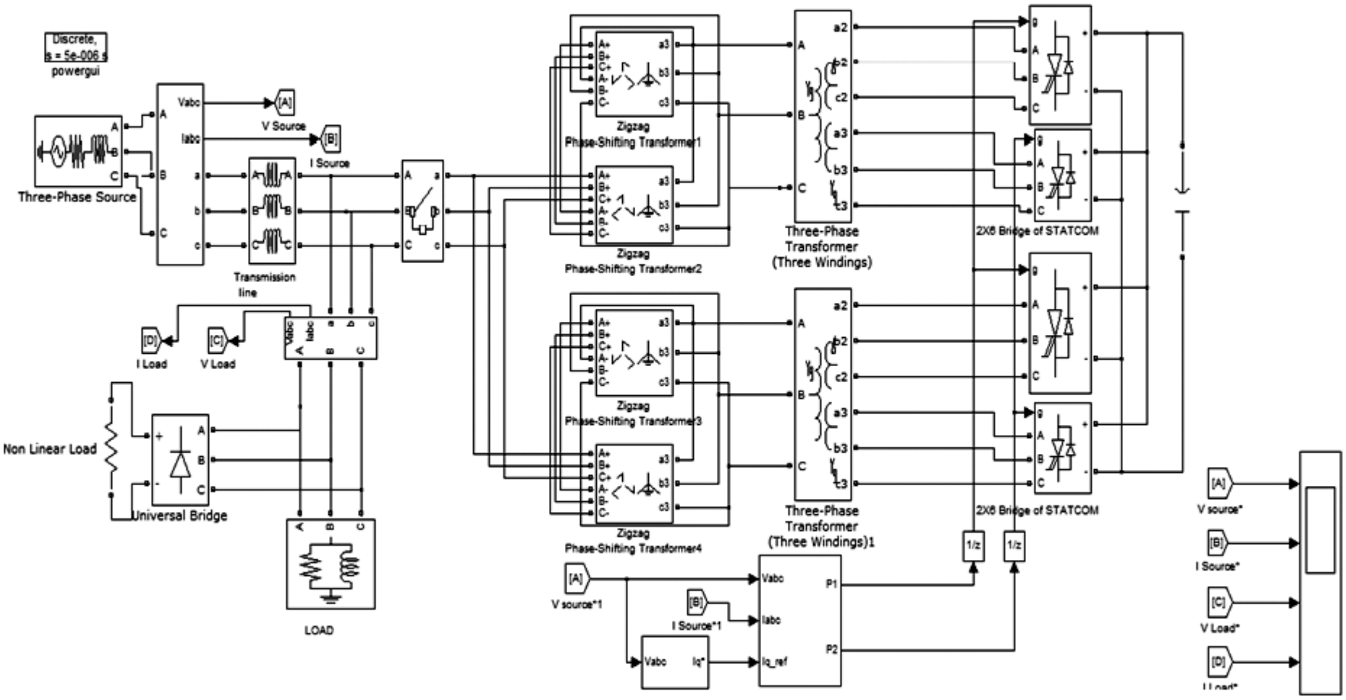

Figure 7: Simulated model of 24 Pulses Multilevel STATCOM with Non Linear Load

These two stages of the Interfacing Magnetics with particular Turn ratios reduce the harmonics.The following equation allows determination of the characteristic harmonics for a given pulse number $h = kq \pm 1$ Where, h is the harmonic number (integer multiple of the fundamental) k is any positive integer, q is the pulse number of the converter 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%.

$$THD_v = \frac{\sqrt{\sum_{k=2}^{\infty} V_{krms}^2}}{V_{Irms}} * 100 \tag{3}$$

The harmonics reduction of this STATCOM is with in limits, which is less than 5% as per IEEE standards and provide a feasible solution for the harmonics suppression while connecting variety of load in parallel [9].

Twelve pulse STATCOM Multi level simulated with the Three phase Voltage source at 50MW of the Non Linear Load, which is in parallel with the 50MW of resistive and 100Kvar Linear parallel load. Non Linear load will produce the harmonics in the load end, where it is connected [10].

4.1. Results and Discussion

Variation of the Reactive power and Voltage are shown. As discussed earlier Voltage will increase at time 0.22sec from 1p.u. to 1.03p.u.and at the same time reactive power from the STATCOM increases to satisfy the required needs for maintaining the voltage level and as the voltage decreases at time 0.44sec. to 0.97p.u. reactive power decreases, and maintain the system performance.

There are harmonics in the Voltage and Current waveform both at the load side, that limits its practical use of circuit. Harmonics content are shown onwards in FFT windows of Voltage and Current individually.

It is shown in results that the voltage and current waveform is distorted and having Harmonics of 10.97% in voltage and 9.92% in Current. Which needed to be improved according to IEEE standards by applying the STATCOM at Point of common coupling (PCC).

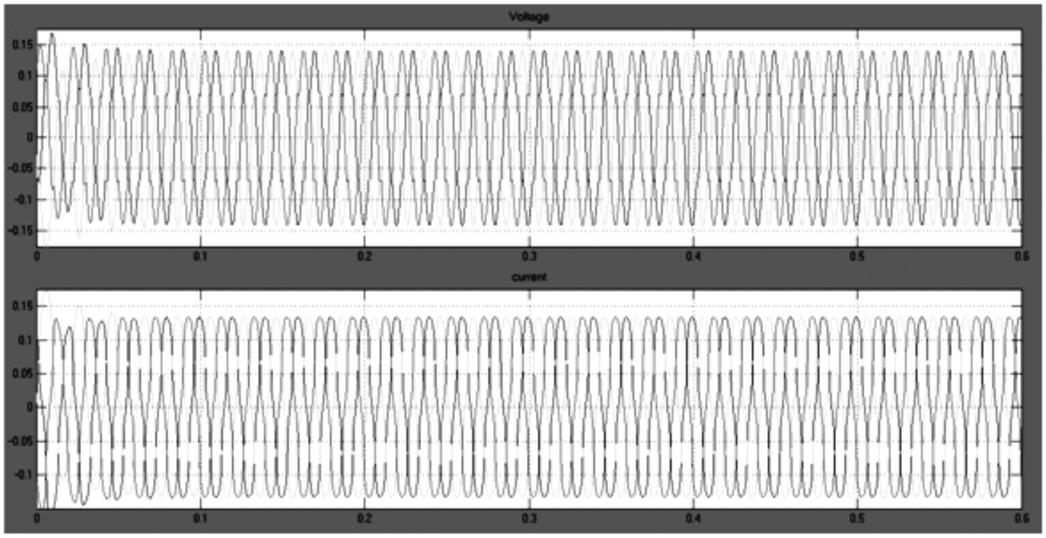

Figure 8: Voltage and Current at Non-Linear load in Multi Level STATCOM

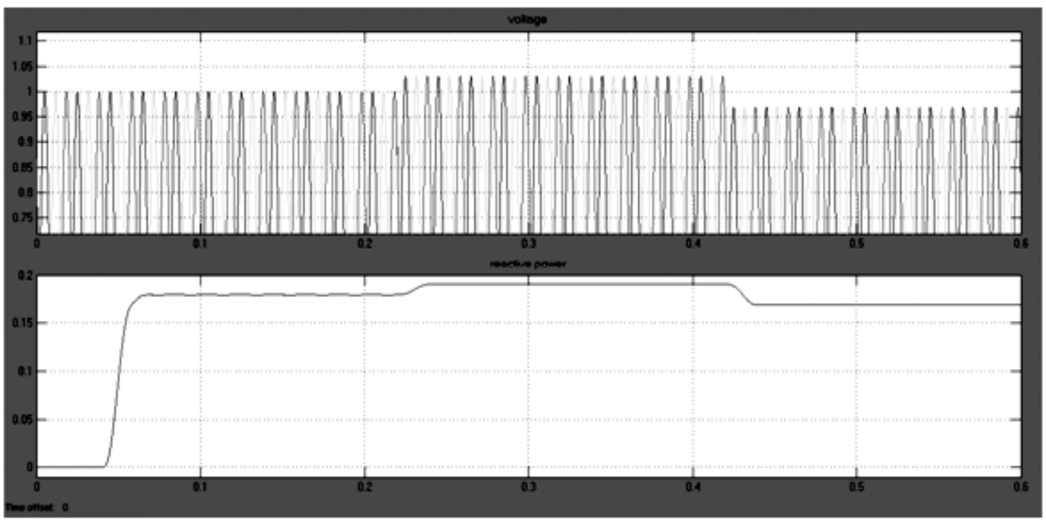

Figure 9: Variation of Reactive power with Voltage variation

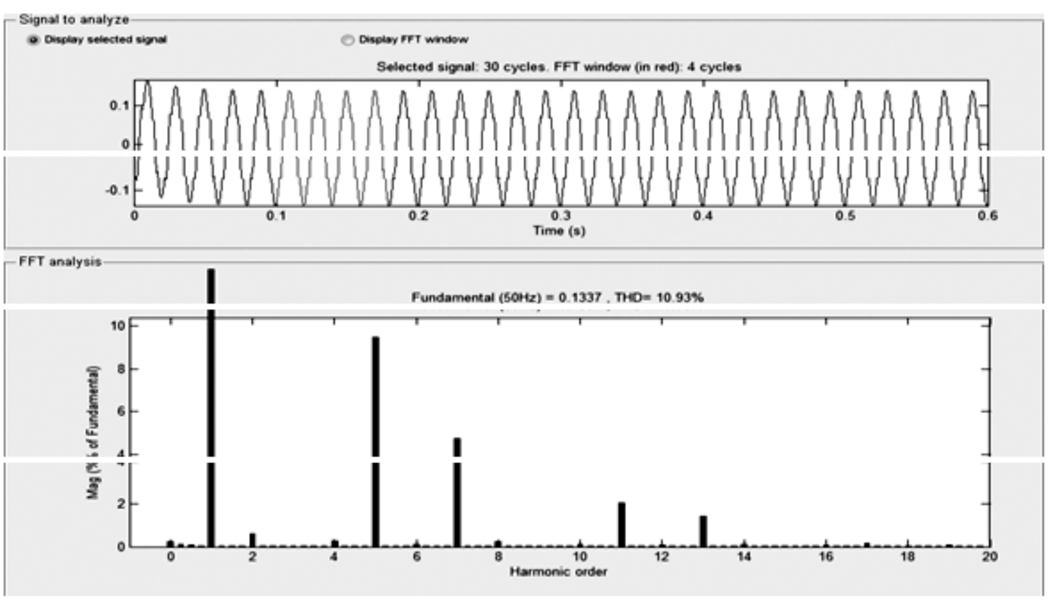

Figure 10: FFT analysis of Harmonics in Voltage at non-Linear Load

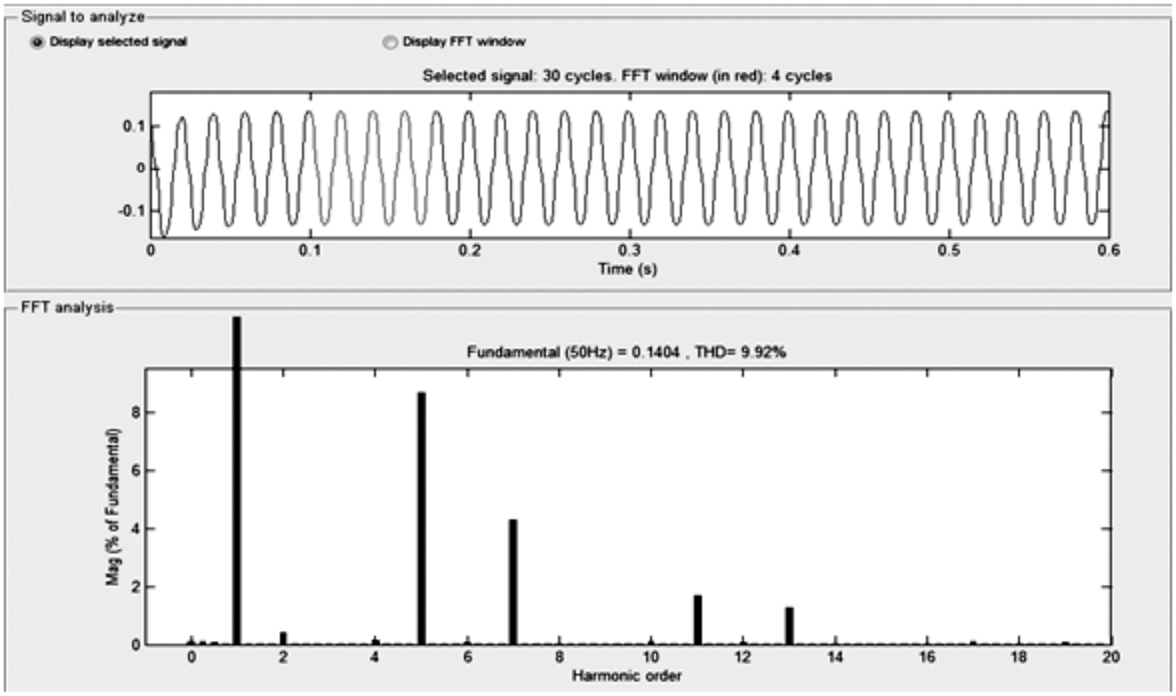

Figure 11: FFT analysis of Harmonics in Current at non-Linear Load

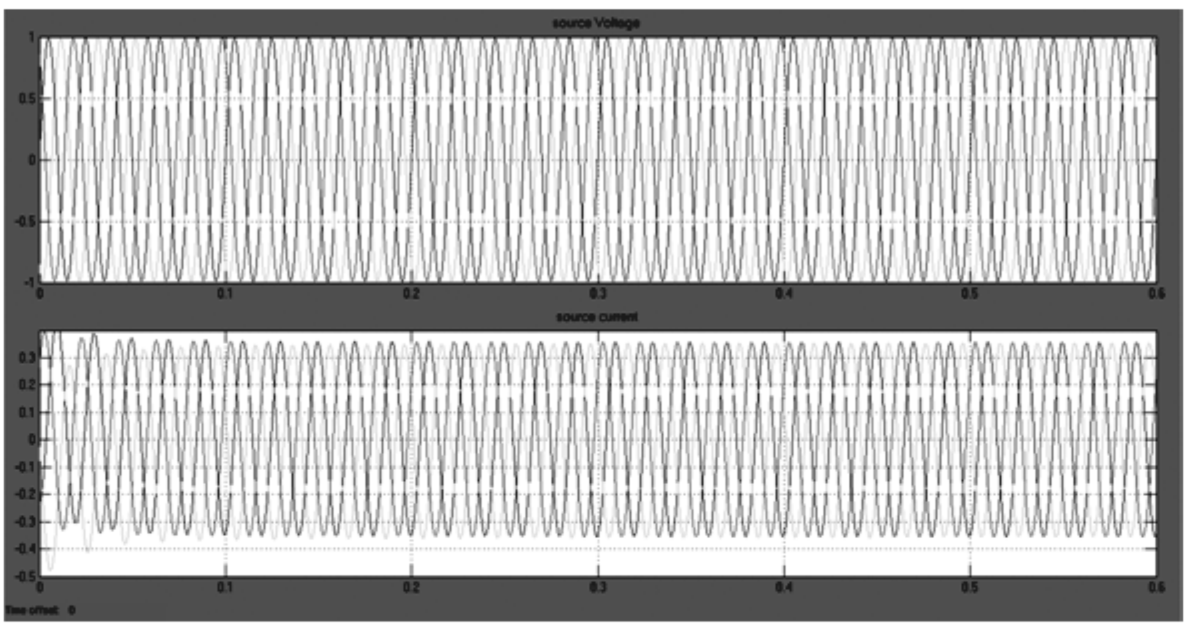

Figure 12: Source Voltage and current waveform with Non-Linear load

At source side the Voltage and Current wave form are more sinusoidal than the load side. FFT analysis revels the same improved results for both voltage and current waveforms.

The Harmonics content in the voltage waveform is reduced form 10.93% to 0.02%. Likewise, in the Source current FFT analysis harmonics Distortion is further reduced to 0.29%, later it was 9.92%. These results showsthat the harmonics content in voltage and current are eliminated successfully and these results are satisfying the IEEE standards. These results are further analyzed at different loads,with and without applying the Saturation of the transformer core used in the Interfacing Magnetics, results are presented in tabular form below.

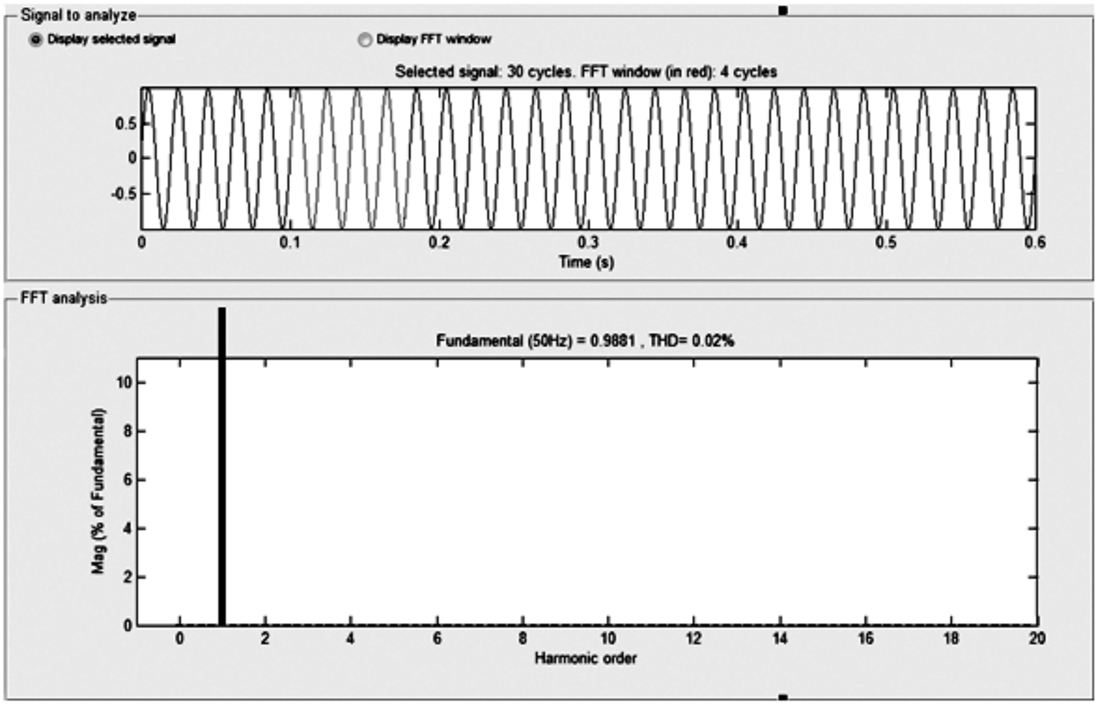

Figure 13: FFT analysis of Harmonics at source Voltage waveform

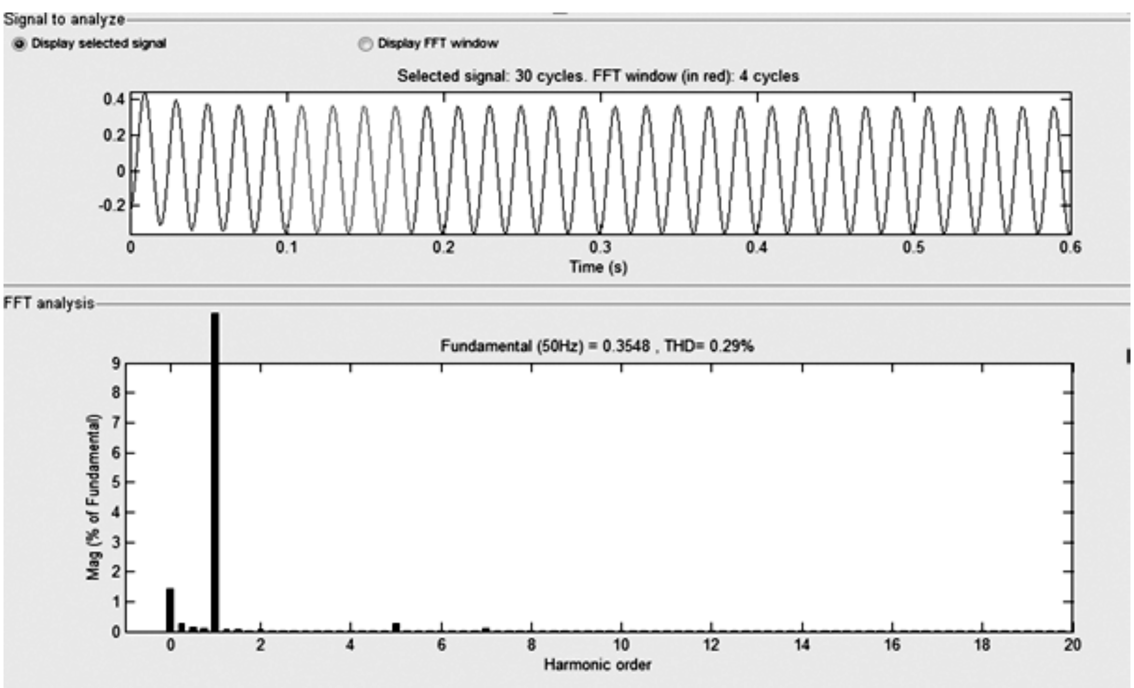

Figure 14: FFT analysis of Harmonics at source Current waveform

24 Pulse STATCOM Harmonics Analysis Results

S. no.	*Electrical Quantities*	*Without Considering Transformer core saturation*		*With Consideration of Transformer core saturation*	
1.	Voltage	Load	10.93%	Load	12.50%
		Source	0.02%	Source	0.02%
2.	Current	Load	9.92%	Load	8.47%
		Source	0.29%	Source	0.37%

Table 1
Harmonics analysis at Load and source at 50MW of Non-Linear load and 50MW,100Kva Linear parallel load.

S. no.	*Electrical Quantities*	*Without Considering Transformer core saturation*		*With Consideration of Transformer core saturation*	
1.	Voltage	Load	14.95%	Load	16.99%
		Source	0.02%	Source	0.03%
2.	Current	Load	13.29%	Load	11.30%
		Source	0.38%	Source	0.5%

Table 2. Harmonics analysis at Load and source at 70MW of Non-Linear load and 50MW,100Kvar Linear parallel load with 24 Pulse STATCOM

On Comparing the results of 12 Pulse and 24 Pulse STATCOM the superiority of 24 Pulse STATCOM is easily reflected in Harmonics Elimination which is shown in tabular form below.

12 Pulse STATCOM Harmonics Analysis Results

S. no.	*Electrical Quantities*	*Without Considering Transformer core saturation*		*With Consideration of Transformer core saturation*	
1.	Voltage	Load	14.31%	Load	15.56%
		Source	0.03%	Source	0.04%
2.	Current	Load	6.66%	Load	5.47%
		Source	0.50%	Source	0.58%

Table 3. Harmonics analysis at Load and source at 50MW of Non-Linear load and 50MW, 100Kva Linear parallel loadof 12 Pulse STATCOM

S. no.	*Electrical Quantities*	*Without Considering Transformer core saturation*		*With Consideration of Transformer core saturation*	
1.	Voltage	Load	19.35%	Load	20.97%
		Source	0.04%	Source	0.05%
2.	Current	Load	8.86%	Load	7.25%
		Source	0.65%	Source	0.76%

Table 4. Harmonics analysis at Load and source at 70MW of Non-Linear load and 50MW,100Kva Linear parallel load of 12 Pulse STATCOM

5. CONCLUSION

24 Pulse GTO-VSC based STATCOM is capable of reducing harmonics content in voltage and current waveform generated because of Non Linear load simulated with power system. It is visible from the results that $5^{th,}$ 7^{th}, 11^{th} and 13^{th} harmonic content is reduced to a greater extent and satisfactory according to IEEE standards. 24 Pulse configuration is better than 12 Pulse configuration of same STATCOM in terms of reactive power control with voltage variation and harmonics reduction in both voltage and current waveform on source side. For Further enhancement of the system other controlling techniques like Artificial Neural Network (ANN) and Genetic Algorithm can be applied in future.

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