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Cascaded Nine Level H-Bridge Inverter Control of STATCOM for Compensation of Reactive Power and Voltage Stability Enhancement

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ABSTRACT: This paper deals with the design and implementation of a multi level based STATCOM to maintain voltage stability by compensating the reactive power in the power system. The static synchronous compensator (STATCOM) is the primary shunt connected Flexible AC Transmission System device, in which the power electronic devices are used to control power flow and to improve transient stability on power grids. The control of reactive power is performed by means of a cascaded nine level H-Bridge inverter. This multi level inverter uses forced commutated power electronic devices (GTOs) to synthesize a voltage from a DC voltage source. The control strategy used to control the output of voltage source converter is sinusoidal pulse width modulation technique in which specified harmonic elimination (SHEM) is possible. This paper presents an investigation of transient modulation-index controller and steady-state Modulation-index regulator for good dynamic response in the transient period and to ensure minimal harmonics at steady state.

KEYWORDS: Reactive Power Compensation, Voltage Source Converter (VSC), STATCOM, GTO, SHEM, Phase Locked Loop (PLL), Multilevel Inverter, THD, SPWM.

I.INTRODUCTION

In a long transmission lines due to unbalanced and non linear loads there is a considerable transmission losses. These transmission losses will give rise to power quality issues in electrical power system. Due to sensitive loads present at the consumer side and deregulated market issues, it is necessary to provide quality power to the consumers. In order to meet all power quality problems like voltage sags, voltage swells, we are placing many fact devices like synchronous condenser, static VAR compensator, static synchronous compensator. So the performance of the ac system can improve by all these fact devices.

Among all these STATCOM is the one which having better reactive power compensation capability and better control over voltage. In STATCOM there is a GTO or IGBT based 3 phase voltage source inverter, step down transformer and a DC capacitor. FACTS technology is the most advanced and most effective technology in which better voltage control, reactive power flow control, steady state stability, transient stability is possible. It can minimize the operational cost, which leads to reduced per unit cost.

II. STATCOM STRUCTURE AND PRINCIPLE OF OPERATION

The STATCOM basically consists of a step down transformer with a leakage reactance, a voltage source inverter (VSI), a capacitor in its DC side and a control system. The inverter in conventional STATCOM, switched with a single pulse per period and the transformer is connected in order to provide harmonic minimization and serve as a link between VSI and the system. For purely reactive power flow the three phase Voltages of the STATCOM must be maintained in phase with the system voltages. The variation of reactive power is performed by means of a VSC connected through a coupling transformer.

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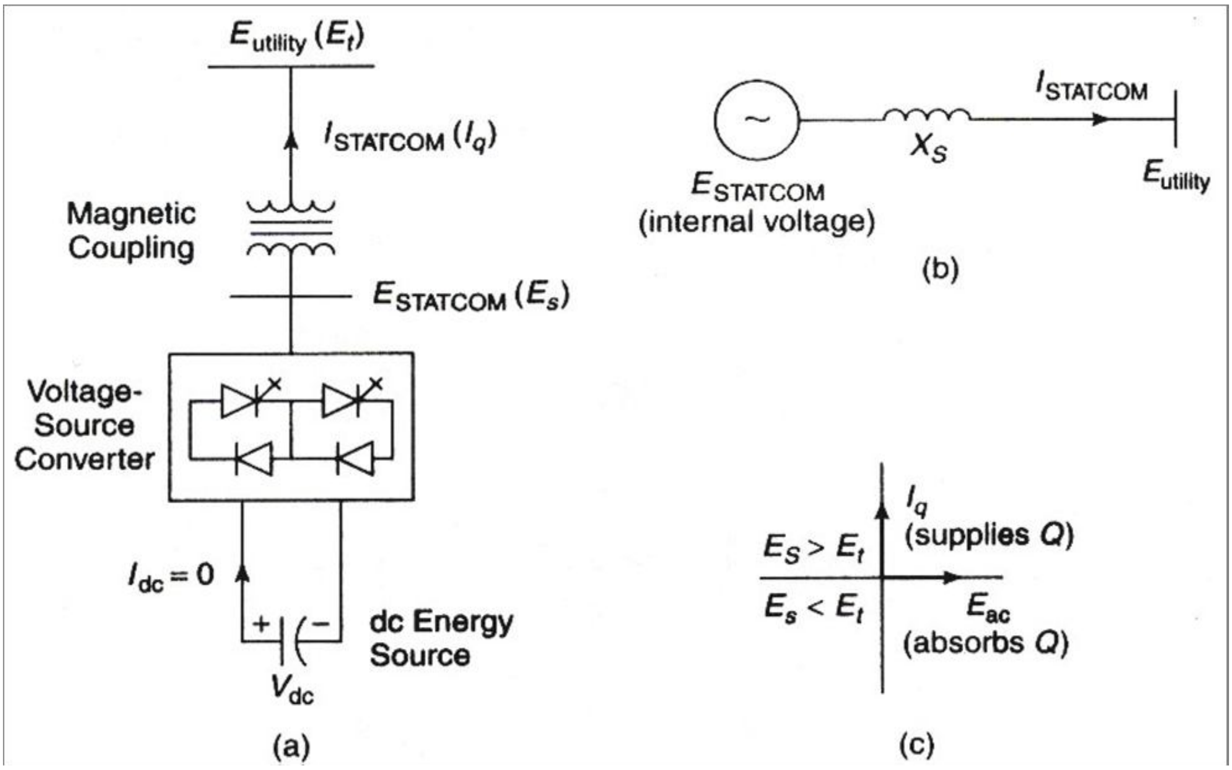

Fig.1: schematic configuration of STATCOM

The VSC uses forced commutated power electronics devices (GTO's or IGBT's) to synthesize the voltage from a dc voltage source. The operating principle of STATACOM is explained in Fig.1. It can be seen that if $E_s > E_t$ then the reactive current Iq flows from the converter to the ac system through the coupling transformer by injecting reactive power to the ac system. On the other hand, if $E_t > E_s$then current Iq flows from ac system to the converter by absorbing reactive power from the system. Finally, if $E_s = E_t$ then there is no exchange of reactive power. The amount of reactive power and real power exchange is given by:

$$P = \frac{(E_t * E_s)\sin\delta}{X}$$

$$Q = \frac{E_t(E_t - 2E_s\cos\delta)}{X}$$

Where,
E_t: Magnitude of system Voltage.
E_s: Magnitude of STATCOM output voltage.
X: Equivalent impedance between STATCOM and the system.

III. CASCADED NINE LEVELS H BRIDGE INVERTER

A cascaded multi level inverter consists of series H-bridge inverter units. The general function of this multi level inverter is to synthesize a desired voltage from several DC sources, which may be obtained from batteries, fuel cells, or solar cells. Each SDCS is connected to an H-bridge inverter.

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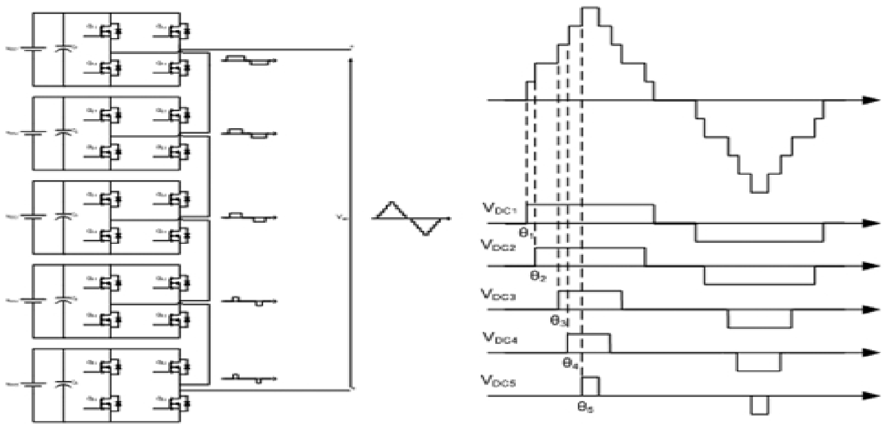

Fig.2: Single phase 9 level H-bridge inverter and switching strategies

The ac terminal voltage of different level inverters are connected i9n series. The amplitude of the odd harmonic order of the output voltage with 2N+1 level can be represented using Fourier's series method as,

Where

$$V_n = \frac{4V_{dc}}{n\pi}\sum_{K=1}^{N}\cos(n\theta_k)$$

V_n is the amplitude of voltage harmonic of n^th order
V_{dc} is the DC voltage across the capacitor
N is the number of the bridges in each phase n is the odd harmonic order
θ_k is the switching angle of the single phase bridge In this paper a nine level cascaded multilevel converter is designed and is simulated in MA TLAB simulink environment.

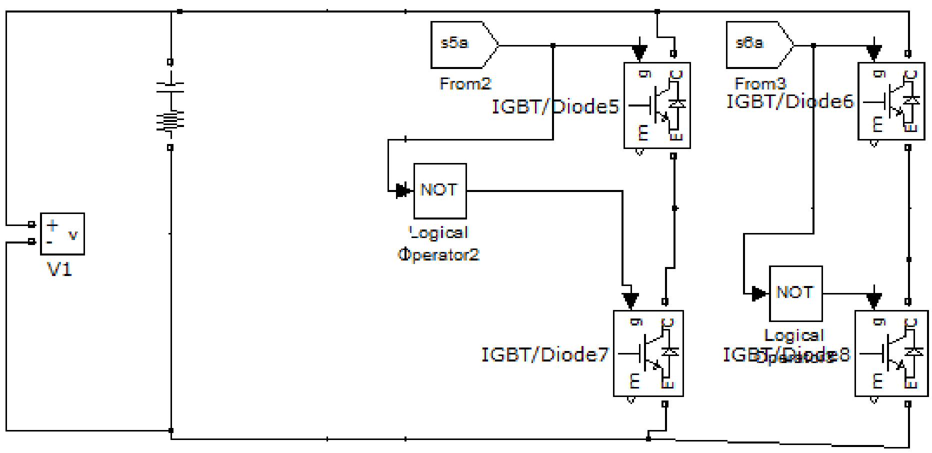

Fig. 3 MATLAB implementation of 9 1evel

The firing angles of the bridges in the converter are so chosen such that 5th, 7th, 11th and13th harmonics are eliminated and the THD of phase voltage is minimized. For the optimal values of firing angles the following equations must be solved (considering the modulation index M = 1)

$$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) + \cos(5\theta_4) = 0$$

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$$\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) + \cos(7\theta_4) = 0$$
$$\cos(11\theta_1) + \cos(11\theta_2) + \cos(11\theta_3) + \cos(11\theta_4) = 0$$
$$\cos(13\theta_1) + \cos(13\theta_2) + \cos(13\theta_3) + \cos(13\theta_4) = 0$$
$$\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) + \cos(\theta_4) = (m-1)M$$

This set of nonlinear transcendental equations can be solved by iterative methods such as the Newton-Raphson method. We get,

$$\theta_1 = 6.57° \ \theta_2 = 6.57° \ \theta_3 = 6.57° \ \theta_4 = 6.57°$$

The 9 level PWM (pulse width modulation) converter is implemented in MATLAB simulink and respective output voltage waveform is shown in Fig 4.

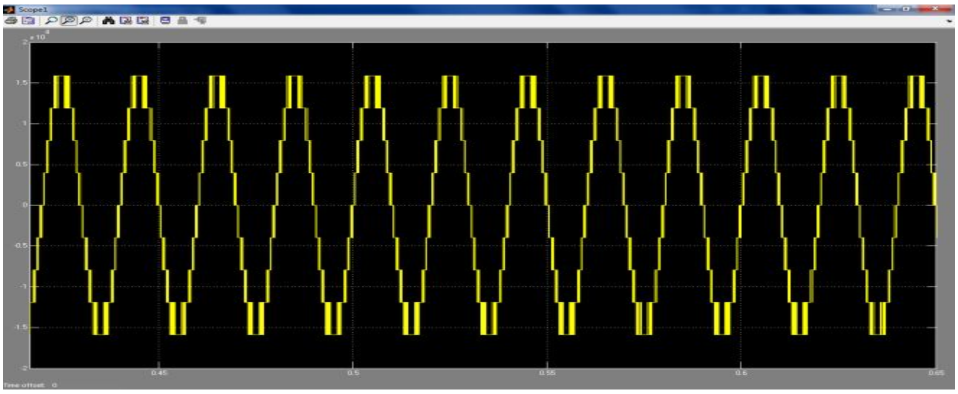

Fig.4 Output voltage of 9 level VSI

IV. CONTOL STRATEGY FOR STATCOM (STATCOM CONTROLLER)

The main objective for control of STATCOM is to enhance the power transmission by injecting or absorbing reactive power to or from the grid. The basic control strategy used for the proposed STA TCOM controller is direct control. In this approach reactive output current can be controlled directly by the internal voltage control mechanism of the converter in which the internal dc voltage is kept constant. The STATCOM is controlled to deliver either inductive or capacitive currents to the power system by varying its output voltages V2a, V2b and V2e. In the design of the STATCOM controller, the three-phase quantities are first transformed into direct and quadrature components in a synchronously rotating reference frame. Then, a current regulator is employed for the current control.

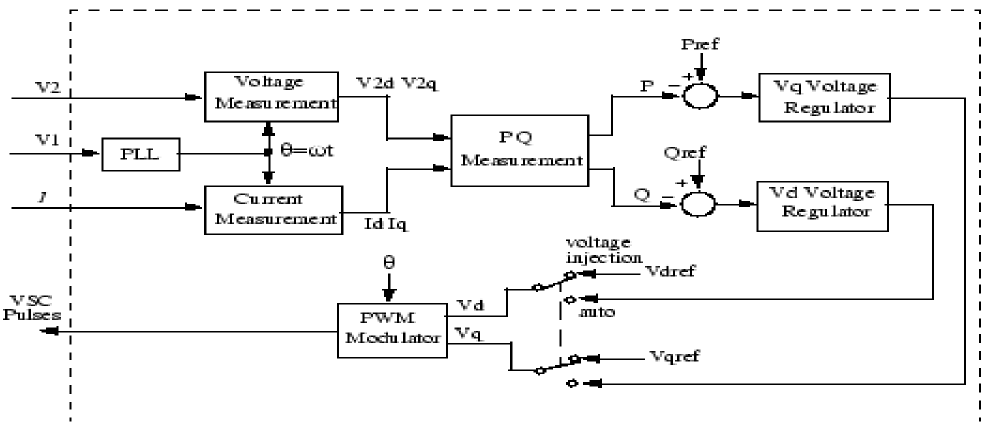

Fig.5: STATCOM controller

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In addition, an ac voltage controller is designed to regulate the PCC bus voltage through a PI controller. The ac voltage controller generates the desired reactive current reference for the current regulator. In the design of the STATCOM controller, it is essential to have good dynamic response in the transient period and to ensure minimal harmonics at steady state. As shown in Fig. 5, a transient modulation-index controller and steady-state modulation-index regulator are proposed to achieve the goals of good transient response and minimal steady-state harmonics respectively. Details for the design of transient modulation index controller, steady-state modulation-index regulator, phase locked loop (PLL), abc to dqo transformation, AC voltage controller, Current regulator, PWM generator are discussed in this paper

V. IMPLEMENTATION AND RESULTS

A basic power system model is designed consisting of 3-phase source of 100MVA and a line voltage of llkV. At the load centre various loads are considered and are connected to system at different instants of time as shown in the Table

No.	Time range	Type of load	Load
1	. 0.1 to 0.2	Nonlinear	R=1800Ω L=l mH
2	0.3 to 0.4	Inductive	R=0.242Ω L=1.537mH
3	0.5 to 0.6	Capacitive	R=400Ω C=5OμF
4	0.0 to 0.5	Normal load	R=300 Ω L= 50mH

Table 1: Load data of power system

Fig. 6 depicts the load voltage and current waveforms of the power system without STATCOM. In the interval 0.3s to O.4s there is a dip in the voltage level due to inductive load and from 0.5s to 0.6s there is a rise in the voltage level due to capacitive loaded conditions, but such voltage fluctuations are not desirable for a power system.

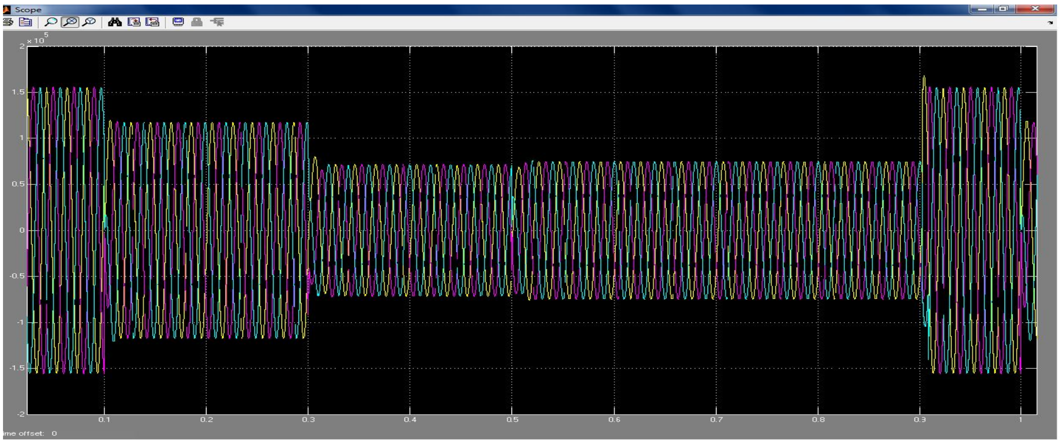

Fig.6 Output Voltage and current of the Power system without STATCOM

Hence the 9 level STATCOM and its controller is connected to the power system as shown in Fig.7 and the corresponding load voltage and current waveforms are shown in Fig. 8. The voltage waveform in the Fig.8 is maintained constant throughout indicating constant load voltage irrespective of the load connected and thereby improving voltage profile of the system.

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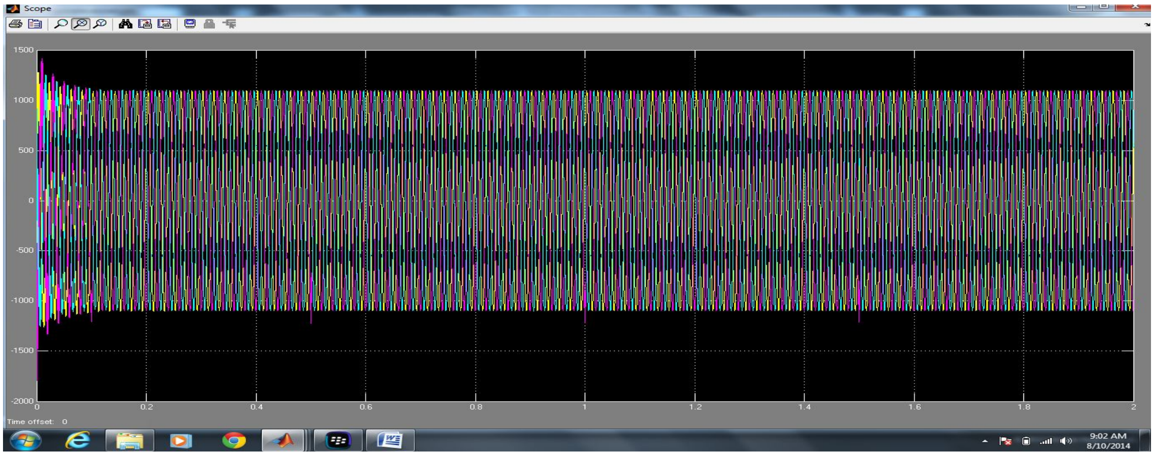

Fig.7 Output voltage of the Power system with STATCOM

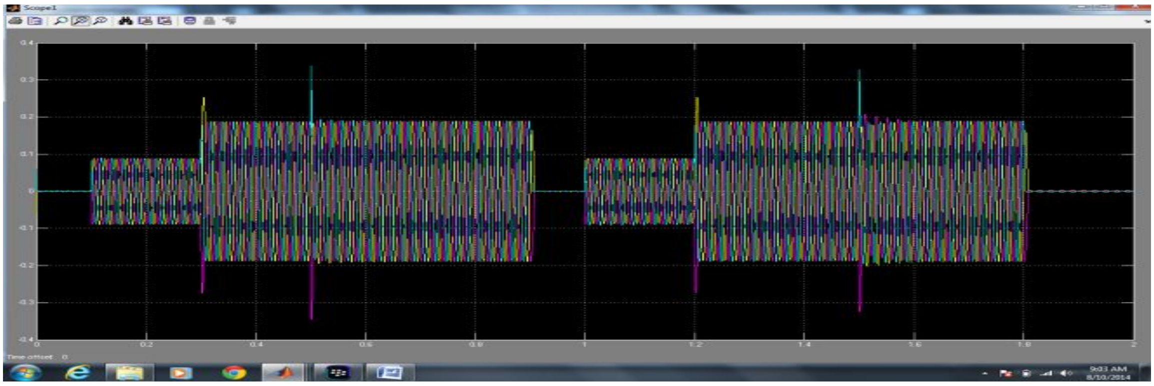

Fig.8 Output current of the Power system

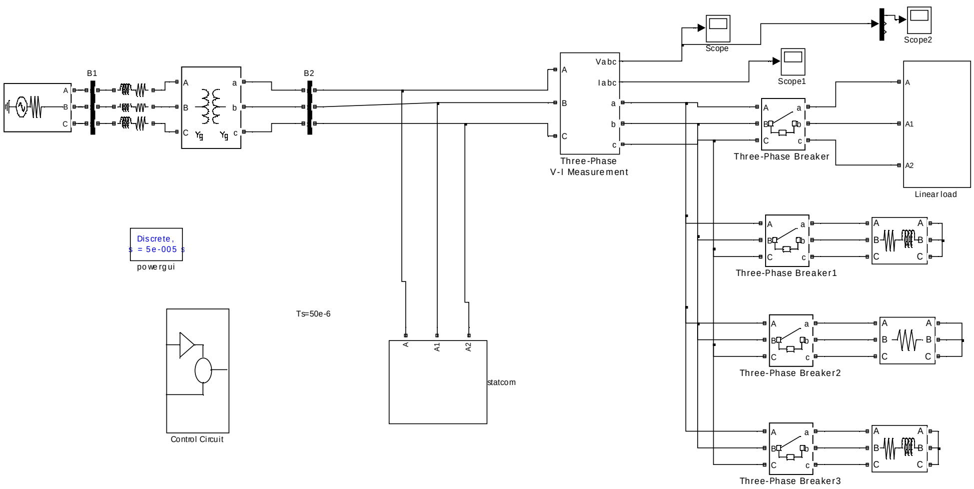

Fig.9 Matlab implementation of power system with STATCOM

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For analyzing the quality of the voltage waveform total harmonic distortion calculations are performed using equation

$$THD = \frac{\sum_{k=2}^{\propto_1} |v_K|}{|V_1|}$$

The THD of output voltage is calculated and is found to be l.77% as shown in the Fig. 9 and the same is compared with the THD of various papers as shown in Table.2 and is found to be minimum.

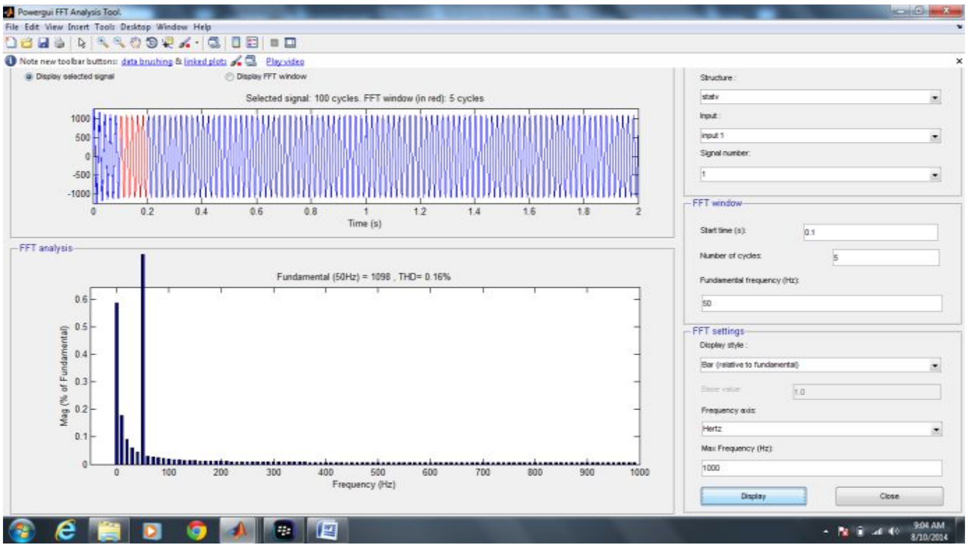

Fig.9: THD analysis of output voltage waveform

S.No	Designs	THD
1	Proposed control	0.76%
2	Paper [3]	4.24%
3	Paper [3]	59.9%
4	Paper [4]	4.84%
5	Paper [5]	6.5%
6	Paper [6] (5-1evel)	24.92%
7	Paper [6] (7-1evel)	15.89%

Table 2: Results comparison

VI.CONCLUSION

The paper presents a STATCOM model, developed with the necessary components and controllers in order to demonstrate its effectiveness in maintaining simple and fast voltage regulation at any point in the transmission line. On the other hand, the harmonics generated by the ST ATCOM is kept minimal with the implementation of SHEM. The effectiveness of the proposed control strategy is demonstrated with the help of THD calculations and is found to be

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minimum when compared with various designs. Hence the proposed S TATCOM with it controller employing the direct control strategy is able to maintain the voltage balance under various load conditions.

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