Performance Analysis of Multilevel Converter Based On Statcom Configuration

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Abstract: **Power electronic devices, nonlinear and inductive loads have given rise to power quality problem in distribution systems. One way to improve the power quality is using a Static Compensator (STATCOM). This paper presents the simulation studies on a Cascaded H-Bridge converter based Static Synchronous Compensator (STATCOM) for improving the power quality of a distribution system. The main object of this paper to maintain the voltage profile by compensating the reactive power. Relative Harmonic analysis is also discussed in this paper based on the total harmonic distortion (THD) calculations.**

Keywords: **Reactive power compensation, STATCOM, H bridge multilevel converter pulse width modulation (PWM), harmonics.**

I. INTRODUCTION

Modern power systems are of complex networks, where hundreds of generating Stations and thousands of load centers are interconnected through long power transmission and distribution networks. Even though the power generation is fairly reliable but the quality of power is not always so reliable. In Power distribution system power should provide with an uninterrupted flow of energy at smooth at the contracted magnitude level to their customers. In distribution network sinusoidal voltage required where consumer uses various non linear, inductive and capacitive load [1]. These load distorted the power quality of the power system. Power quality depends on the voltage rather than current and power. To improve the power quality different approaches such as reactive power compensation has been implemented to meet the requirements. In order to overcome this poor quality some facts devices (STATCOM, SVC) were incorporated in power system but these devices leads generation of harmonics in power system. So, the converter used within the STATCOM should be able to withstand the increased power levels. So, in order to overcome this problem, the term multi level is brought out in 1981. The very important thing of multilevel inverters is that creating more output steps and to reduce the Total Harmonic Distortion (THD) [2]. An increased number of levels capable of eliminating the coupling transformer and replace it with cheap reactors to allow a power exchange with the power system.

II. STATCOM CONFIGURATION

The basic operating configuration of a STATCOM is given in Fig 1. It consists of a voltage source inverter (VSI), dc side equivalent capacitor(C) with voltage Vdc on it and a coupling reactor (LC).[2] STATCOM is a primary shunt device of the FACTS family, which uses power electronics to control power flow and improve voltage stability on power system [3]. The STATCOM regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. For purely reactive power flow in three phase voltages of the STATCOM must be maintained in phase with the system voltages [4]. The variation of reactive power is performed by means of a VSC connected through a coupling reactor or transformer .The VSC uses forced commutated power electronics devices (MOSFET or IGBT's) to synthesize the voltage from a dc voltage source. [3]The operating principle of STATACOM is explained in Fig.1. It can be seen that if Vc>Vs then the reactive current 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 V C< V S then current flows from ac system to the converter by absorbing reactive power from the system. 6Finally, if VC= VS then there is no exchange of reactive power.

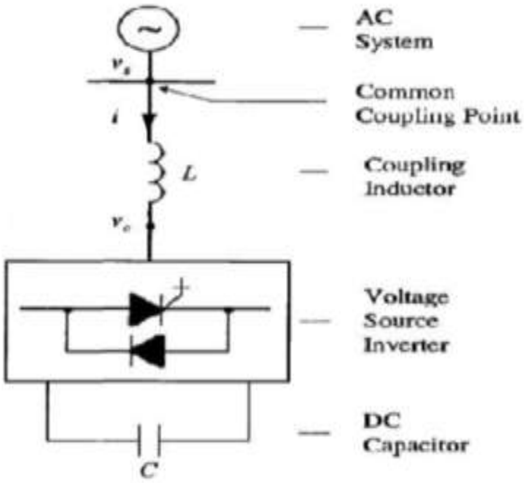

Fig.1 Single lines diagram of Statcom

III. MULTILEVEL CONVERTER CONFIGURATION

The cascade multilevel inverter consists of number of H-bridge inverter units with separate dc source for each unit and is connected in cascade or series as shown in figure 2. Each H-bridge can produce three different voltage levels: +V dc, 0, and -V dc by connecting the dc source to ac output side by different combinations of the four switches S 1, S2 ,S 3, and S 4. The ac output of each H-bridge is connected in series such that the synthesized output voltage waveform is the sum of all of the individual H-bridges' outputs [4,5] .By connecting the sufficient number of H-bridges in cascade and using proper modulation scheme, a nearly sinusoidal output voltage waveform can be synthesized, fig. 2 Five level h bridge inverter The magnitude of the ac output phase voltage is given by:[2]

Van = Va1+Va2+Va3+Va4+Va5. … (1)

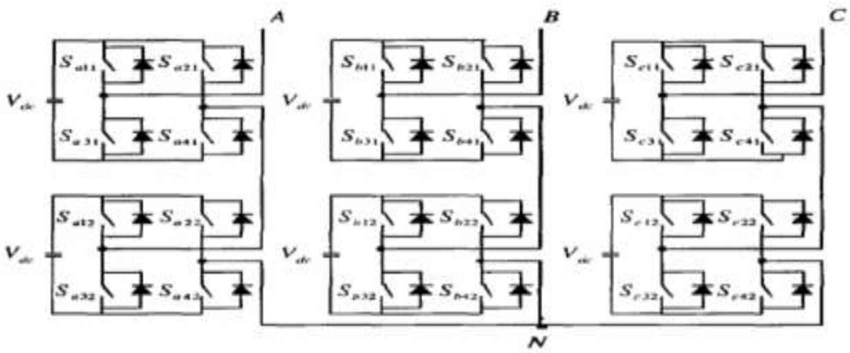

Fig. 2 Five Level H bridge converters

IV. FIVE-LEVEL CASCADE H-BRIDGE INVERTER BASED STATCOM

In this study, five-level cascade h-bridge inverter is presented for power circuit of STATCOM. Power circuit of STATCOM based five-level cascade H-bridge inverter is illustrated in Figure 2. STATCOM consists of six h-bridge cells, six dc link capacitors C that providing the dc voltages to H bridge cells and a coupling inductance with internal resistance ωLs + Rs connecting to AC grid the inverter[6,7]. From Figure 3, AC circuit equations of STATCOM in the stationary reference frame can be acquired as follows-

$$L_S \frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + R_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}$$ - - -(2)

$$\overline{V_s} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \text{ and } \overline{V_i} = \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}$$ - - - - - - -(3)

The Vs. and Vi respectively are defined as complex voltage vector of network and complex voltage vector of inverter. Space vector theory based on synchronous reference frame is exerted to STATCOM. Coordination of space vector is shown in Figure 7. Stationary reference and synchronous rotating frame are respectively shown with αβ and d q –axes [7, 8].

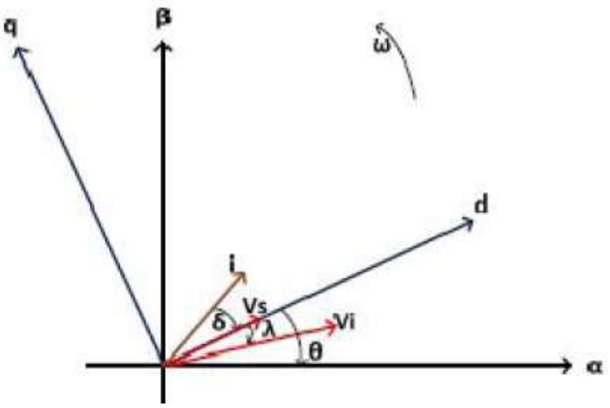

Fig. 3 coordinate system for synchronous rotating reference frame

Current vector and voltage vectors in complex plane are representing in stationary reference frame as follows

$$\overline{V_i} = V_{ia} + V_{ib}\, e^{j\varphi} + V_{ic}\, e^{j2\varphi} = V_i\, e^{j(\theta-\lambda)}$$ - -(4)

$$\overline{V_s} = V_{sa} + V_{sb} e^{j\varphi} + V_{sc} e^{j2\varphi} = V_s\, e^{j(\theta)}$$ - - -(5)

$$i = i_a + i_b\, e^{j\varphi} + i_c\, e^{j2\varphi} = i\, e^{j(\delta+\theta)}$$ - - - - -- - -(6)

where ϕ = 2π / 3 , Vs(a,b,c) and Vi(a,b,c) respectively are instantaneous phase voltages of power system and STATCOM.[7,8] The d-axis of the space vector figure and Vi are assigned together. By multiplying complex vectors in the stationary reference frame with unity space vector e−iθ can transformed them in to synchronous rotating as follows

$$L_s \frac{di_d}{dt} + R_s i_d = v_{sd} - v_i \cos\lambda + L_s \omega i_q$$ - - -(7)

$$L_s \frac{di_q}{dt} + R_s i_q = v_{sq} - v_i \sin\lambda - L_s \omega i_d$$ - - - -(8)

where, ω is frequency of power system. Maximum magnitude of inverter output voltage is expressed as:

V= MaVdc - - - - - - - - - - - - - - - - - - -(9)

where Ma modulation is index and Vdc is dc-link voltage. From instantaneous power quality on the DC and AC side of the inverter, power equation can be written as:

$$P_c = V_{dc} I_{dc} = \frac{3}{2}(v_{id} i_d + v_{iq} i_q) \quad \text{- - - - - (10)}$$

Where, Idc is the capacitor current.

V. SWITCHING STRATEGY WITH SPWM

The output voltage waveform of the cascaded five level H bridge converters based STATCOM depends on the switching pattern that is controlled by the switching angles of the converters. These switching angles can be selected, but appropriate switching angles are required to achieve best quality of the output voltage waveform. By employing sinusoidal harmonic elimination method (SHEM) lower order harmonics can be eliminated in the output waveform [9,10].For a stepped waveform Fourier analysis by selective harmonic elimination reduction (SHEM) .

Vw(t)=4$vdc/\pi\sum$[cos($n\theta$1)+cos(nθ2)+------ - - - - - - - - - cosn(θ5)] sin($n\omega t$)/n-- - - - - - (11)

Where n=1,3,5 The conducting angles, θ1, θ2, ..., θ5, can be chosen such that the voltage total harmonic distortion is a minimum. Generally, these angles are so chosen that predominant lower frequency harmonics, 5th, 7th, 11th, and 13 harmonics are eliminated.

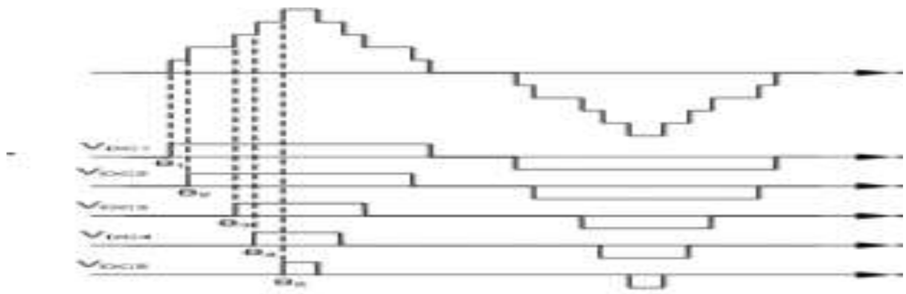

Fig. 4(a) Staircase wave form gained by 5 level inverter using SPWM technique

VI. SIMULATION

A power system model is designed consisting of 3 phase source of 100 MVA and a line voltage of 11 KV. Five levels H bridge inverter based Statcom controller is connected to the power system as shown in fig. 4.

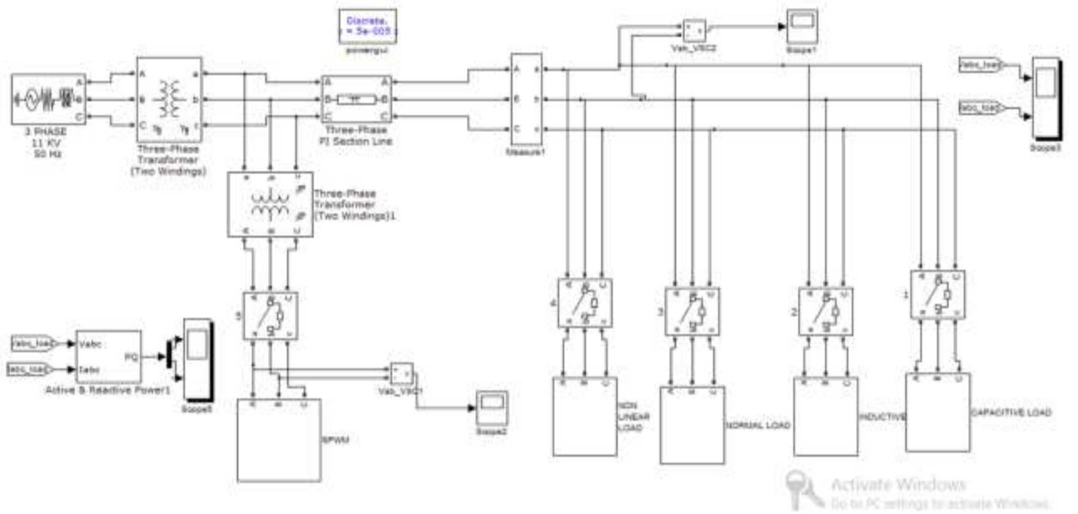

Fig. 4(b) Simulink model of a power system with STATCOM controller

The power is transmitted through a transmission line of 100 km to load center. At load center different loads are connected to the system at different duration of time as shown in fig. 4. The power is coming from the three phase source is transmitted through a step down transformer to a load center. Here step down transformer is used for the commercial industrial purpose. There is a subsystem contains multi-winding transformer next to the three phase step down transformer. This is used for injecting reactive power into the transmission line when the power deviation occurs.

There is another subsystem below to the multi-winding transformer is called STATCOM controller. Thepower is coming from a three phase source is step down by three phase step down transformer. Statcom mainly used for injecting or absorbing reactive power from or to thesystem. In fig.4 , four different load (load centre) are connected to the three phase ac supply through a circuit breaker.Here Circuit breaker acts as a switch.Whenever power deviation occurs statcom controller will improve that power deviation and after compensation the power is transmitted to load centre.

VII. SIMULATION RESULT

Case 1 : when non linear load connected to the 3 phase ac supply during time 0.0 to 0.2 second by circuit breaker (switch) it leads harmonics and distorted power quality .To minimize total harmonic distortion multilevel inverter with statcom topogy is used in this paper .Fast fourier transform analysis (FFT) is done for harmonic calculation. Fig 5 and 6, shows FFT analysis result with and without statcom.Witout statcom it found 16% and after compensation harmonic minimized up to 4.76%.

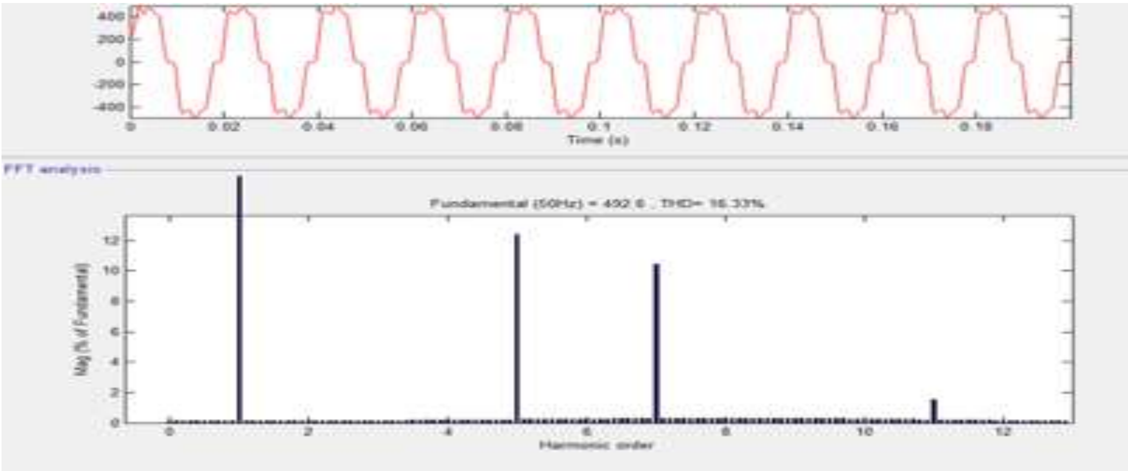

Fig. 5 FFT analysis without compenstion

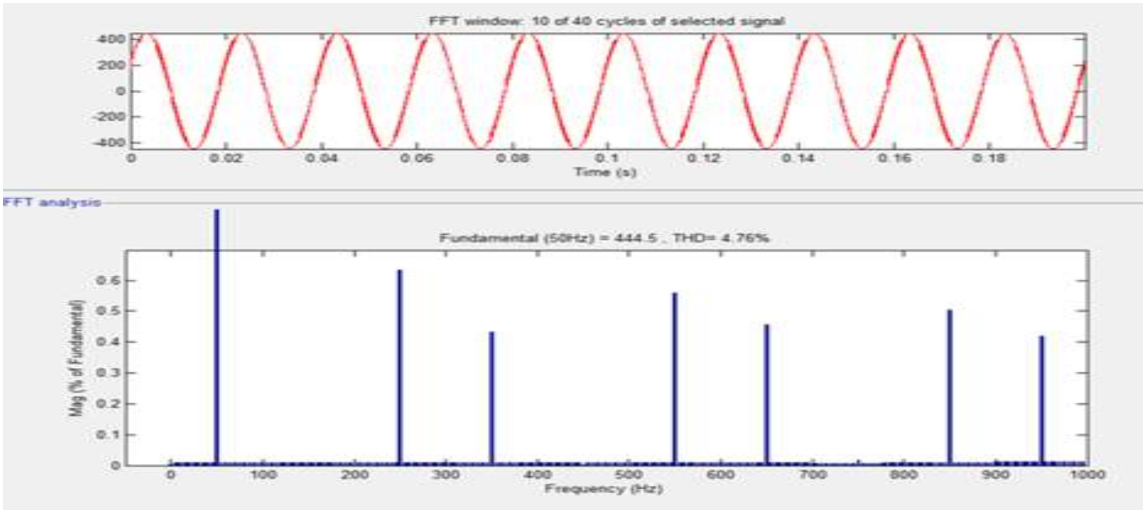

Fig. 6 FFT analysis with STATCOM

Case2: When linear load connected to ac supply novoltage deviation has found because of pure linear load in simulation study.

Case3: At interval 0.4 to 0.6 second there is a voltage dip when inductive load connected to ac supply .voltage dip is shown in fig.7.

Due to switching on of the load the source voltage become reduced from normal level .In that duration statcom injects the voltage to source and boost up that voltage up to the normal level.Reactive and active power without STATCOM shown in fig.8

Case4: At interval 0.6 to 0.8 second when capacitive load connected to ac supply ,due to switching on of the load there is a momentary increase in voltage but these fluctuations are not desirable in power system.

If voltage level rised due to switching on of capacitive load in that case statcom absorbs that voltage and maintain voltage up to normal level.Fig.7 shows voltage and current waveforme without statcom.Fig. 9 shows maintain voltage profile with statcom.

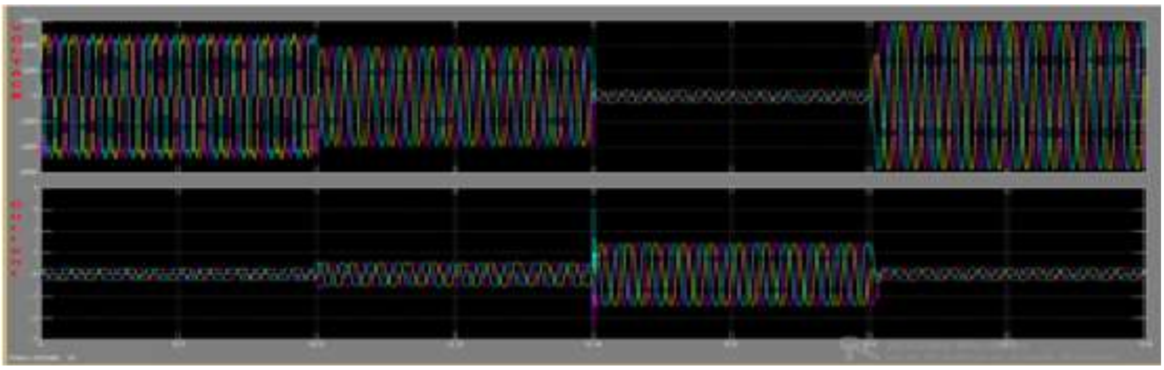

Fig. 7 Voltage and current waveform without statcom

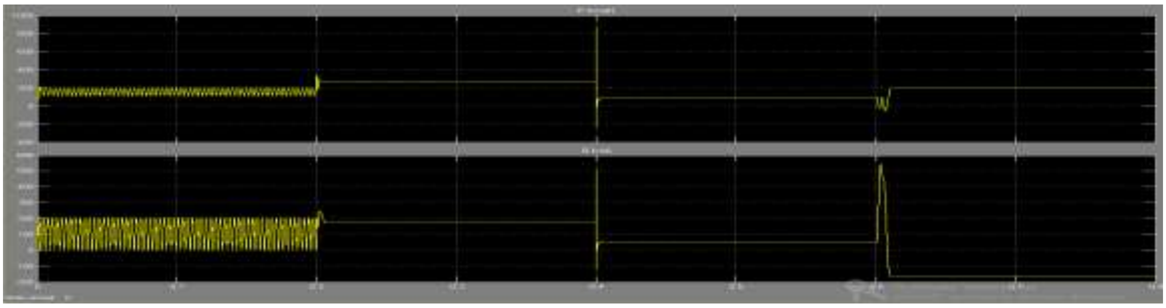

Fig. 8 Active and reactive power without Statcom

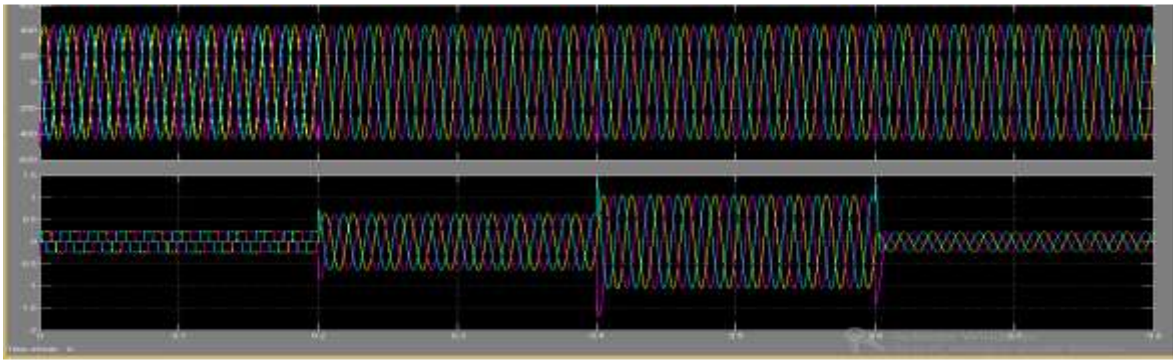

Fig.9 Maintain voltage profile after Compensation

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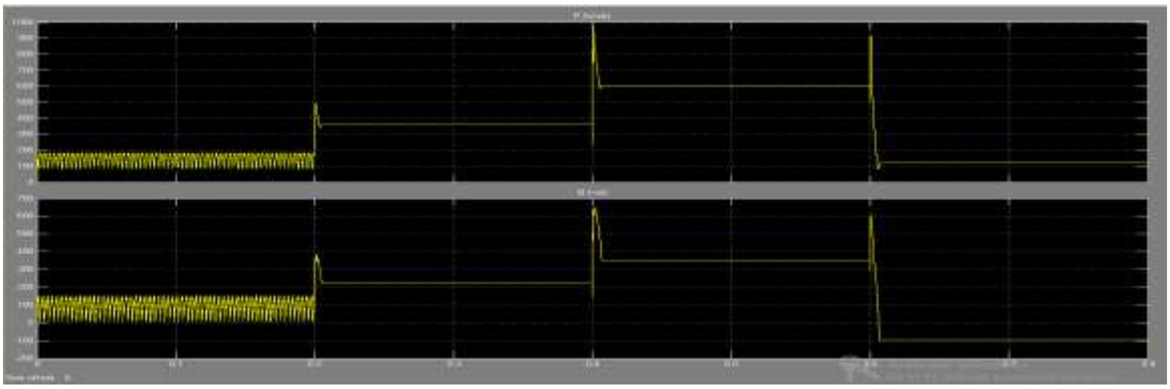

Fig. 10 Reactive power with statcom

Total Harmonic Distortion:

For analyzing the quality of the voltage waveform of satcom total harmonic distortion calculation[7,8] are performed by using equation:

$$\text{THD} = \frac{\sqrt{\sum_{K=2}^{\infty} |V_k|}}{|V_1|} \ldots\ldots\ldots\ldots(6)$$

The total harmonic distortion of statcom output voltage of cascade three level inverter based STATCOM is found 41% after simulation as shown in fig10. Another output of Cascade 5 level inverter based STATCOM is found 33.73% as ahown in fig. 11.

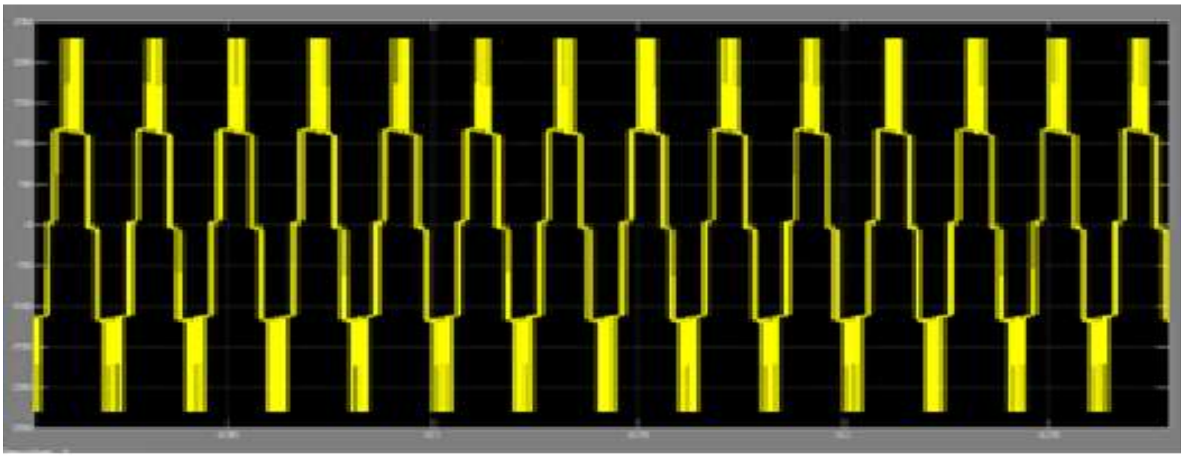

Fig. 11 Statcom output voltage waveform

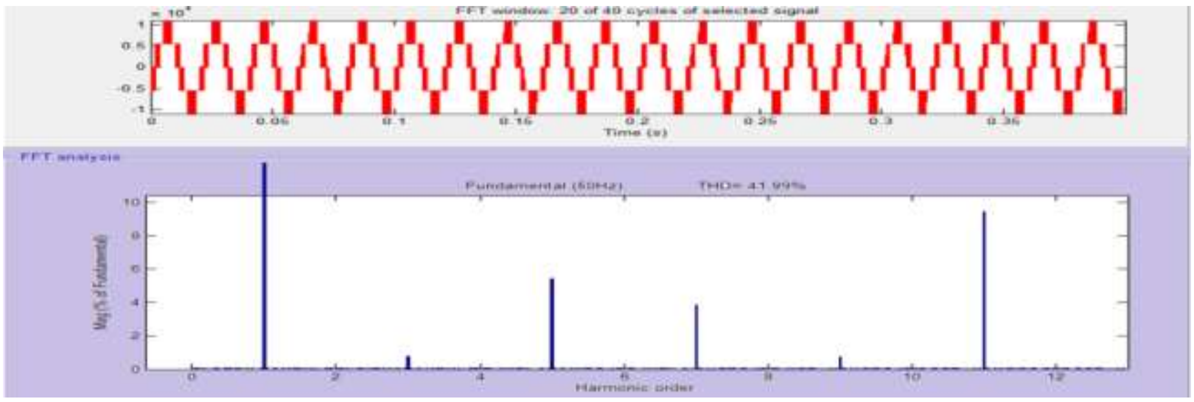

Fig. 12 Total harmonic distortion analysis of STATCOM output voltage

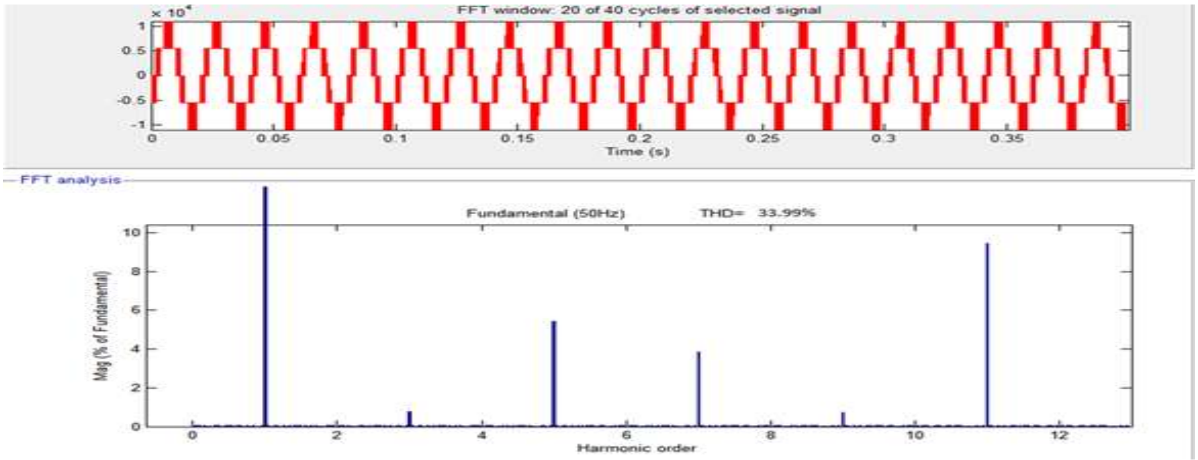

Fig.13 THD analysis of STATCOM output voltage

VIII. CONCLUSIONS

This work gives the solution of reactive power compensation in the field o distribution lines, industries, as well as in generating stations. The STATCOM controller is designed for five level H bridgemulti level Converter based STATCOM. These control schemes regulates the capacitor voltage of the STATCOM and maintain rated supply voltage for any load variation with in the rated value. It has shown in the simulation result that MC is able to reduce the THD values of output voltage effectively.

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