MODELLING, ANALYSIS AND PERFORMANCE OF FAST ACTING PI BASED D-STATCOM FOR POWER QUALITY IMPROVEMENT

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Abstract - *This paper presents a combination of voltage source converter and capacitor banks which is called as Static Compensator (STATCOM), voltage source converter (VSC) based diversion connected Flexible AC Transmission System (FACTS) devices which improves the dynamic and static voltage control in transmission in addition with distribution system. Active power filtering is boon in the field where power quality is a major concern. There are many control algorithms for active power filters .It is a reactive power return device which can produce and absorb the reactive power. The power quality has ongoing to play an important role in electronic and electrical industries. A system concerning the power quality measurement is voltage flicker and harmonics. Normally DSTATCOM is connected in distribution system. In some application DSTATCOM is used instead of capacitor banks because it is having low power losses. The IGBT is used as a power switch which has low switching loss and the turn off is very simple. In this paper THD is evaluated, disturbances obtained in the voltage and current waveforms are reduced by means of DSTATCOM. To interface the inverter, series inductor with shunt filter capacitor is applied to ensure correct injection of the compensation current. The control algorithm used is Instantaneous Reactive Power Theory. In IRPT algorithm the three phase abc reference frame is transformed in two phase αβ reference frame by using PQ theory. The distribution system with DSTATCOM and the control scheme used for power quality enhancement is simulated and validated by means of MATLAB/SIMULINK.*

Key Words: S DSTATCOM, IGBT, FACTS, THD.

1. INTRODUCTION

This Many electronic devices have been used in power distribution systems in last decades such as; rectifiers, variable speed drives, electronic ballast, switched mode power supplies, etc. These electronic devices are considered as nonlinear loads as the waveform of absorbed current from the source is distorted and leading to increasing the total harmonic distortion (THD). The upstream feeder impedance affects the voltage waveform at the point of common coupling (PCC) and makes it distorted due to the distortion of the current waveform. On the other hand, the inductive load in the power distribution system causes poor power factor of the system which increases the line losses and degrades the power quality of the system [1]. The sensitive equipment in the distribution system may have malfunction due to the distortion of the PCC voltage waveform.

The distribution flexible alternating current transmission system (D-FACTs) or custom power devices have been developed recently to mitigate the power quality problems in power distribution systems [2]. DSTATCOM, dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) are the major enabling D-FACTs devices to solve power quality problems such as sag, swell, poor power factor, harmonics and voltage fluctuations [3 – 5]. These devices are connected in the distribution network in the vicinity of the load to be more efficient and reduce the losses effectively. The DVR is connected in series with the supply source and it is used to mitigate the voltage disturbances of the supply and decrease the distortion of the voltage waveform.

The DSTATCOM is connected in shunt with supply and used to improve power factor of the system, eliminate the source current harmonics and keep voltage stability [6]. The UPQC device is composed from both DVR and DSTATCOM. It has the advantages of the two devices. The two devices are connected to the same DC-link bus voltage and simultaneously operate to ensure satisfactory power quality of the distribution system.

The basic components of DSTATCOM are voltage source inverter (VSI), coupling reactance and DC-link capacitor. DSTATCOM is connected directly in shunt through a coupling reactance to the PCC and in parallel with the load. When working in current control mode (CCM), it injects the generated reference current that will compensate the supply voltage or load current to the grid to improve both of the drawn current and source power factor. It can also stabilize the supply voltage to a reference voltage when it works in voltage control mode (VCM) by injecting appropriate amount of fundamental reactive power [7].

The power rating of the DSTATCOM is directly proportional to the current to be compensated and dc link voltage [8]. In general, the dc link voltage is kept at much higher value than the maximum value of phase-to-neutral voltage in three-phase four-wire system for satisfactory compensation whereas in three-phase three wire system, it is higher than the phase-to-phase voltage [9]. The voltage source converter (VSC) converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system [10].

This paper presents a modification of the interfacing filter and DC-link capacitor of the DSTATCOM to improve the compensation efficiency and remove the spikes generated due to the switching of the IGBTs on the interfacing coil. The modified DSTATCOM has a three-leg inverter with a DC-link.

1.1 POWER QUALITY

Power quality generally refers to eminence of voltage supply [9]. To an application it means supply of adequate and reliable power. To a consumer, it means adequate, uninterrupted power which does no longer have an effect on the equipment. For a manufacturer it resources the quality and tolerance of voltage and current parameters that is written, the range of parameters for which they are artificial and tested the product[11].

1.2 Why power quality is important: It is important because

- Client pays for good quality power. If power quality is corrupted that means it is a breach of trust.
- Meager quality damages consumers' equipment and affects equipment life.
- Bad eminence power such as flicker etc. causes irrigation and health threats.
- Poor voltage and high current with harmonics cause heating and high losses.
- Reliability of energy delivered is affected due to relay operation, frequent faults and equipment botches.

1.3 How does poor power quality affect the economy?

- In a state of high harmonics generated through the load or power electronic devices, the rotating machines each on generation facet and client side get over heated and their life is affected [12]. Shutdown because of the system failure or deliver failure charges huge money.
- Bad power supply impacts system industry like rolling mills, fabric mills, paper mills etc. manufacturing loss due to interruptions could be very high.
- Systems are generally designed to withstand over voltages and harmonics with certain positive limit. If they must be considered for frequent unusual conditions, their cost increases. This upturns the project costs and affects scheme viability.
- Meager power quality rises losses, generators must supply more power, to supply these losses. Intensification in thermal generation affects environment by liberating greenhouse gases [13].
- Non-availability in power since of interruption forces, general public to use diesel or kerosene which is far additional expensive.

1.3 Advantages of power quality monitoring:

- Guarantees power system reliability.
- Detect the source of disturbance.
- Benefits in the anticipation and prediction Maintenance.
- Calculation of conventional electrical supply and disorders are impacting.
- Reduction of energy costs and avoids hazards.

1.4 Power system troubles: The trouble is a passing deviation from the steady state wave form produced by faults of brief duration or unexpected change in load. Some of the power system troubles are

- Voltage dips (sag)
- Interruptions
- Voltage increase (swell)
- Voltage impulses
- Transients

2. THE PROPOSED MODIFICATION OF DSTATCOM TOPOLOGY

It consists of three-leg inverter VSI with dc-link and neutral capacitor. The inverter currents in three phases are denoted by I_{fa},I_{fb} and I_{fc}. The PCC voltages are denoted by V_a.V_b and V_c for the three-phases a, b and c, respectively. The three-phase source currents are denoted by i_a.i_b and i_c. The system loads contain balanced inductive load as well as nonlinear load that drawing currents I_{la},I_{lb} and i_{lc}. Each phase of the feeder is assumed to have a resistance and inductance of R_s and L_s, respectively. The modified DSTATCOM topology has a single dc capacitor C_{dc} for the dc link and additional small ac neutral capacitor C_n connected between the neutral and the negative point of dc link. The selection of the C_{dc} is based on the rating of the compensator, more details are explained in sub-section II-A. The interfacing of the inverter contains series interfacing inductor, Lf, and resistance, Rf, in parallel with RC arm filter that contains a resistance, Rd, in series with a capacitor, C_f, to ensure that the compensation current is correctly injected.

3. CONTROL ALGORITHM

The overall control block diagram of the DSTATCOM is shown in Fig. 2. The DSTATCOM control function is to maintain the source currents balanced, sinusoidal and to have the required angle with the respective terminal voltages. To achieve the DSTATCOM ambition, the instantaneous symmetrical component theory (ISCT) is used to generate the reference current of the VSI . The ISCT has also the capability to control the power factor of the source current. Since, a non-stiff source voltage is considered in this paper, the direct use of terminal voltages to calculate the reference filter currents will not provide satisfactory compensation. Hence, fundamental positive sequence component of voltages is extracted to generate reference filter currents as described in sub-section B. According to this theory when a compensator is supplying reactive, harmonic and unbalanced components of load currents with fundamental positive sequence components of PCC voltages V(abc), the reference compensator currents are given as

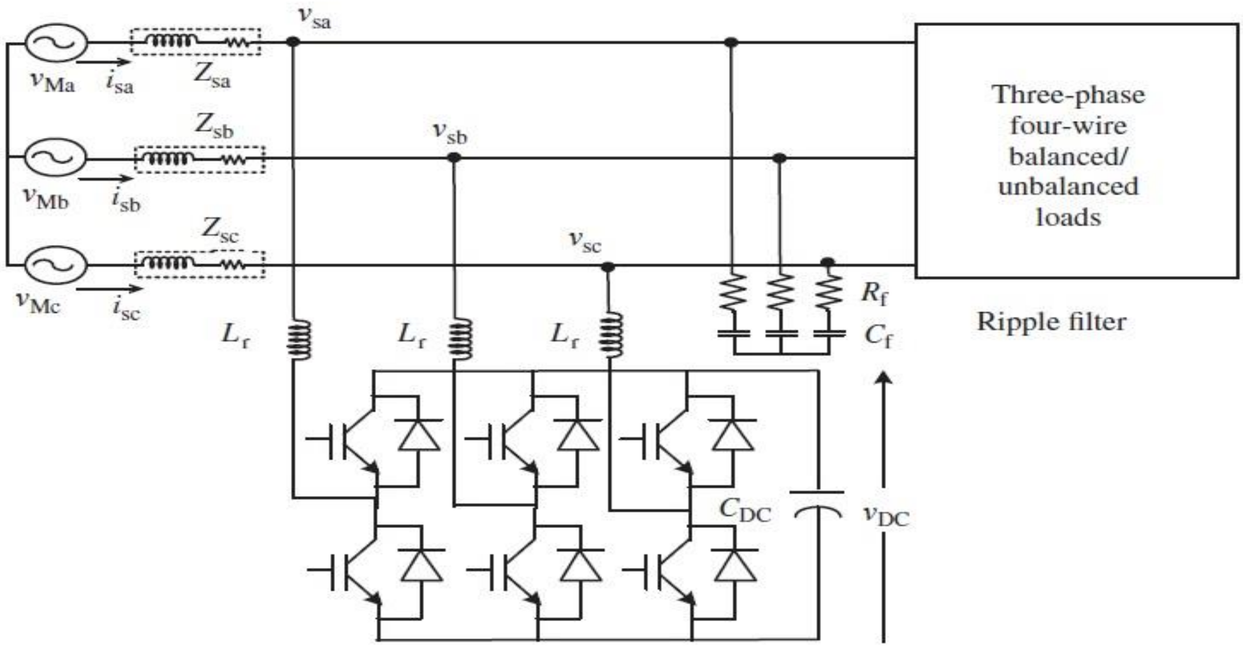

Figure 1. A three-leg VSC-based three-phase three-wire DSTATCOM

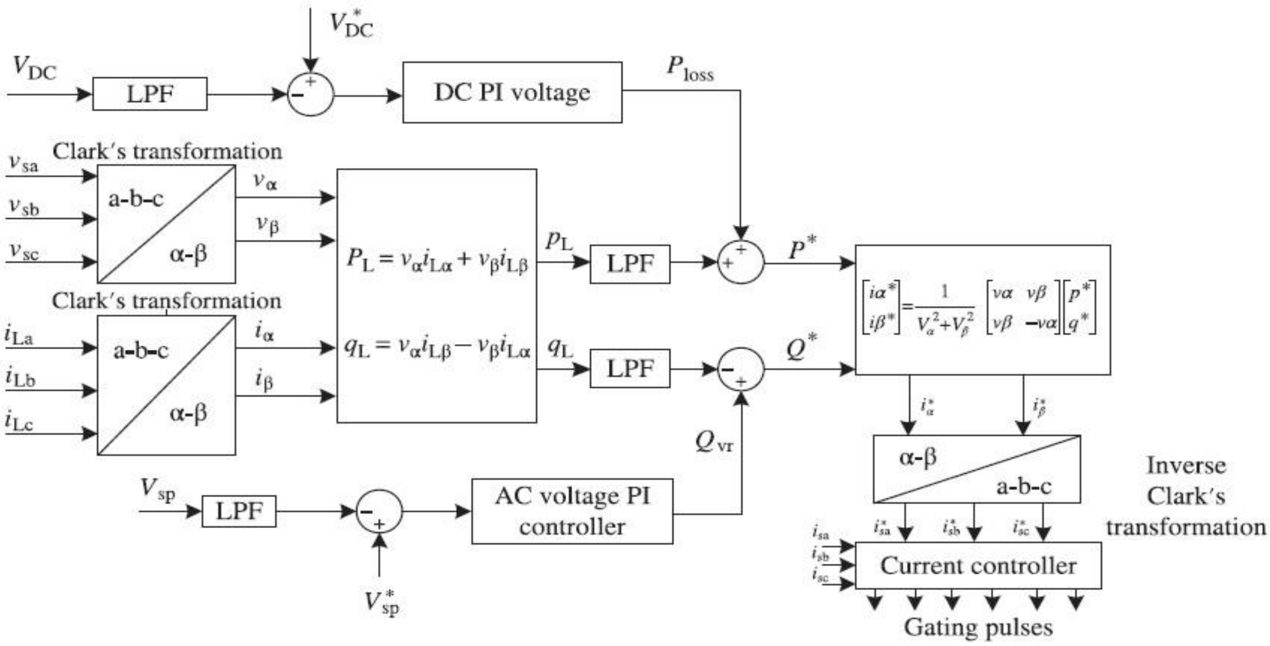

Figure 2.Instantaneous reactive power theory-based control algorithm of DSTATCO

These 3-phase filtered load voltages are converted in α–β orthogonal 2-phase coordinates (vα ,vβ) as

$$\begin{bmatrix} V s\alpha \\ V s\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V sa \\ V sb \\ V sc \end{bmatrix} \quad [3.1]$$

$$\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ila \\ Ilb \\ Ilc \end{bmatrix} \quad [3.2]$$

These two expressions calculate the instantaneous active power P_L and the instantaneous reactive power QL which flow into the load side

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} Vs\alpha & Vs\beta \\ Vs\beta & -Vs\alpha \end{bmatrix} \begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} \quad [3.3]$$

Let $\widetilde{P_L}$ and $\overline{P_L}$ be the DC component and the P_L AC element, and let $\widetilde{Q_L}$ and $\overline{Q_L}$ be the DC component and the Q_L AC element, alternately.

$$P_L = \widetilde{P_L} + \overline{P_L} \quad [3.4]$$

$$Q_L = \widetilde{Q_L} + \overline{Q_L} \quad [3.5]$$

In these terms, the basic load power is transformed into P_L and Q_L DC components and the distortion or negative sequence is transformed into $\widetilde{P}_L$ and $\widetilde{Q}_L$ AC components. The effective and passive power parts of DC are obtained using two LPFs

The reference current in two phase system is

$$\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} = \frac{1}{Vs\alpha^2 + Vs\beta^2} \begin{bmatrix} Vs\alpha & Vs\beta \\ Vs\beta & -Vs\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad [3.6]$$

Isa* Isb* Isc* are the reference three-phase storage signals

$$\begin{bmatrix} Isa^* \\ Isb^* \\ Isc^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vs\alpha & Vs\beta \\ -Vs\beta & Vs\alpha \end{bmatrix}^{-1} \begin{bmatrix} p^* \\ q^* \end{bmatrix} \quad [3.7]$$

To regulate demand cycles for implicit present command, this IRPT-based power algorithm can be readily altered. In this case, for the DSTATCOM power factor correction mode, p*, P_L, P_{LOSS} and Q*, Q_L, P_{VP} in equation 3.4,3.5 and after the transformation from the α–β frame to the abc frame, three-phase transformed currents are reference supply currents and must be compared with sensed supply currents in the PWM current controllers as shown in Figure 4.2. The term P_{LOSS} is an instant active power needed to adjust to its reference value the voltage of the VSC's DC capacitor used as a DSTATCOM. In addition, qvr is Instantaneous reactive power theory-based control algorithm of DSTATCOMs Power Quality Problems and Mitigation Techniques instantaneous reactive power necessary to adjust the PCC voltage to its reference value (these are achieved using a PI controller similarly to the above algorithms as shown in Figure 4.2), and P_L and Q_L are the extracted load fundamental active and reactive power components, respectively. In the case of ZVR at PCC (voltage regulation mode of operation of the DSTATCOM), a PI voltage controller over the PCC voltage is used similarly to the above algorithms and its output is used to estimate p* and q* as

$$P^* = P_L + P_{loss} \quad [3.8]$$

$$Q^* = Q_{vp} - Q_L \quad [3.9]$$

After the transformation, three-phase transformed currents are reference supply currents and these are compared with sensed supply currents.

4. SIMULATION AND RESULTS

Modeling and simulation of proposed method is done MATLAB Simulink.

A three-phase generator with 415 V of voltage in phase to phase composed of an unbalanced load in three phases is intended and modeled in order to get the origin and load voltage and current waveforms.

A shunt linked device with a three-phase, three-leg inverter with IGBTs as switching instruments is the compensator modeled. A non-linear load composed of a R-L converter with an R-L load of 25 and .05H is used for an unbalanced system.

Simulation parameters	
Three phase supply voltage(L-L)	415V
Non Linear Load	Three phase uncontrolled rectifier with R-L connected load of 1.5 ohm & 40mH
D-C capacitor	20 mF
Interfacing reactance	R=.01ohm L= 4 mH
Reference dc link voltage	700 v

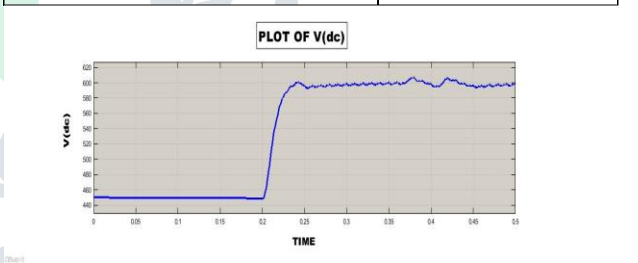

Figure 4.1 Simulation result of Vdc

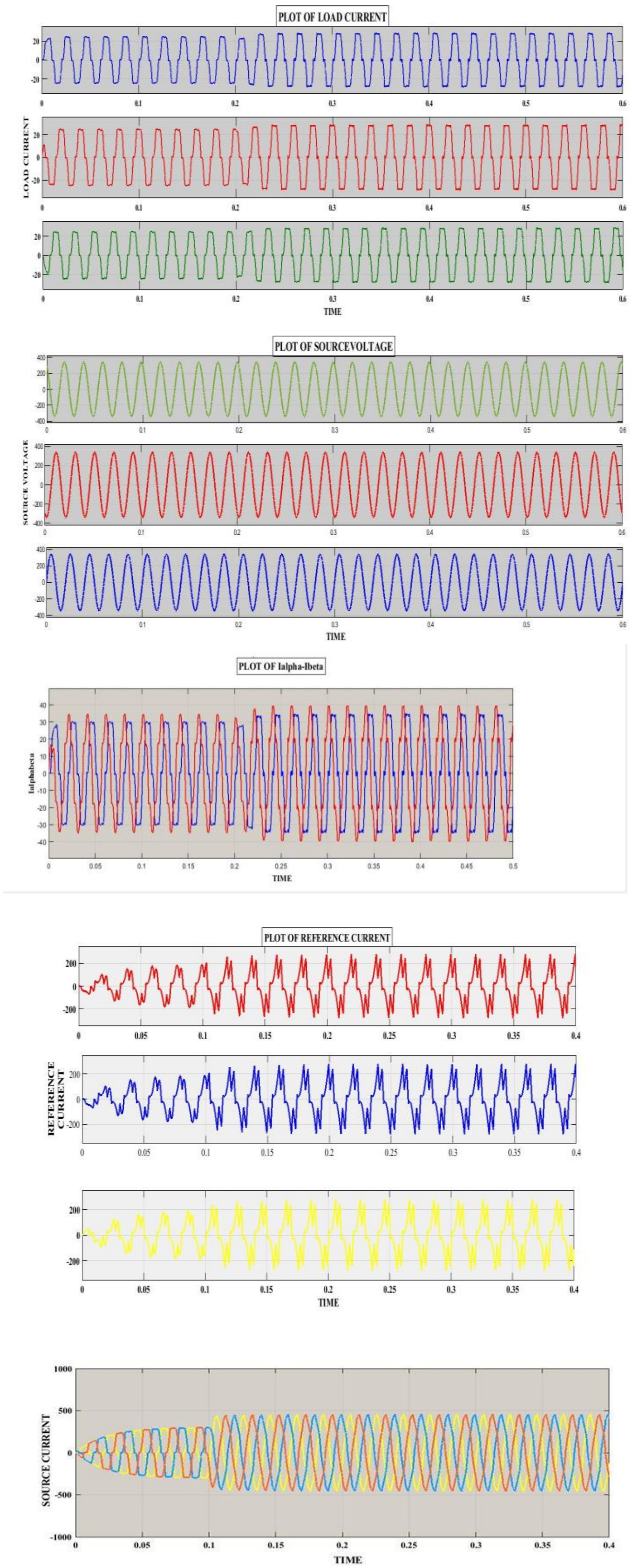

Figure 4.2 Three phase load current, three phase source current, Ialpha and I beta, Compensating current and source phase current.

Above simulation result shown in figure is waveform of source current without compensation & with compensation. After 0.1 second when the STATCOM starts operating it injects reactive power to compensate harmonics with increased current. The THD graph before compensation and after compensation is shown below

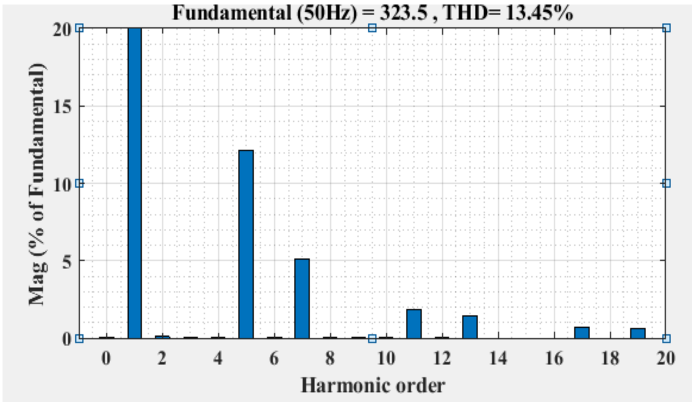

Figure 4.3 Total harmonics distortion before compensation

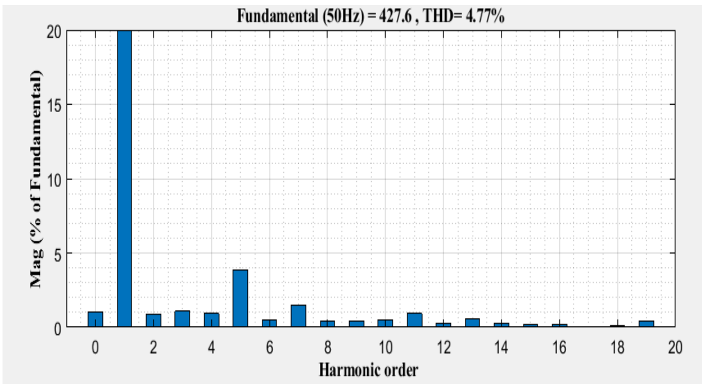

Figure 4.4 Total harmonics distortion after compensation

The graph shown above is THD before & after compensation. The harmonics was found to be 13.45% before compensation in which 5th& 7th harmonics are prominent. After t = 0.1sec when compensation is applied the harmonics is reduced to 4.77% which decrement of 5th & 7th harmonics.

5. CONCLUSIONS

D-STATCOMs have excellent characteristics such as the ability to deliver the same reactive power, regardless of demand voltage changes, quicker reaction and lower device volume. In these research work, VSC based 3 leg 6 pulse converter is used for injection of reactive power to the PCC at the line. The total harmonic distortion before compensation was 13.85% and after compensation is 4.77% which meet the IEEE519-1992 standard.

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