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Harmonics Extraction and Mitigation in Power Distribution System using modified IRPT in D-STATCOM control under a polluted grid

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***Abstract*-In this paper design and modeling of modified instantaneous reactive power theory (IRPT) has been discussed. Complete elimination of harmonics has been attempted by using modified IRPT and conventional IRPT method. Voltages of non- sinusoidal as well as non-sinusoidal grid are taken in the result. The harmonics induced due to reactive load are reduced by a compensator designed in the project which can improve voltage quality, and rectify impaired power factor. In this paper we are using three phase three wire system where several aspects of control are being compared.**

***Index Terms*—compensation, power quality, DSTATCOM, voltage regulation**

I.INTRODUCTION

Unbalancing due to reactive power leads to issues like deviation in voltage in conditions of load change and limitation in power transfer. Reactance in AC loads leads to heavy consumption of reactive power which leads to poor voltage quality. Thus the reactance in transmission of power has caused a significant effect on various power distribution systems. [1]. Maintaining the quality of electricity „PQ" in the distribution system of electricity is currently a major concern. The term energy quality usually refers to maintaining the best quality of energy in the production, transmission, distribution and use of energy. [2].
Harmonics is an important factor that influences poor energy quality and leads to many disruptions in the distribution system such as power outages, overheating when cables and low power. The Distribution Static Compensator (DSTATCOM) is used to compensate for power disturbances established such as active power, neutral currents, flexibility, synchronization and uneven currents. A DSTATCOM is designed by using a CC-VSC (3 phase three leg voltage source converter) which is based on insulated gate bipolar junction transistor. In general, a DSTATCOM has a VSC connected to a DC bus and AC side is connected across the consumer end of the power distribution system in shunt. A control algorithm is used to generate reference
currents that are compared to the supply currents in indirect current control of Typically, DSTATCOM has a VSC connected to a DC bus and the AC side is connected across the end of the buyer to the shunt power supply system. The control algorithm is used to generate reference currents compared to the currents to supply the current indirect control of VSC; these are used to produce gas cylinders fed directly to DSTATCOM [3].

The performance of DSTATCOM depends on the control scheme used to extract the current reference components. The concept of Instantaneous Reactive Power (IRP) and Synchronous reference Frame (SRF) theory of paying for active energy and inequality in loading compared to the new adaline control algorithm in [4] proposed by B. Singh and J. Solanki.
L.S. Czarnecki proposed a new reference for Shunt switching Compensator (SSCs) control using Instantaneous Reactive Power (IRP) pq theory in [5] in 2009. On the other hand J. Bangarraju, V. Rajagopal and A. Jayalaxmi proposed the immediate use of the Power (IRP) theory control algorithm for the three-legged VSC and used the Dynamic Voltage Regulator (DVR) in [6].

Effective filtration usually focuses on compensatory techniques where resource volumes are sinusoidal where compensation for harmonic currents by active force provides a unity of force (UPF) that leads to harmonics free currents [7]. But when the dosage of the sources is not sinusoidal then some difficulty arises as compensation. Without the method used to compensate, complete compensation for harmonious and active forces is not possible and the power of unity is not available. Salmerón no R. S. Herrera in [8] proposed burden compensation strategies under distorted resource volumes.

This paper illustrates the effectiveness of DSTATCOM controlled by (IRPT) or p-q theory under different current index output strategies. These currents are then used to compensate for the load where the distribution grid cables are sinusoidal and contaminated and feed the indirect load. The effectiveness of DSTATCOM using these techniques is tested and verified in both Power Factor Correction (PFC) and Zero Voltage Regulation (ZVR) modes for both mountain (sinusoidal) and practical (non-sinusoidal) distribution systems.

II. SYSTEM CONFIGURATION

A three phase non linear load is fed by a source of three phase with source impedance Zs. The system is provided with DSTATCOM which is connected in shunt at the consumer end. A current controlled VSC which is modeled by using IGBT is connected to a capacitor known as DC link capacitor named C_{DC}. MATLAB R2016a is used for testing and verification of stratigies used in the project. Fig. 1 shows the lock diagram of the grid connected system.

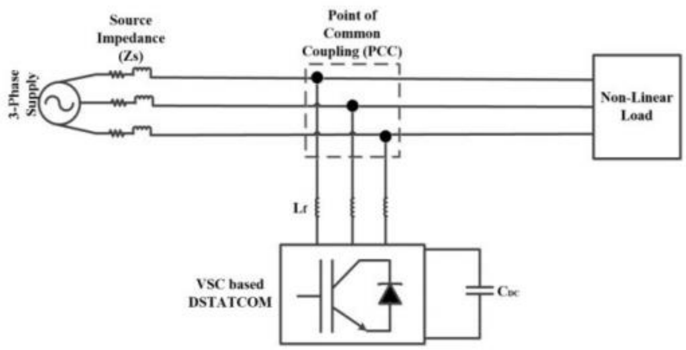

Fig. 1 Block diagram of DSTATCOM connected to grid

III. CONTROL ALGORITHM

In this section conventional algorithm of IRPT and its modified versions have been discussed.

A. *Conventional Algorithm under Ideal Grid Conditions*

In conventional PQ theory three phase load load currents and voltages are converted to αβ0 stationary reference frame which uses Clarke transformation or αβ0 transformation.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{2}/\sqrt{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{2}/\sqrt{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (3)$$

So the calculation of instantaneour reactive and active power is done by:

$$\begin{bmatrix} P_L \\ Q_L \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

A low pass filter is then used to extract out the AC component from these powers.

$$\begin{bmatrix} P_L \\ Q_L \end{bmatrix} = \begin{bmatrix} \overline{P_L} + \widetilde{P_L} \\ \overline{Q_L} + \widetilde{Q_L} \end{bmatrix} \quad (5)$$

The DC and AC components of active and reactive powers are shown as $\overline{P_L}$, $\overline{Q_L}$ and $\widetilde{P_L}$, $\widetilde{Q_L}$ respectively. The PCC voltage V_t and DC bus voltages are regulated by two PI controllers.

At n^{th} sampling instant the DC bus voltage error between V_{dc}^* and V_{dc} ie reference and sensed DC bus voltage is given as:

$$V_{DC}(n)=V_{dc}^*(n)-V_{dc}(n) \quad (5)$$

So the active power loss component which is DC PI controller loss 'P_{Loss}'

$$P_{Loss}(n)=P_{LOSS}(n-1)+K_{pd}\{V_{DC}(n)-V_{DC}(n-1)\}+K_{pi}V_{DC}(n) \quad (6)$$

So the PI controller integral and proportional gain are represented by K_{id} and K_{pd}. The fundamental component of active power denoted by P is obtained by Adding DC component of active power to P_{loss}.

$$P=\overline{P_L}+P_{Loss} \quad (7)$$

At instant of n^{th} sampling the error in PCC voltage is obtained by substracting V_t^* with V_t where $V_t^*$is reference PCC voltage amplitude and sensed PCC voltage V_t.

$$V_{te}=V_t^*(n)-V_t(n) \quad (8)$$

$$V_t=\sqrt{\frac{2}{3}(V_{sa}^2+V_{sb}^2+V_{sc}^2)} \quad (9)$$

The second PI controller output at n^{th} sampling used to get constant PCC voltage is 'Q_{Loss}'.

$$Q_{Loss}(n)=Q_{Loss}(n-1)+K_{pd}\{Vte(n)-Vte(n-1)\}+K_{pi}Vte(n) \quad (10)$$

So the fundamental active power component denoted as Q is obtained by sum of DC active power component to Q_{Loss}.

$$Q=\overline{Q_L}+Q_{Loss} \quad (11)$$

So i_α^* and i_β^* which are reference currents in αβ reference frame are

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2+V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} \quad (12)$$

So by inverse Clarkes Transformation the three phase currents in grid supply are given as:

$$\begin{bmatrix} i_{refa} \\ i_{refb} \\ i_{refc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (13)$$

There are some changes in equation 11 for power factor correction mode and reactive component is taken as zero

$$Q=\overline{Q_L}+Q_{Loss}=0 \quad (14)$$

B. *Modified versions under non ideal grid conditions*

Under this scenario, the grid is considered contaminated and has 5th and 7th harmonics on the voltage grid and basic. The standard p-q algorithm will not work well in such case; thus the correction has been suggested in this section. Three such changes have been made, modified and tested under these conditions namely. Power Factor Correction (PFC) mode, Zero Voltage Regulation (ZVR) mode and a complete Harmonic Elimination (CHE) strategy using ip-q theory.

Both the PFC and ZVR methods are not able to completely eliminate the harmonics currents, so the modification of the PFC mode for harmonic elimination in the distribution system is considered. Thus the complete Harmonic Elimination strategy, third-phase voltages and loading currents are converted to αβ0 standard reference frame by Clarke Transformation as shown in Eq 1. The maximum amount of active energy is calculated by:

$$P=i_{La}v_{sa}+ i_{La}v_{sa}+ i_{La}v_{sa}=\overline{P_L}+\widetilde{P_L} \qquad (15)$$

So a LPF is used to get load active power filter DC component and two band pass filters are used to to get V_α^* and V_β^* which are fundamental values of Vα and Vβ. So the generated reference currents are

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{\overline{P_L}}{V_\alpha^2+V_\beta^2}\begin{bmatrix} V_\alpha^* \\ V_\beta^* \end{bmatrix} \qquad (16)$$

Eq 13 can be used to calculate reference currents from source which are in a-b-c reference frame. We are using CHE method to filter disturbed voltages by filtering $\overline{P_L}$. Thus the gating pulses are generated after comparing i_{sa}, i_{sb}, i_{sc} to obtained reference source currents by a VSC based DSTATCOM.

IV. MODELLING AND SIMULATION

In this section, detailed models are designed for the standard and modified version of the IRPT. Figure 2 shows the file for diagram of voltages in PCC (V_{sa}, V_{sb}, V_{sc}) and load currents(i_{sa}, i_{sb}, i_{sc}) in α-β Frame using the Clarke transformation.

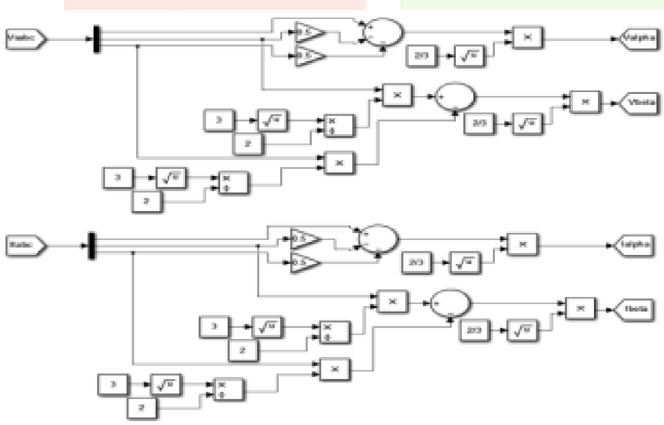

Fig. 2 Conversion from a-b-c to α-β for voltage and currents

Figure 3 shows a blockchain diagram for extracting the basic part of the actual and active power using phase power and loading loads on the α-β frame and the results obtained from the PI controllers to maintain the DC bus voltage and AC PCC voltage amplitude respectively.

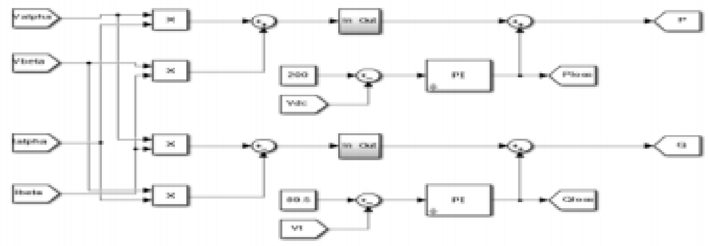

Fig.3 Calculation of fundamental components of real and reactive powers

Figure 4 shows how the basic supply currents in the α-β framework are extracted from phase power and loading currents in α-β Independent and the main active and active energy components.

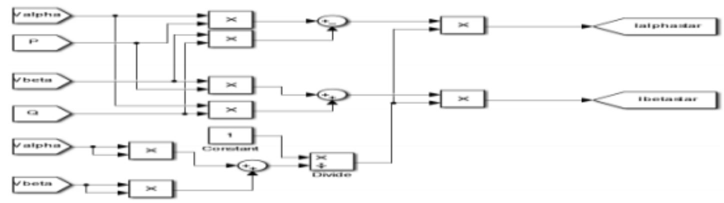

Fig4. Computation of fundamental supply currents in αβ reference frame

Now the VSC based DSTATCOM receives six pulses by comparing phase reference currents ans sensed source voltage.

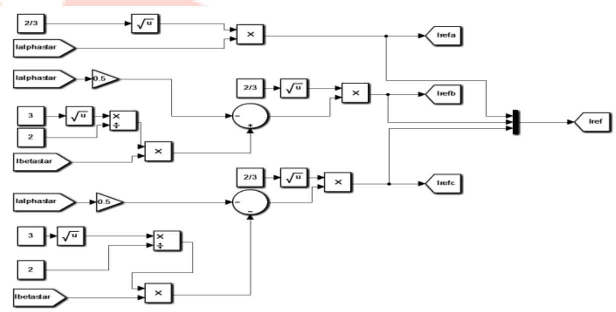

Fig. 5 Computation of reference source currents from α-β to a-b-c frame

Taking the reactive power as zero the results in PFC correction mode are obtained by applying changes in algorithm

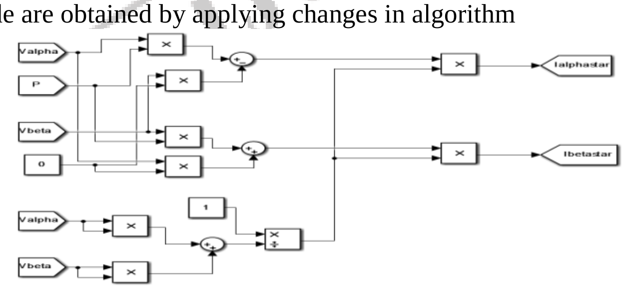

Fig. 6 Fundamental Source Currents in α-β Frame in PFC mode

Now the CHE strategy was used to extract source currents in α-β reference frame.

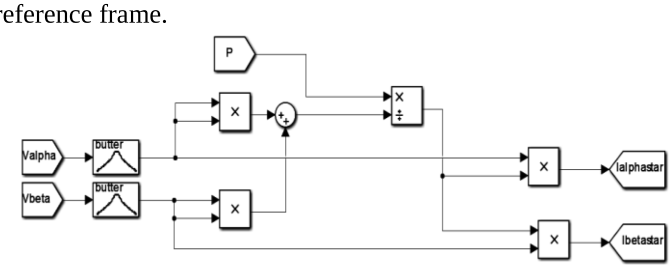

Fig.7: CHE implantation to extract source current in α-β reference frame

V. RESULTS AND DISCUSSION

Developed three control algorithms on MATLAB / SIMULINK using the Sim power system (SPS) toolbox. The simulation was performed in discrete mode using an ode 23tb solution (stiff / TR-BDF2) during sampling time of (5e-6) sec. FFT analysis of load and supply PFC / ZVR mode for sinusoidal distribution and non-sinusoidal voltage is indicated.

A. FFT Analysis under Sinusoidal Grid Voltages

Fig. 8 shows that at load current 27.17% the total harmonicc distortion (THD) and the current is 3.93% after compensation in phase-a in the PFC mode where the values in the distribution system are sousoidal. Electrical energy is sinusoidal and has a low THD of 0.04%.

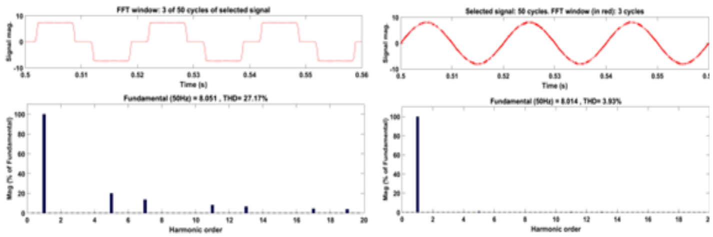

Fig. 8 FFT Analysis of load and source current in PFC mode

For sinusoidal voltage distribution system Fig. 9 shows the load and source FET analysis of source and load current.thich shows load current THD as 27.16% and for supply current 3.86%.. It is done with three cycles with sinusoidal distribution system.

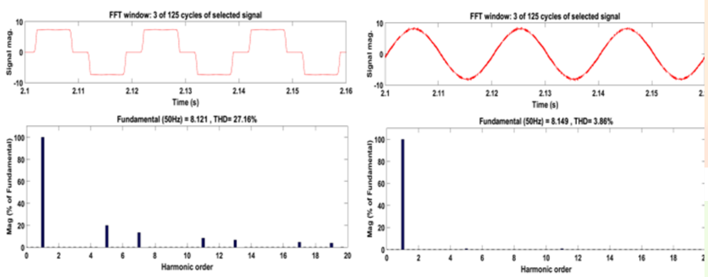

Fig. 9 FFT Analysis of load and source current in ZVR mode

B. FFT Analysis under Non-Sinusoidal Grid Voltages

Fig 10-12 shows the FET analysis for parameters for non-sinusoidal voltage distribution system such as source and load currents, PCC voltages, ZVR, and CHE mode.

Fig. 10 shows THD in supply current, load current and PCC voltage to be 8.52%, 24.75%, 6.4%. This is after compensation in phase-a in power correction mode.

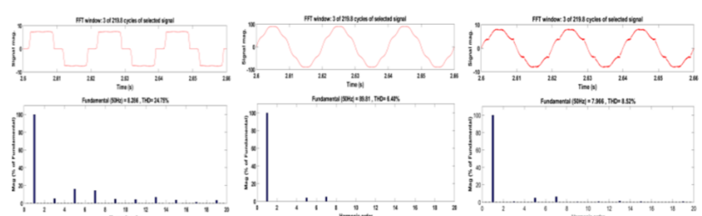

Fig. 10 FFT Analysis of load current, PCC voltage and source current in PFC mode with distorted voltages

Using IRPT strategy in ZVR in DSTATCOM the tital harmonic distortion in PCC voltage and load current is same as after compensation done above but THD in supply current decreases to 7.60%. which is shown in Fig.11.

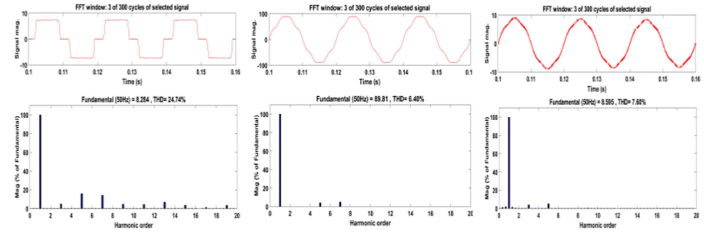

Fig. 11: FFT Analysis of PCC Voltage, load current and source current in ZVR mode with distorted voltages

Fig.12 shows CHE implementation for the same where supply current THD was seen as 3.64%.

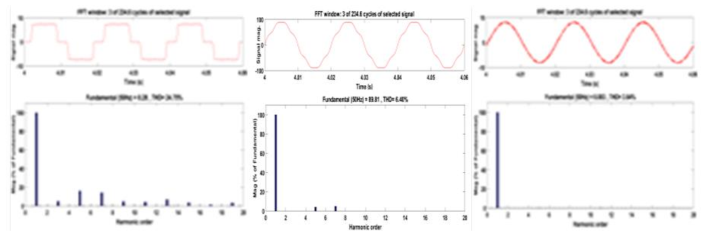

Fig. 12: FFT Analysis of PCC Voltage, Load Current and Source Current

Performance of system underSsinusoidal Grid Voltages

The effectiveness of the program with DSTATCOM controlled by p-q theory in various ways is now shown below.

When the distribution system has the sinusoidal effect of DSTATCOM performance using pq theory in PFC mode is shown in Fig. see that the dc link voltage V_dc rises temporarily and starts to settle down to 200V due to control action.

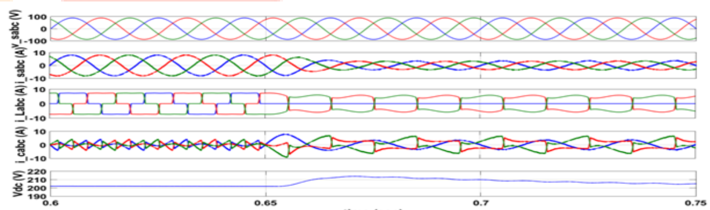

Fig. 13 Performance of DSTATCOM using p-q theory in PFC mode.

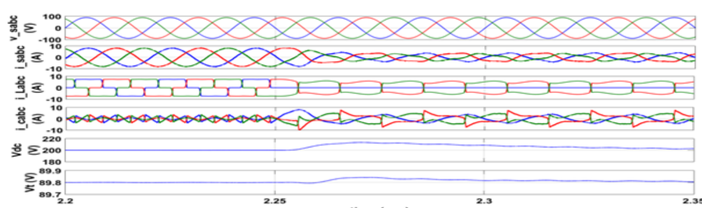

Fig. 14 Performance of DSTATCOM using p-q theory in ZVR mode

In Fig. 14 the effectiveness of DSTATCOM using p-q theory in ZVR mode is observed. Two DC link voltage controllers and PCC voltage are used here. At t = 2.25 sec, section 'a' of the load is cut to read the results of the unequal load. It is evident that both DC link voltage V_dc and Vt went up temporarily and then stabilized at their reliable values of 200V and 89.8V as shown in Fig. 14.

5.4 System Performance under Non-Sinusoidal Grid Voltages

Where the distribution system has non-sinusoidal electrical power DSTATCOM performance using pq theory in PFC mode is shown in Fig. we see that the dc link voltage V_dc rises for a while and then starts to settle down to 200V as shown in the figure. It is evident that the supply cables and supply currents are distorted.

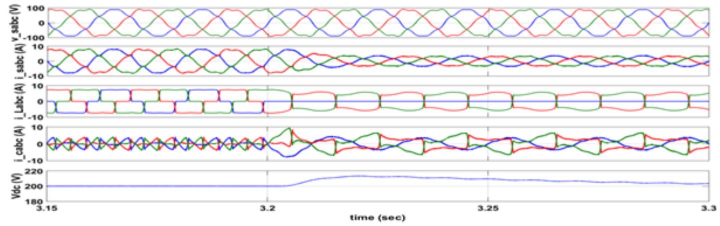

Fig. 15: Performance of DSTATCOM using p-q theory in PFC mode

In Fig. 16, implementation of p-q theory in ZVR mode using DSTATCOM is checked. When the t = 1.05 sec phase 'a' of the load is cut off to study the effects of the unequal load and as we can see that the dc link voltage V_dc rises for a while and starts to settle down to 200V as shown in the figure. Also, the final Vt voltage has oscillations of + 2V.

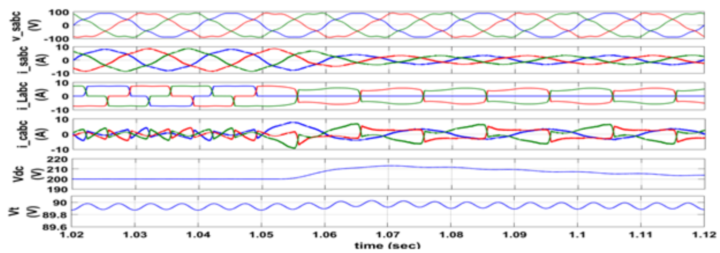

Fig. 16: Performance of DSTATCOM using p-q theory in ZVR mode

In figure 17 the performance of the system using CHE strategy in pq theory in DSATCOM is checked. To get the response of the system with unbalanced load phase a of the load is disconnected which shows dc link voltage rises and then again falls to 200V. Thus the pure sinusoidal currents have been achieved.

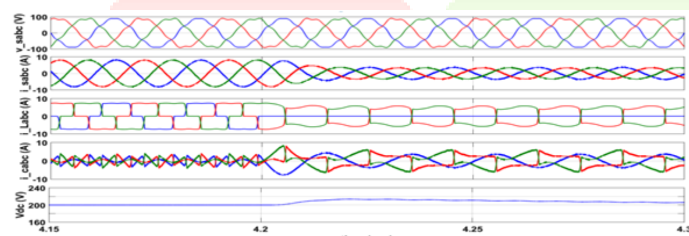

Fig. 17: Performance of DSTATCOM using p-q theory using CHE strategy.

VI. CONCLUSION

1. PFC and ZVR mode ia applied in pq theory and its performance in DSTATCOM is checked for sinusoidal voltage.
2. PFC and ZVR mode ia applied in pq theory and its performance in DSTATCOM for non sinusoidal voltage is checked using complete harmonic elimination scheme.

The table given below shows outcomes of THD in all cases

Table1: THD IN DIFFERENT CASES

VOLTAGE	MODE	THD %		
		PCC Voltage	*LOAD CURRENT*	*SOURCE CURRENT*
SINUSOIDAL	PFC	0.04	27.17	3.93
	ZVR	0.04	27.16	3.86
NON SINUSOIDAL	PFC	6.40	24.75	8.52
	ZVR	6.40	24.74	7.60
	CHE	6.40	24.75	3.64

APPENDIX

Supply (grid): 110V, three-phase, 50Hz; Z_s composed of R_s=0.01Ω, L_s=0.1mH; V_{dc}=200V; C_{dc}=1500µF; L_f=2.25mH; PI controller tuned at: k_{pd}=5, k_{id}=20; Nonlinear load: three phase uncontrolled diode rectifier with R=20Ω, L=100mH.

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