Design & Performance analysis of D-STATCOM for Non-Linear Load Composite Compensation

Gokulananda Sahu[1,*] ,Kamalakanta Mahapatra[1],Subrat Kumar Sahu[2]
[1]Dept. of Electronics and Communication Engg. NIT,Rourkela,India
gokulanandasahu@gmail.com ,kmaha2@gmail.com
[2]GHITM,Puri, India
Sahu487@gmail.com

Abstract – This paper investigates the design,analysis and simulation of a Distribution-STATic COMpensator(D-STATCOM) for non-linear load Composite(harmonic and reactive power) compensation on a three phase bus network. Composite compensation is achieved by implementation of a p-q controller, which monitors the load current and injects equal amplitude and opposite phase compensation currents to neutralize load reactive power and harmonics. This ensures the source current remains fundamental. This paper simulated results in MATLAB platform and showed that a D-STATCOM is suited for use in reactive power and harmonic compensation on any bus on a power system network.

Key Words – D-STATCOM , p-q, Harmonics, Unbalance

I. INTRODUCTION

During the last decade, there has been sudden increase in the nonlinear load(Computers, Laser printers, SMPS, Rectifier etc.), which degrades the power quality causing a number of disturbances e.g. heating of home appliances , noise etc in power systems[1], [2] due to harmonics. These nonlinear load along with reactive power loads such as fan, pump, motors etc increase the burden on the power system. These loads draw lagging power factor currents and therefore give rise to reactive power burden in the distribution system. Excessive reactive power demand increases feeder losses and reduces active power flow capability in the power system. Sometimes their unbalance can worsen the system performance like affecting the active power flow capability of lines and operation of transformers. Therefore restoring the system for better functionality becomes a matter of concern for the utilities. To compensate the harmonics and reactive power due to non-linear load, a Distribution STATic COMpensator (D-STATCOM) is used [3]. The performance of DSTATCOM largely depends on the control algorithm used for reference current current extraction. The control algorithm used conventionally, were based on active and reactive power are found unsuitable for unbalance and harmonic conditions. Significant contribution for development of control algorithm was made by Budeanu and Fryze [2]. They provide power definition in frequency and time domain. They set the pathways for development universal set of power definitions which led to the development of p-q theory by Akagi et al.[4]. In this paper performance of one algorithm such as instantaneous p-q theory is investigated in **three phase three wire system** for balanced source and nonlinear balanced and unbalanced Load. The measures of the performance is the source current total harmonic distortion and power factor.

Rest of the paper is organized as follows. In section II the system configuration is described. In section III brief discussion on p-q control theory is presented. In section IV the performance indices used for evaluation are discussed. Simulation results are described in section V. Finally in section VI , conclusion are drawn.

II. SYSTEM CONFIGURATION

Fig.1 shows the basic circuit diagram of a D-STATCOM system with non -linear load connected three phase three wire distribution system. A nonlinear load is realized by using a three phase full bridge diode rectifier. A three phase voltage source converter (VSC) working as a D-STATCOM is realized using six insulated gate bipolar transistor (IGBTs) with anti-parallel diodes. At ac side, the interfacing inductors are used to filter high frequency components of compensating currents. The first harmonic load currents of positive sequence are transformed to DC quantities. The first harmonic load currents of negative sequence and all the harmonics are transformed to non-DC quantities and undergo a frequency shift in the spectrum. The voltage regulator in the converter DC side is performed by a proportional –integral(P-I) controller. Its input is the capacitor voltage error vdcref-vdc and through the regulation of the first harmonic active current of positive sequence . It is possible to control the active power flow in the VSI and thus the capacitor voltage vdc. The dynamics of each VSC are modeled by solving differential equations governing two modes of the inverter. The switching of the inverter is done by monitoring the reference and actual currents and comparison of error with the hysteresis band of hysteresis current controller(HCC)[6].

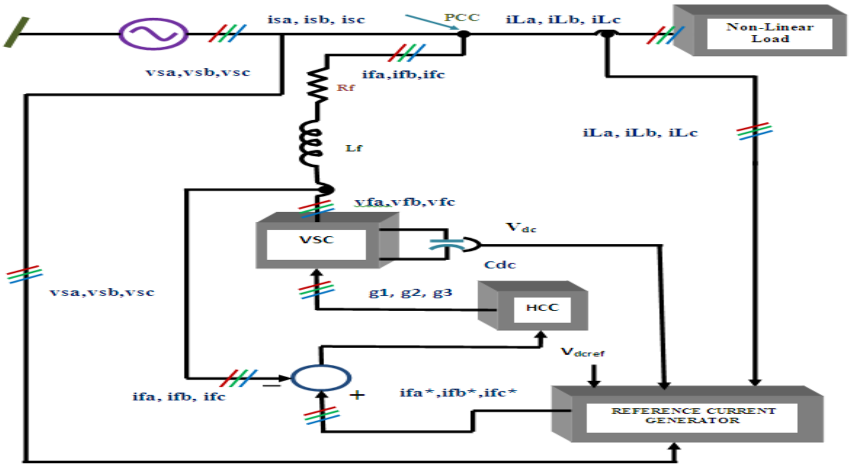


Fig. 1 System Design of D-STATCOM

The reference current generator(**p-q controller**) generates reference(compensating) currents which are fed to hysteresis current controller to generate the switching pulses for VSC.

III. CONTROL ALGORITHM

A. Instantaneous p-q Theory

Instantaneous **p-q** Theory was initially proposed by Akagi[4]. This theory is based on the transformation of three phase quantities to two phase quantities in α-β frame and the Instantaneous active and reactive power is calculated in this frame [4],[5]. Sensed inputs v_{sa} ,v_{sb} and v_{sc} & i_{La} ,i_{Lb} and i_{Lc} are fed to the p-q controller shown in fig.2 and these quantities are processed to generate reference commands($i_{fa}^*, i_{fb}^*, i_{fc}^*$) which are fed to a hysteresis based PWM current controller to generate switching pulses for D-STATCOM.

The system terminal voltages are given as

$$\left.\begin{aligned} v_{sa} &= V_m \sin(wt) \\ v_{sb} &= V_m \sin(wt - 2\pi/3) \\ v_{sc} &= V_m \sin(wt + 2\pi/3) \end{aligned}\right\} \tag{1}$$

and the respective load current are given as

$$\left.\begin{aligned} i_{La} &= \Sigma I_{Lan} \sin\{n(wt) - \theta_{an}\} \\ i_{Lb} &= \Sigma I_{Lbn} \sin\{n(wt - 2\pi/3) - \theta_{bn}\} \\ i_{Lc} &= \Sigma I_{Lcn} \sin\{n(wt + 2\pi/3) - \theta_{cn}\} \end{aligned}\right\} \tag{2}$$

In a.b and c coordinates a,b and c axes are fixed on the same plane apart from each other by 2π/3. These phasors can be transformed into α-β coordinates using Clarke's transformation as follows.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \tag{3}$$

,

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{4}$$

Where α and β axes are the orthogonal coordinates . Conventional instantaneous power for three phase circuit can be defined as

$$p = v_\alpha i_\alpha + v_\beta i_\beta \tag{5}$$

Where p is equal to conventional equation

$$p = v_{sa}i_{sa} + v_{sb}i_{sb} + v_{sc}i_{sc} \tag{6}$$

Similarly , the instantaneous reactive power is defined as

$$q = v_{\beta}i_{\alpha} - v_{\alpha}i_{\beta} \tag{7}$$

Therefore in matrix form, instantaneous real and reactive power are given as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} \tag{8}$$

The α-β currents can be obtained as

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{9}$$

Where $\Delta = v_{\alpha}^2 + v_{\beta}^2$

Instantaneous active and reactive powers p and q can be decomposed into an average(dc) and oscillatory

$$\left.\begin{aligned} p &= \bar{p} + \tilde{p} \\ q &= \bar{q} + \tilde{q} \end{aligned}\right\} \tag{10}$$

Where p and q are the average dc part and p and q are the oscillatory (ac) part of these real and reactive instantaneous power. Reference currents are calculated to compensate the instantaneous reactive and the oscillatory component of the instantaneous active power. Therefore the reference compensating currents $i_{f\alpha}^*$ and $i_{f\beta}^*$ in α-β coordinate can be expressed as

$$\begin{bmatrix} i_{f\alpha}^* \\ i_{f\beta}^* \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} -\tilde{p} \\ -q \end{bmatrix} \tag{11}$$

The oscillatory part of real power p is obtained by using 4th order low pass Butterworth filter of cut-off frequency 25 Hz. These currents can be transformed in abc quantities to find reference currents in a-b-c coordinates using reverse Clarke's transformation.

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{f\alpha}^* \\ i_{f\beta}^* \end{bmatrix} \tag{12}$$

Fig. 2 shows the block diagram of p-q controller which is used to generate reference currents.

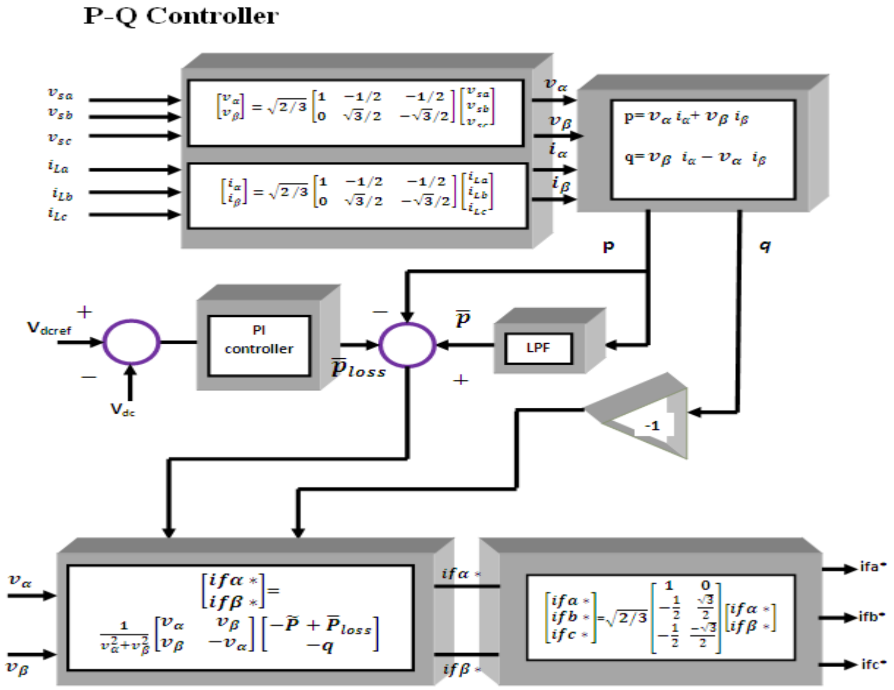


Fig. 2 p-q controller

IV. PERFORMANCE INDICES

Total harmonic distortion

The total harmonic distortion (THD) [7]is used to define the effect of harmonics on the power system voltage. It is used in low-voltage, medium-voltage, and high-voltage systems. It is expressed as a percent of the fundamental and is defined as

$$THD(current) = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_1} \qquad (39)$$

According to IEEE-519 the permissible limit for distortion in the signal is 5%.

Power Factor

The ratio of average to apparent power is called as power factor.

Power Factor= P/S where P= Average power and S= Apparent power.

V. RESULTS AND DISCUSSION

To investigate the performance of the D-STATCOM for p-q control algorithm, simulations are performed on matlab platform . A three phase three wire distribution system with parameters given below is considered for simulation. The performance of the control algorithm is evaluated based on two different cases.

System Parameters:

Supply voltage : 50Vrms(L-N),50Hz, three phase balanced
Source impedance:Rs=0.1Ω,Ls=.5mH
Nonlinear load: Three phase full bidge diode rectifier with load(L=10mH,R_L=3.7Ω)
DC storage Capacitor Cdc=2000μF
Interface inductor Lf=2.2mH ,Rf=0.1Ω
DC Link voltage Vdc=100V

Case1- Balanced Source and balanced Non-Linear load

Case2- Balanced Source and Unbalanced Non-linear load.

SIMULATION

Case-1

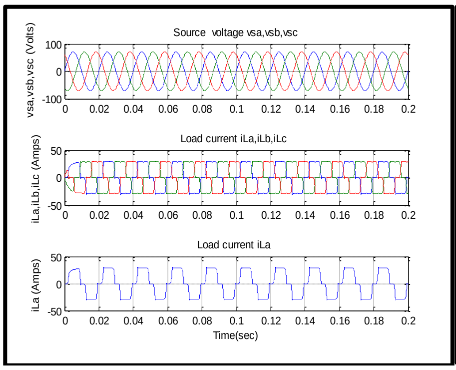


Fig. 3a Balanced source voltage, Load current .Load currentPhase A

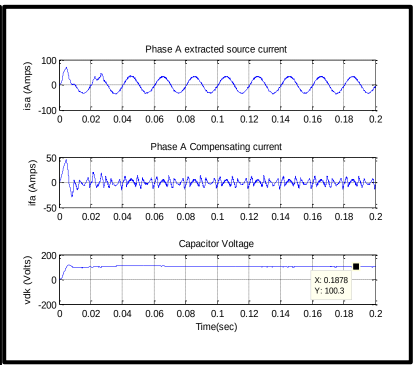


Fig.3b Phase A extracted Soure current, Compensating current , DC link Capacitor Voltage

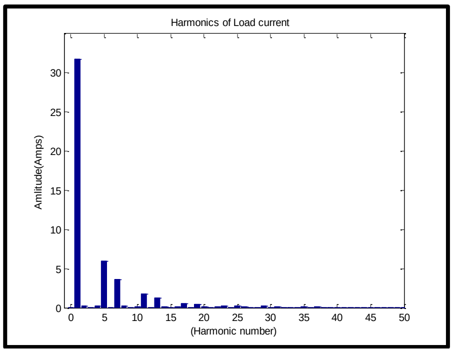


Fig. 3c Harmonics of Load current of Phase A

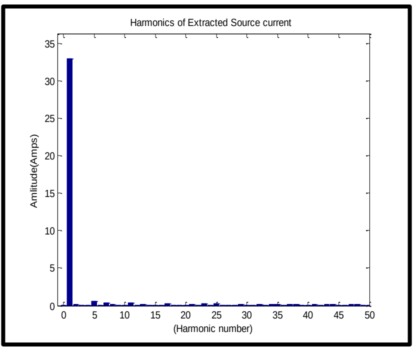
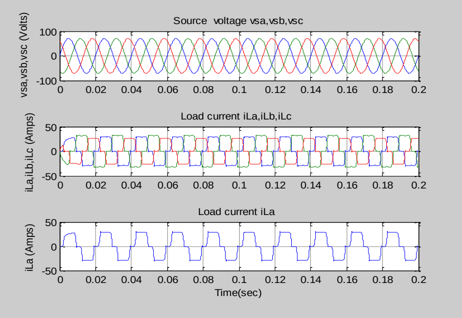


Fig. 3d Harmonics of extracted Source current of phase A

Case-2



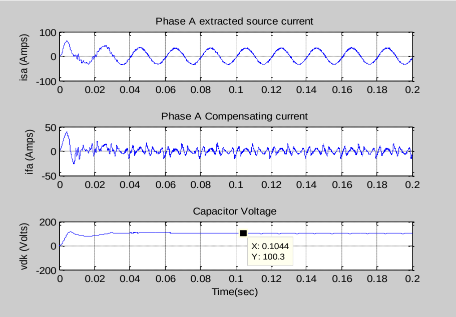
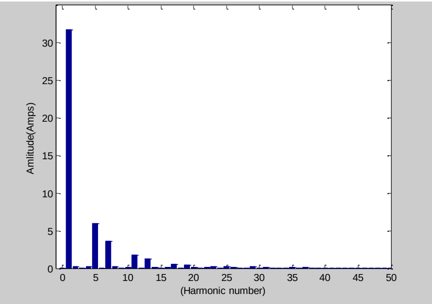


Fig. 4a Balanced source voltage, ,Unbalanced Load current,Load currentPhase A

Fig.4b Phase A extracted Soure current, Compensating current and DC link Capacitor Voltage



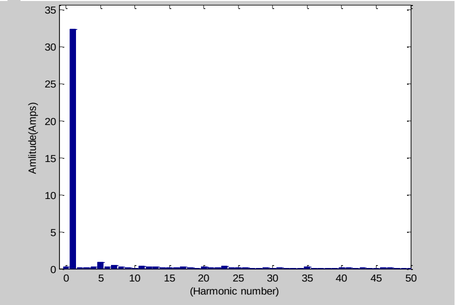
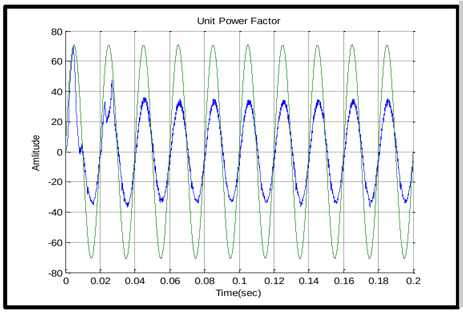


Fig. 4c Harmonics of Load current of Phase A

Fig. 4d Harmonics of extracted Source current of phase A

Case-1

Case-2



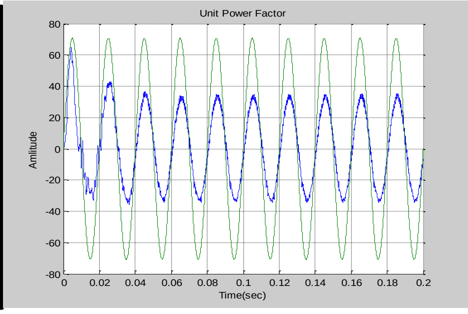


Fig.5a case 1 power factor

Fig.5b case 2 power factor

In **case 1** the source is assumed to be sinusoidal and balanced whereas the load is considered as non-sinusoidal and balanced with load as six pulse diode full bridge rectifier. Before compensation the THD of load current is found to be **23.2361%.** After compensation the THD is listed in the T**able1.** In **case 2** the source is balanced and sinusoidal but the load is unbalance non sinusoidal .The THD of the load current for phase A after compensation is summarized in **Table 1.**The results demonstrated here are considered for phase A.

Table1 THD &POWER FACTOR

Control strategy	**THD(%)**		**POWER FACTOR**	
	CASE-1	CASE-2	CASE1	CASE2
After Compensation	3.0748	3.4863	0.9981	0.9971

VI . CONCLUSION

In all cases it was observed that the D-STATCOM is working fine and able to compensate the nonlinear balanced and unbalanced load successfully. The THD obtained here are within the limit of 5% prescribed by IEEE 519. From the above comparison table it has been found that p-q algorithm has better performance for harmonic cancellation and reactive power compensation.

REFERENCES

1. Rose, Francisco C. De La; , "*Harmonics and Power Systems*," New York, Taylor & Francis Group, LLC, 2006.
2. M. Aredes, H. Akagi, E. H. Watanabe, E.V. Salgado, L. F. Encaracao,"Comparison between the p-r and p-q-r theories in three phase four wire systems, " *IEEE Trans. Power Electronics*, vol. 24, No. 4, pp. 924-933,Apr. 2009.
3. A Moreno-Munoz," *Power Quality: Mitigation Technologies in a Distributed Environment"*. London, U. K.: Springer-Verlag, 2007.
4. H. Akagi, E. H. Watanabe, and M. Aredes," *Instantaneous Power Theory and Applications to Power Conditioning"*, Hoboken, NJ: Wiley, 2007.
5. H. Akagi, Y. Kanazawa, and A. Nabae, "Instantaneous reactive power compensator comprising switching devices without energy storage components," *IEEE Trans. Ind. Appl.* , vol. IA-20, no. 3, pp. 625-630,Mar. 1984.
6. J.Zeng,Chang.Yu et al,"A Novel Hysteresis Current Control for Active Power Filter with Constant Frequency",*Electrical Power Systems Reasearch* 68,pp.75-82, 2004
7. IEEE Recommended Practices and Requirements /or Harmonic Control in Electrical Power Systems, *IEEE Standard 519*, 1992.