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Modeling and Simulation of SRF and P-Q based Control DSTATCOM

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Abstract**—***With the widespread use of harmonic generating devices, the control of harmonic currents to maintain a high level of power quality is becoming increasingly important. An effective way for harmonic suppression is the harmonic compensation by using active power filter. This paper presents a comprehensive survey of DSTATCOM control strategies put forward recently. It is aimed at providing a broad perspective on the status of DSTATCOM control methods to researchers and application engineers dealing with harmonic suppression issues. Many control techniques have been designed, developed, and realized for active filters in recent years. This paper presents different types of Synchronous reference frame methods for real time generation of compensating current for harmonic mitigation and reactive power compensation. All the techniques are analyzed mathematically and simulation results are obtained which are being compared in terms of its compensation performance with different parameters under steady state condition. The three techniques analyzed are the Synchronous Reference Frame Theory (SRF), SRF theory without synchronizing circuit like phase lock loop (PLL) also called instantaneous current component theory and finally modified SRF theory. Simulation results are obtained under sinusoidal balanced voltage source balanced load condition. The comparison and effectiveness of all the methods is based on the theoretical analysis and simulation results obtained with MATLAB employing a three phase three wire DSTATCOM test system.*

Keywords**—** *D-STATCOM, Voltage Sags, Voltage Source Converter (VSC).*

I. INTRODUCTION

One of the most common power quality problems today is voltage dips. A voltage dip is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with a duration from half a cycle to 1 min. In a three-phase system a voltage dip is by nature a three-phase phenomenon, which affects both the phase-to-ground and phase-to-phase voltages. A voltage dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged [1, 2].

Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in some cases for the utility. Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated. There are different ways to mitigate voltage dips, swell and interruptions in transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications [3, 4]. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle.

STATCOM is often used in transmission system. When it is used in distribution system, it is called D-STATCOM（STATCOM in Distribution system). D-STATCOM is a key FACTS controller and it utilizes power electronics to solve many power quality problems commonly faced by distribution systems. Potential applications of D-STATCOM include power factor correction, voltage regulation, load balancing and harmonic reduction. Comparing with the SVC, the D-STATCOM has quicker response time and compact structure. It is expected that the D-STATCOM will replace the roles of SVC in nearly future D-STATCOM and STATCOM are different in both structure and function, while the choice of control strategy is related to the main-circuit structure and main function of compensators [3], so D-STATCOM and STATCOM adopt different control strategy. At present, the use of STATCOM is wide and its strategy is mature, while the introduction of D-STATCOM is seldom reported. Refer to the strategies for STATCOM, in this paper, a compound control strategy used in D-STATCOM is presented to achieve the purpose of rapid-response compensation. A PWM-based control scheme has been implemented to control the electronic valves in the two-level VSC used in the D-STATCOM [5, 6].

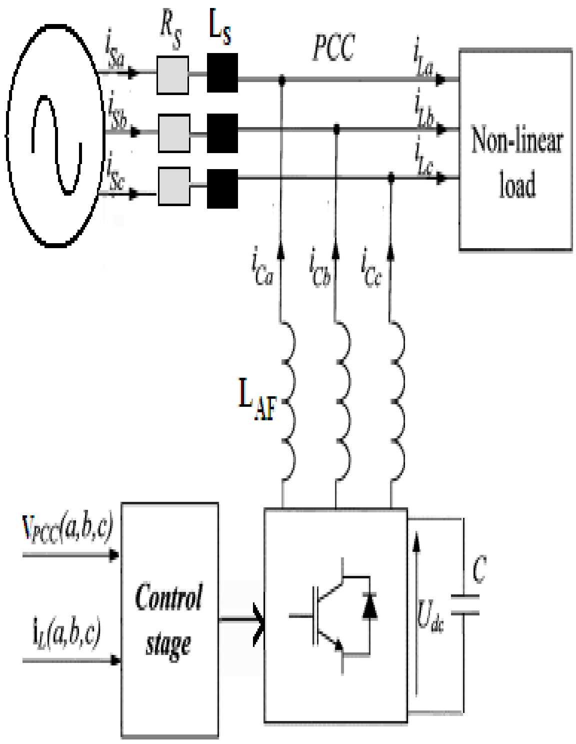

Figure. 1 Basic principal of shunt current compensation DSTATCOM

II. DESIGN OF DSTATCOM

A. Principle of DSTATCOM

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure-1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The 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 DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

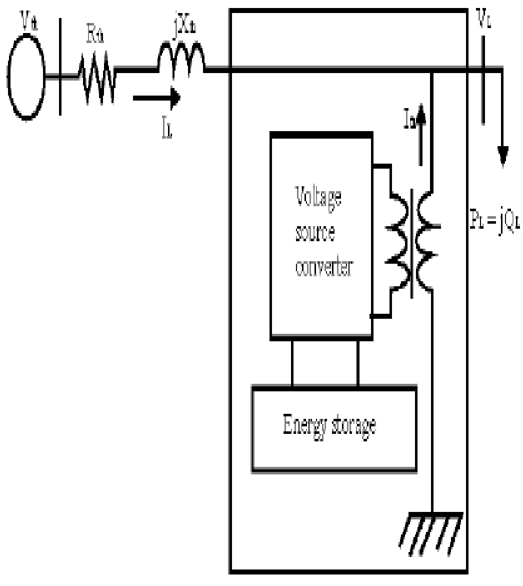

Figure – 1 Schematic Diagram of a DSTATCOM

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. As shown in Figure-1 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter. The shunt injected current I_{sh} can be written as,

$I_{sh} = I_L - I_S = I_L - (V_{th} - V_L) / Z_{th}$ (1)

$I_{sh} /\_\eta = I_L /\_- \theta$ (2)

The complex power injection of the D-STATCOM can be expressed as,

$S_{sh} = V_L I_{sh}^*$ (3)

It may be mentioned that the effectiveness of the DSTATCOM in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with V_L, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system.

III. SRF METHODS

Among the several methods presented in the literature, the Synchronous Reference Frame method (SRF) is one of the most common and probably it is widely used method. This section is organized as to describe succinctly the SRF methods. The three methods presented in this section with some results obtained with the above mentioned methods. The nonlinear load considered is a three-phase diode bridge rectifier.

A Synchronous Reference Theory (SRF)

In the SRF [5], the load current signals are transformed into the conventional rotating frame d-q. If theta is the transformation angle, the transformation is defined by:

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ -\sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{4\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

Fig.2 shows the basic configuration of synchronous reference frame. In the SRF is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltages. In the SRF is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltages. To implement the SRF method some kind of synchronizing system should be used. In [6] phase-locked loop (PLL) is used for the implementation of this method. In this case the speed of the reference frame is practically constant, that is, the method behaves as if the reference frame's moment of inertia is infinite. The fundamental currents of the d-q components are now dc values. The harmonics appear like ripple. Harmonic isolation of the d-q transformed signal is achieved by removing the dc offset. This is accomplished using high pass filters (HPF). In spite of a high pass filter, a low pass filter is used to obtain the reference source current in d-q coordinates.

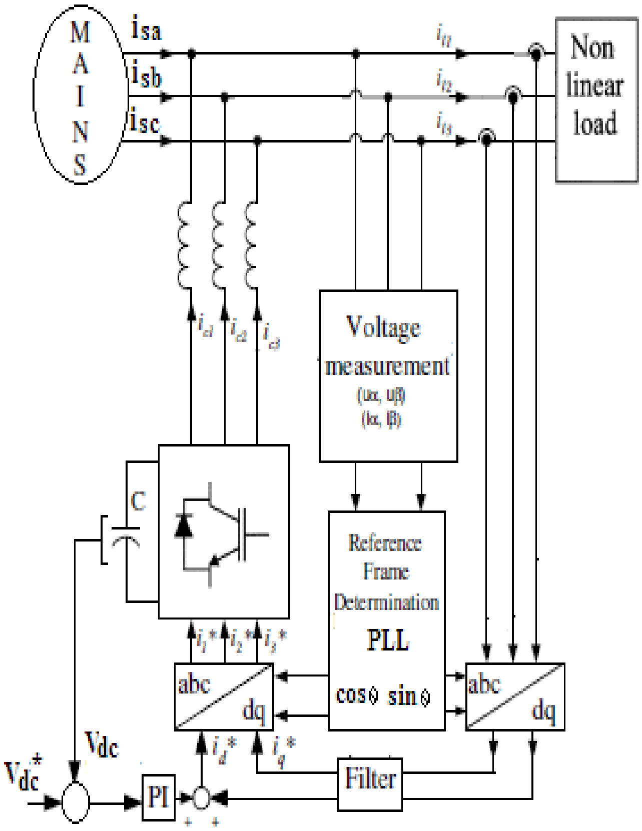

Figure. 2 Basic principal of SRF

B. Instantaneous Current Component (id-iq) Theory

The Modified Synchronous Frame method is presented in [7]. It is called the instantaneous current component (id-iq) method. This is similar to the SRF frame method. The transformation angle is now obtained with the voltages of the ac network. The major difference is that, due to voltage harmonics and imbalance, the speed of the reference frame is no longer constant. It varies instantaneously depending of the waveform of the three phase voltage system. In this method the compensating currents are obtained from the instantaneous active and reactive current components and of the nonlinear load. In the same way, the mains voltages V(a,b,c) and the polluted currents il(a,b,c) in α-β components must be calculated as given by (2), where C is Clarke Transformation Matrix. However, the load current components are derived from a synchronous reference frame based on the Park transformation, where represents the instantaneous voltage vector angle (3).

$$\begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} = [C] \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix}$$

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix} ,\theta = \tan^{-1}\frac{v_\beta}{v_\alpha}$$

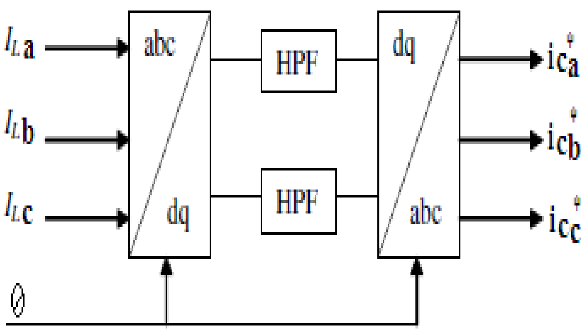

Figure.3 Principal of the synchronous reference frame method

Fig. 3 shows the block diagram SRF method. Under balanced and sinusoidal mains voltage conditions angle θ is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and unbalance; therefore dθ/dt may not be constant over a mains period. With transformation (2) and (3) the direct voltage component is

$$\begin{bmatrix} il_d \\ il_q \end{bmatrix} = \frac{1}{\sqrt{V_\alpha{}^2+V_\beta{}^2}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} il_\alpha \\ il_\beta \end{bmatrix}$$

$$\begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} = \frac{1}{\sqrt{V_\alpha{}^2+V_\beta{}^2}} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} ic_d \\ ic_q \end{bmatrix}$$

$$\begin{bmatrix} I_{comp,a} \\ I_{comp,b} \\ I_{comp,c} \end{bmatrix} = [C]^T \begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix}$$

IV. MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Fig. 5 shows the Matlab/Simulink model of Shunt active power filter. Here simulation is carried out for four cases. In case one APF is simulated using Synchronous Reference Theory (SRF), in case two APF is simulated using Instantaneous Current Component (id-iq) Theory, in case three APF is simulated using Modified (id-iq) Theory and case four APF is simulated in BLDC drive application.

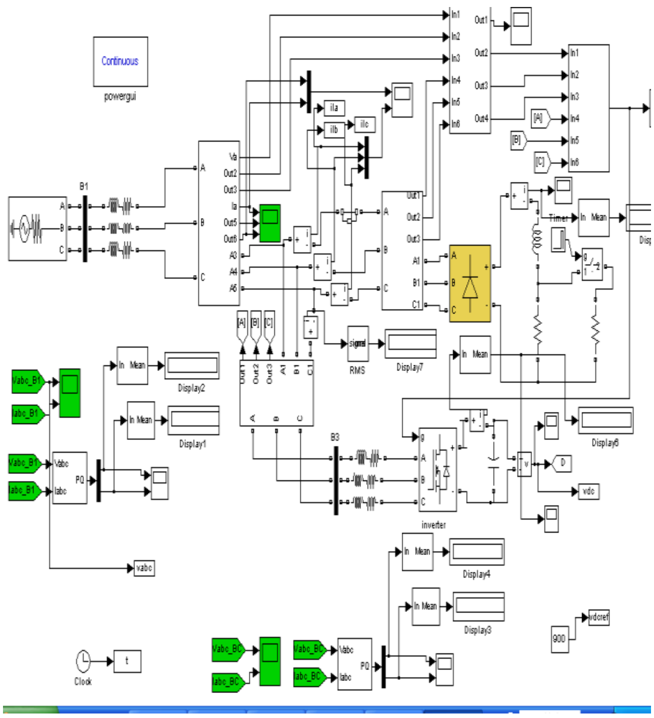

Figure.5 Matlab/Simulink Model of Shunt Active Power Filter

A Case one

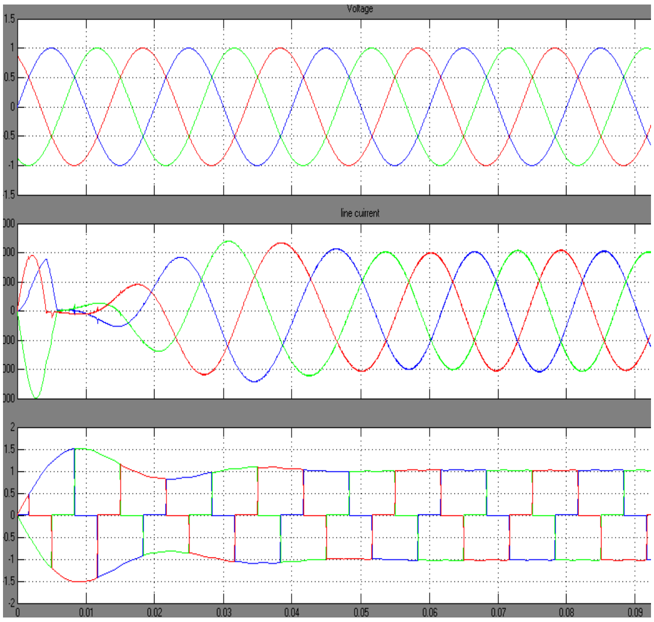

Figure. 6 Simulation results for Synchronous Reference Theory (SRF)

Fig.6 shows the simulation results for SRF theory. It shows three phase source voltage, three phase source currents and three phase non sinusoidal load currents.

B Case two

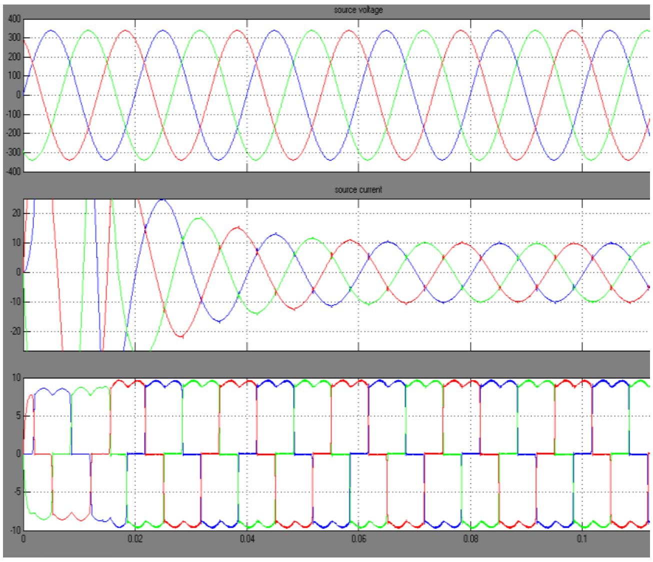

Figure. 7 Simulation results for Instantaneous Current Component (id-iq) Theory

Fig.7 shows the simulation results for Instantaneous Current Component (id-iq) Theory theory. It shows three phase source voltage, three phase source currents and three phase non sinusoidal load currents.

V. CONCLUSION

This paper presents the compensation performance of all the different SRF techniques under sinusoidal voltage source condition as shown in table-1. Results are similar with gained source THD under IEEE 519, but under various filter type the chebyshev type filter is having superior performance compare to Butterworth filter for all methods. The Synchronous Reference Frame method is one of the most common and performing methods for detection of harmonics in active filters. An Improved Synchronous Reference Frame Method for the control of active power filters was presented. It is called Filtered Modified Reference Frame Method (FMRF) and is based on the same principle as the Synchronous Reference Frame method. However, this new method explores the fact that the performance of the active filter to isolate harmonics depends on the speed of the system that determines the rotating reference frame, but doesn't depend on its position. So, the delay introduced by the ac voltage filters, used for the detection of the reference frame, has no influence on the detection capability of the method. Compared with other methods, this new method presents some advantages due to its simplicity. Finally a BLDC drive application is considered for simulation purpose. THD plots without APF and with APF are presented

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