COMPREHENSIVE REVIEW OF INVESTIGATIONS ON POWER QUALITY IMPROVEMENT IN DISTRIBUTION NETWORK USING DSTATCOM

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Abstract: A large number of single-phase linear and non-linear loads may be supplied from three phase ac mains with neutral conductor. They cause excessive neutral current, harmonics and reactive power burden and unbalance. A four wire DSTATCOM (distribution static compensator) is used for neutral current compensation along with reactive power compensation, harmonics elimination and load balancing. A novel control approach is proposed for the control of four wires DSTATCOM under non-ideal supply voltage conditions. A four-leg voltage–source converter (VSC) with a dc capacitor is used as a four wire DSTATCOM. The proposed control approach is based on synchronous reference frame (SRF) theory and an indirect current control technique. The switching signals for the voltage–source converter (VSC) of the DSTATCOM are derived from the estimated reference supply currents. The load balancing, harmonics elimination and the neutral current compensation are demonstrated along with unity power factor (UPF) and zero voltage regulation (ZVR) modes of operation. Simulation results based on MATLAB software with its Simulink and power system blockset (PSB) toolboxes are presented to validate the control strategy. The DSTATCOM is able to maintain the self-supported dc bus under various disturbances.

Keyword: DSTATCOM, harmonic, synchronous reference frame

I. INTRODUCTION

The distribution systems are facing severe power quality problems due to the proliferation of different types of linear and non-linear loads such as solid-state controllers, which draw harmonics and reactive currents from ac mains [1–3]. Similarly, the single-phase linear and non-linear loads in the three-phase four wire distribution systems may lead to unbalance and excessive neutral current resulting in low power factor and increased loss [3]. Moreover, it may lead to poor power quality at AC source such as swell, swell, notch, flicker, unbalance, etc. Because of such severity of power quality problems, several standards have been developed and are being enforced on consumers and utilities [4]. The remedial options reported for these problems include distribution static compensators (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) and are called under the generic name of custom power devices [2]. Power quality has become a very important issue recently due to the impact on electricity suppliers, equipment manufacturers and customers. Power quality is described as the variation of voltage, current and frequency in a power system. It refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location in the power system. Nowadays, there are so many industries using high technology for manufacturing and process unit. This technology requires high quality and high reliability of power supply. The industries like semiconductor, computer and the equipments of manufacturing unit are very sensitive to the changes in the quality of power supply [10]. This power quality is essential for proper operation of industrial processes which involves a good protection to the system for being well and progressive for long uswelle. Power quality problems such as voltage swell, swell, harmonic distortion, unbalance, transient and flicker may have impact on customer devices which will cause malfunctions and loss of production. The last decade has seen a marked increase on the deployment of end-user equipment that is highly sensitive to poor quality controlled electricity supply. Several large industrial users are reported to have experienced large financial losses as a result of even minor lapse in the quality of electricity supply. Efforts have been made to remedy the situation, where solutions based on the use of the latest power electronic technologies prominently. Indeed, custom power technology, the low- voltage counterpart of the more widely known flexible ac transmission system (FACTS) technology, aimed at high-voltage power transmission applications, has emerged as a credible solution to solve many problems relating to continuity of supply at the end-user level. Both the FACTS and custom power concepts may be directly credited to EPRI (Electric Power Research Institute).

II. ISSUE OF POWER QUALITY OF VOLTAGE SWELL

Voltage swell is defined as a sudden drop in the root mean square (R.M.S) voltage and is usually characterized by the remaining (retained) voltage. Voltage swell is thus, short duration reduction in RMS voltage, caused mainly by short circuits, overloads and starting of large motors. In the IEEE standard 1159-1995, the term "swell" is defined as decrease in RMS voltage or current to values to between0.1 to 0.9 per unit for duration of 0.5 cycles to one minute. Voltage swell is an important power quality problem as compared to harmonics, flicker, EMI, noise etc. Loads can suffer detrimental effect from voltage swell resulting in economic loss. The most severe swell is caused by faults in the power system at transmission and distribution level. The characteristic of swell will depend on type and location of fault in the system. Voltage swells are the most common power disturbance whose effect is quite severe especially in industrial and large commercial customers such as the damage of the sensitivity equipments and loss of daily productions and finances. The examples of the sensitive equipments are Programmable Logic Controller (PLC), Adjustable Speed Drive (ASD) and Chiller control. Voltage swell at the equipment terminal can be due to a short circuit fault hundreds of kilo meters away in the transmission system. Most of the current interest in voltage swell is directed to voltage swell due to short circuit faults. These voltage swells are the ones which causes majority of equipment tripping [5].

A. Voltage Swell:
Voltage Swell is defined by IEEE 1159 as the increase in the RMS voltage level to 110% - 180% of nominal, at the power frequency for durations of ½ cycles to one (1) minute. It is classified as a short duration voltage variation phenomena, which is one of the general categories of power quality problems [16].

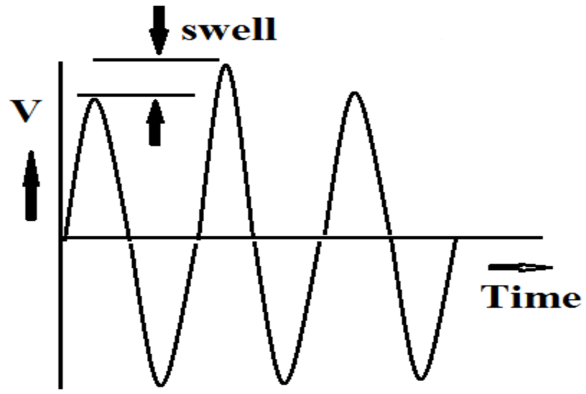

Fig.1 Voltage Swell

B. Categories of voltage swell:
Voltage swells are characterized by their RMS magnitude and duration. The gravity of the PQ problem during a fault condition is a function of the system impedance (i.e. relation of the zero-sequence impedance to the positive-sequence impedance of the system), location of the fault and the circuit grounding configuration. As an example, on an ungrounded system, the line-to-ground voltages on the unfaulted phases can go as high as 1.73 p.u. during a Single L-G fault. On the contrary, on a grounded system close to the substation, there will be no voltage rise on the unfaulted phases because the substation transformer is usually connected delta-wye, providing a low impedance zero-sequence path for the fault current [16].

C. Terminology Used:
The term "momentary overvoltage" is used as a synonym for the term swell. According to IEEE 1159-1995, voltage swell magnitude is to be described by its remaining voltage, in this case, always greater than 1.0 p.u. For example, “a swell to 150%” means that the line voltage is amplified to 150% of the normal value.

III. DSTATCOM AND METHODOLOGY

Distribution Static Compensator (D-STATCOM) also known as shunt voltage controller consists of a two level voltage source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network and associated control circuit [13] as shown in the fig below. 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 allow effective control of active and reactive power exchanges between the D-STATCOM and ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

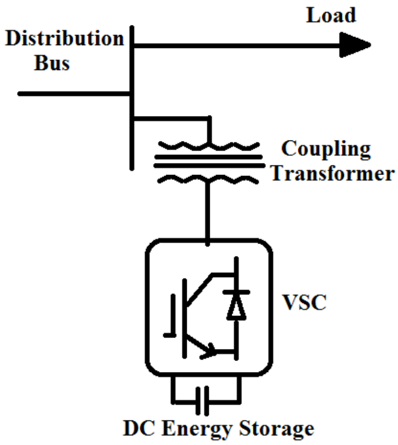

Fig.2 Basic Structure of D-STATCOM

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes.
a) Correction of power factor.
b) Voltage regulation and compensation of reactive power.
c) Elimination of current harmonics.

The DC voltage across the storage device will be converted by VSC into a set of three phase AC output voltages. Several adjustments have to be made to the phase and magnitude of the D-STATCOM output voltage in order for the active and reactive power exchanges between the AC system and the device controlled effectively.

Basic Configuration and Operation of D-STATCOM:
Active Power filters are basically classified in to three types: Single phase, three phase three wire and three phase four wire systems to meet the requirements of the nonlinear loads in the distribution systems. Single-phase loads, such as domestic lights, TVs, air conditioners, and laser printers

behave as nonlinear loads and cause harmonics in the power system. Active power filters can classify based on the type of converter, topology, control scheme, and compensation characteristics. The most popular classification is based on topology such as series and shunt. The different active filter topologies are shown in figure.

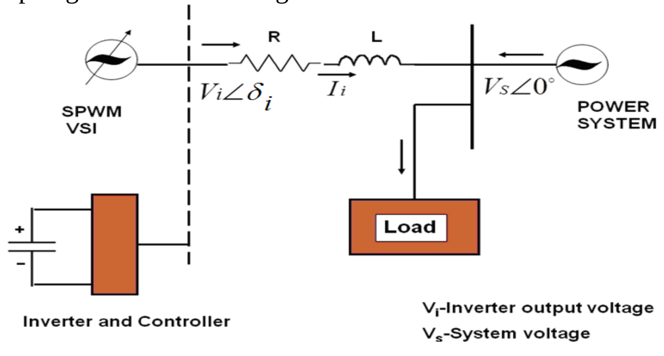

Fig.3 Basic building blocks of D-STATCOM [10]

It consists of a dc capacitor, three phase inverter usually a GTO or an IGBT, ac filter (coupling transformer) and a control strategy. The basic electronic block of the D-STATCOM is the voltage sourced inverter that converts input dc voltage into a three phase output voltage at fundamental frequency. The D-STATCOM employs an inverter to convert the dc link voltage Vdc on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage controlled source. The D-STATCOM can also be seen as a current controlled source. Fig. 4.2 above shows the inductance L and resistance R which represents the equivalent circuit elements of the step down transformer and the inverter are the main components of D-STATCOM. The reactive power output of D-STATCOM can be either inductive or capacitive depending on the operation mode of D-STATCOM. Referring to the Fig. 4.2 above the controller of D-STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the D-STATCOM generates or absorb the desired VAR at the point of connection. The phase of the output voltage of the thyristor based inverter Vi is controlled in the same way as the distribution system voltage Vs. Here, as we can see from the figure 4.3 below, the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Xth.

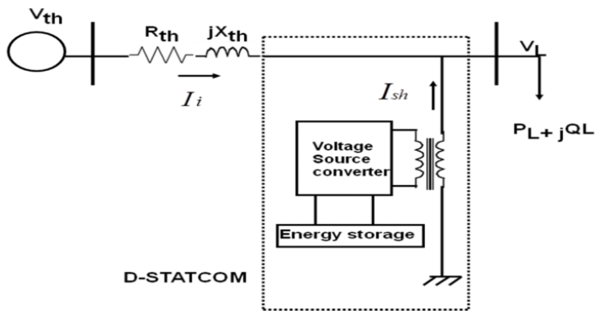

Fig.4 Basic circuit diagram of D-STATCOM [9]

The value of the shunt current Ish can be controlled by adjusting the output voltage of the converter. The shunt injected current Ish can be written as:

$$I_{SH} = I_L - I_i$$

Here, the effectiveness of the D-STATCOM in correcting voltage sag depends upon the value of Zth or fault level of the load bus. When the shunt injected current Ish is kept in quadrature with VL, the desired voltage correction is achieved without injecting any active power into the system. On the other hand when the value of Ish is minimized the same voltage correction can be achieved with minimum apparent power into the system.

IV. CONTROL OF THREE-PHASE FOUR WIRES DSTATCOM

The control of DSTATCOM has two parts:

(a) Derivation of reference signals using the required feedback signals.

(b) Generation of the gate signals using PWM current controller by comparing the sensed and reference signals. In this case, the proposed control technique for deriving the reference supply current is based on the synchronous reference frame (SRF) theory. The sensed load current is converted to rotating reference frame using 'sine and cosine' signals, with unity magnitude, generated by a PLL in-phase with the load voltage. Hence the influence of the disturbance of the electrical network is eliminated in the voltage waveform.

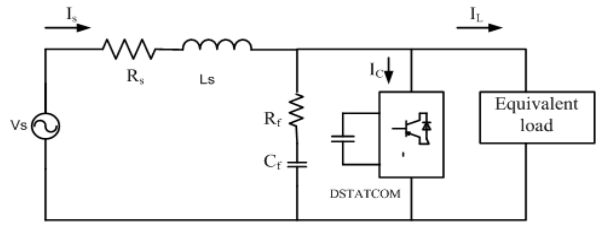

Fig.5 Single line diagram of DSTATCOM [1]

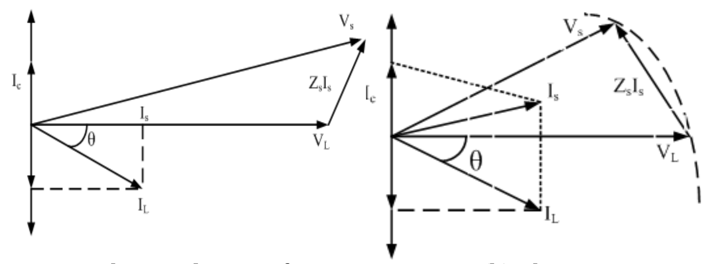

Fig.6 Phasors diagram for UPF operation (b) Phasors diagram for ZVR operation [1]

A set of voltages and currents can be transformed into α–β–0 axis using the following transformation.

$$\begin{bmatrix} v0 \\ v\alpha \\ v\beta \end{bmatrix} = C = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} v0 \\ v\alpha \\ v\beta \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = C = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} \quad (2)$$

The reference d–q (d-direct axis, q-quadrature axis) frame is determined by the angle θ with respect to the α–β frame and the angle is obtained using a PLL. The transformation from α–β–0 frame to d–q–0 frame is given by

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix} \begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} \quad (3)$$

Each current component has an average value or dc component and an oscillating value or ac component as:

$$i_d = i_{ddc} + i_{dac} \quad (4)$$

$$i_q = i_{qdc} + i_{qac} \quad (5)$$

The compensating strategy for reactive power compensation for UPF operation considers that the source must deliver the mean value of the direct-axis component of the load current along with the active power component current for maintaining the dc bus and meeting the losses (iloss) in DSTATCOM. The output of PI (proportional– integral) controller at the dc bus voltage of DSTATCOM is considered as the current (iloss) for meeting its losses.

$$i_{loss} = i_{loss(n-1)} + K_{pd}(v_{de} - v_{de(n-1)}) + K_{id}v_{de(n)} \quad (6)$$

Kid are the proportional and the integral gains of the dc bus voltage PI controller. The reference source current is therefore as,

$$i_d^* = i_{ddc} + i_{loss} \quad (7)$$

The reference source current must be in-phase with the voltage at the PCC but with no zero-sequence component. It is therefore obtained by the following reverse transformation.

$$\begin{bmatrix} is0 \\ is\alpha \\ is\beta \end{bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix} \begin{bmatrix} 0 \\ id \\ 0 \end{bmatrix} \quad (8)$$

The reference source current in the a–b–c frame is obtained by reverse transformation of the above current vector:

$$\begin{bmatrix} isa \\ isb \\ isc \end{bmatrix} = C = \sqrt{\frac{2}{3}} \begin{pmatrix} 0 & 1 & 0 \\ 0 & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ 0 & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} is0 \\ is\alpha \\ is\beta \end{bmatrix} \quad (9)$$

ZVR operation

The compensating strategy for ZVR operation considers that the source must deliver the same direct-axis component, id as mentioned in Eq. (7) along with the sum of quadrature axis current (iqdc) and the component obtained from the PI controller (iqr) used for regulating the voltage at PCC using the PI controller. The output of PI controller is considered as the reactive component of current (iqr) for zero voltage regulation of ac voltage at PCC. The amplitude of ac terminal voltage (vt) at PCC is calculated from the ac voltages (vsa, vsb, vsc) as,

$$v_{Lt} = (2/3)^{1/2}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)^{1/2} \quad (11)$$

$$i_{qr(n)} = i_{qr(n-1)} + K_{pq}(v_{te(n)} - v_{te(n-1)}) + K_{iq}v_{te(n)} \quad (12)$$

The reference supply quadrature axis current will therefore be

$$i_q^* = i_{qdc} + i_{qr} \quad (13)$$

The reference source current will not be in-phase with the voltage at the PCC but with no zero-sequence component. It is therefore obtained by the following reverse transformation.

$$\begin{bmatrix} is0 \\ is\alpha \\ is\beta \end{bmatrix} = C = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix} \begin{bmatrix} 0 \\ id \\ iq \end{bmatrix} \quad (14)$$

The reference source current in the a–b–c frame is obtained from Eq. (9).

$$i^*_{sn} = 0 \quad (15)$$

$$i_{sn} = -(i_{sa} + i_{sb} + i_{sc}) \quad (16)$$

Neutral current reference signal:

The reference supply neutral current should be zero for compensating the neutral current of the load.

Current-controlled PWM for generating gating pulses:

In a current controller, the sensed and reference supply currents are compared and a proportional controller is used for amplifying current error in each phase before comparing with a triangular carrier signal to generate the gating signals for six switches.

V. MODELLING OF DSTATCOM

A block diagram of the control scheme equipped with the function of voltage regulation is shown in Fig. 4.6. Two PI controllers are used for the purpose of control of dc bus voltage of DSTATCOM and ac voltage at PCC. The compensation current should lead or lag by 90_ from the voltage. The DSTATCOM draws a lagging current to reduce the line-voltage amplitude, when the load injects capacitive reactive power. In other words, the DSTATCOM acts as an inductor. The compensating current produces a voltage drop and then, the line-voltage amplitude is kept at its reference value. In the case, when the load is an inductive, the DSTATCOM operates as a capacitor. Along with reactive current control, the control of DSTATCOM consists of the following control functions: harmonic elimination, load balancing and neutral current compensation.

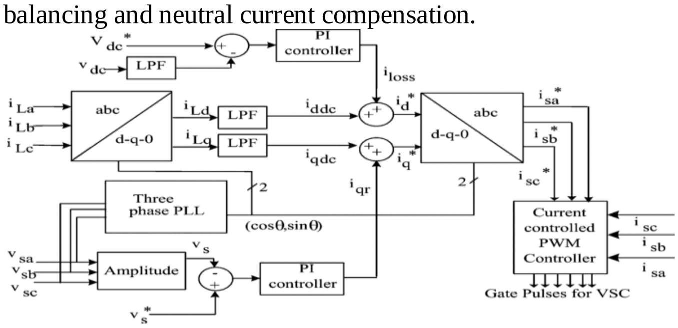

Fig. 7 Control algorithm for the operation of DSTATCOM

VI. CONCLUSION

In this paper single-phase non-linear loads may be supplied from three phase ac mains with neutral conductor. Using of the non-linear loads cause excessive neutral current, harmonics and reactive power is disturbed and unbalance. To mitigate this problem, four wires DSTATCOM (distribution static compensator) is used for neutral current compensation along with reactive power compensation, harmonics elimination and load balancing. In this work, the investigation on the role of DSTATCOM will carried out to improve the power quality in distribution networks with linear and nonlinear loads. Harmonic current compensation, Load balancing, Reactive current compensation for unity power factor (UPF) under linear, unbalanced as well as non – linear load situations.

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