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A Review on Architecture, Topologies and Control Techniques of DSTACOM

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Abstract - *This paper presents a comprehensive review of the distribution static compensator employed for harmonic filtering, power factor correction, neutral current compensation, and load balancing in the distribution network. The intention of this review is to provide a wide spectrum on architecture, topologies, and control techniques to the researchers, designer, and engineers working on power quality improvement. Many research publications on the topologies, configuration, control techniques, and applications of distribution static compensator have been thoroughly reviewed and classified for quick reference.*

Key Words: DSTACOM, Control techniques, topologies, VSC, power quality.

1. INTRODUCTION

Power quality problems related to both current and voltage such as poor voltage regulation, high harmonics current burden, load balancing, poor power factor(PF), excessive neutral current, voltage flicker, sag and swell originate in distribution networks [1]. Increasing penetration of renewable energy (RE) sources has further affected the quality of power supplied [2]. Different power quality(PQ) detection and classification techniques have been reported in [3]. Power electronic converters such as distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR), and unified power Quality conditioner (UPQC) can eliminate harmonics and unbalancing on both the source and load side of the system [4,5].

DSTATCOM is a synchronous voltage generator capable of supplying rapid and uninterrupted capacitive and inductive reactive powers [6,7]. Many DSTATCOM topologies related to three-phase three-wire (3P3W) and three-phase four-wire(3P4W), isolated and non isolated, And with and without transformers are reported in the literature. DSTATCOM in current control mode injects harmonic and reactive components of load current addressing power quality [8]. In voltage control mode, it regulates load voltage at a constant value protecting loads from voltage disturbances [9,10]. The performance of DSTATCOM depends on the control algorithm used for extraction of Reference current components [11] such as instantaneous reactive Power (IRP) theory, symmetrical component (SC) theory, synchronous Reference frame(SRF) theory, average unit power factor(AUPF) theory, sliding mode control and based neural network. [12,13]. The optimal location and sizing of the DSTATCOM which plays an important role in PQ improvement has been employed using fire fly algorithm [14] and particle swarm optimization technique [15].

This paper aims at presenting a comprehensive review on the configuration, topologies and control techniques of DSTATCOM. A lot of research publications are critically reviewed and classified broadly in to four categories. The first category is based on general concepts of power quality and DSTATCOM. The second category [16] comprises of DSTATCOM configuration, principle of operation and its potential applications. The third category is on the DSTATCOM topologies which is further sub-classified into 3P3W [43–54] and 3P4W. The fourth category is on DSTATCOM control techniques which are sub-classified in to IRP theor, SRF theory, SC theory , AUPF theory, PI controller , adaline based neural network, sliding mode controller, and miscellaneous control techniques. However, some publications include more than one category and have been classified based on their dominant field and some publications are included in more than one category depending on their utility.

This paper is divided into seven sections. Section 2 covers principle of operation, major components and applications of DSTATCOM. The DSTATCOM topologies are covered under Section3. Section 4 describes control techniques. Section 5 relates to the application specific selection criteria of DSTATCOM. The proposed future work for DSTATCOM is presented in Section 6. The conclusions are drawn in Section7.

2. DISTRIBUTION STATIC COMPENSATOR

A static synchronous compensator (STATCOM) with a coupling transformer, an inverter, and energy storage device used in distribution system is called DSTATCOM and has configuration as the STATCOM [16].

2.1. Principle of operation

A typical DSTATCOM connected to the point of common coupling (PCC) in distribution system having unbalanced and no-linear loads is shown in Fig. 1.

The main function of DSTATCOM is to supply reactive power (as per requirement) to the system in order to regulate the voltage at the PCC. Active power can also be supplied if a storage battery or flywheel is available on dc-side of the DSTATCOM.

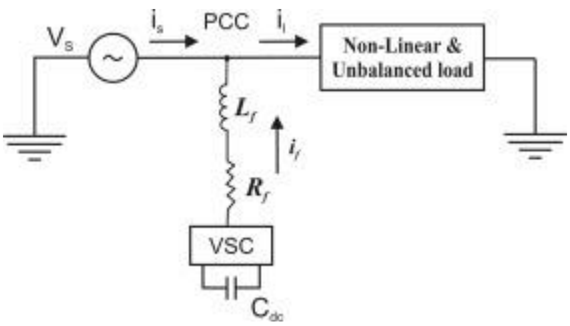

Fig. 1. Single-line diagram of the DSTATCOM.

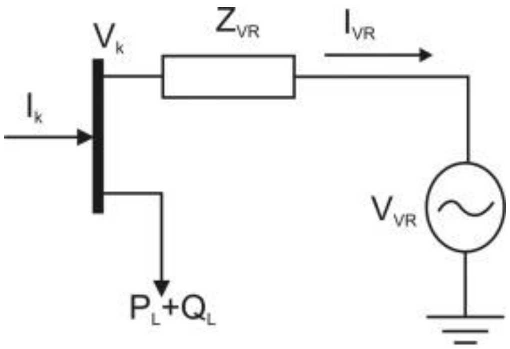

Fig. 2. Equivalent circuit of DSTATCOM

Equivalent circuit of the DSTATCOM as shown in Fig. 2 is represented by a controlled voltage source (VVR) in series with transformer impedance ZVR. The voltage VVR can be regulated to control voltage of the bus k. Fig. 3 represents phasor diagram related to the DSTATCOM operation under both lagging and leading power factor modes.

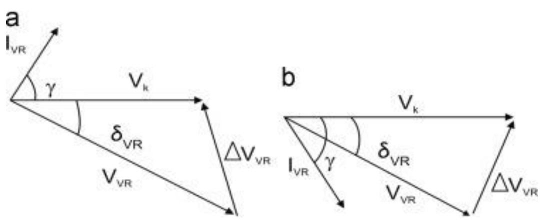

Fig.3. Phasor diagram: (a) lagging operation and (b) leading operation.

2.2. Major components of DSTATCOM

The various components of DSTATCOM include voltage source converter (VSC), dc bus capacitor, transformer and ripple filter as shown in Fig. 4. The VSC converts a dc voltage in to a three-phase ac voltage and synchronized with PCC through a tie reactor and capacitor. The transformer is used to match the inverter output to the line voltage. The important components are described in the following subsections.

2.2.1. Voltage source converter

The VSC allows bidirectional power flow and realized using devices such as insulated gate bipolar transistors (IGBT)and metal oxide field effect transistors (MOSFET). The switching of these devices is based on pulse-width modulation (PWM) technique. In addition to switching devices, VSC also has components like dc bus capacitor and interfacing inductor. The minimum dc bus voltage should be greater than twice the peak value of the phase voltage of the system. The value of dc capacitor depends on the instantaneous energy available to the DSTATCOM during transients. The dc bus capacitor may also be used with two split sections having equal or unequal values. The dc capacitor C_{dc} and dc bus voltage V_{dc} are calculated as

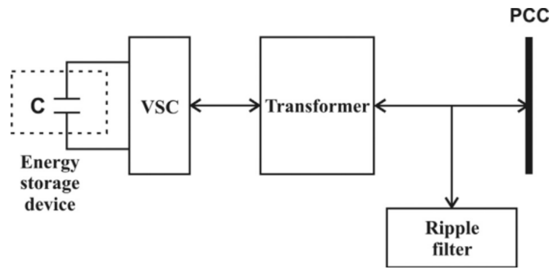

Fig. 4. Block diagram of the DSTATCOM.

$$V_{dc} = 2\sqrt{2}V_{LL} / \sqrt{3}m \quad (1)$$

$$C_{dc} = \frac{6aVIt}{V_{dc}^2 - V_{dc1}^2} \quad (2)$$

Where m is the modulation index; V_{LL} is the ac line voltage; a is the overloading factor; V is the phase voltage; I is the phase current; V_{dc1} is the phase voltage; t is the time by which the dc bus voltage is to be recovered.

2.2.2. Ripple filter

A first-order high-pass filter tuned at half the switching frequency is used to filter the high-frequency noise from the voltage at the PCC. It consists of a series resistance R_f in series with the capacitor C_f. The time constant of the filter should be very small compared to the fundamental time period (T).

$$R_f C_F < T/10 \quad (3)$$

2.2.3. AC inductor

For reducing ripple in compensating currents, the tuned values of interfacing inductors are connected at the ac output of VSC. The ac inductance L_f of VSC depends on the current ripple, switching frequency f_s, and dc bus voltage V_{dc} and its value is given as

$$L_f = \frac{\sqrt{3}mV_{dc}}{12af_{s\sigma,\rho-\rho}} \quad (4)$$

Where m is the modulation index and a is the overloading factor.

3. TOPOLOGIES OF DSTATCOM

The DSTATCOM topologies can be classified based on the application in 3P3W and 3P4W distribution systems. Further topological classification can be based on the use of transformer for isolation and neutral current compensation, number of switching devices, type of converter, etc. The classification of DSTATCOM topologies is shown in Fig. 5. In

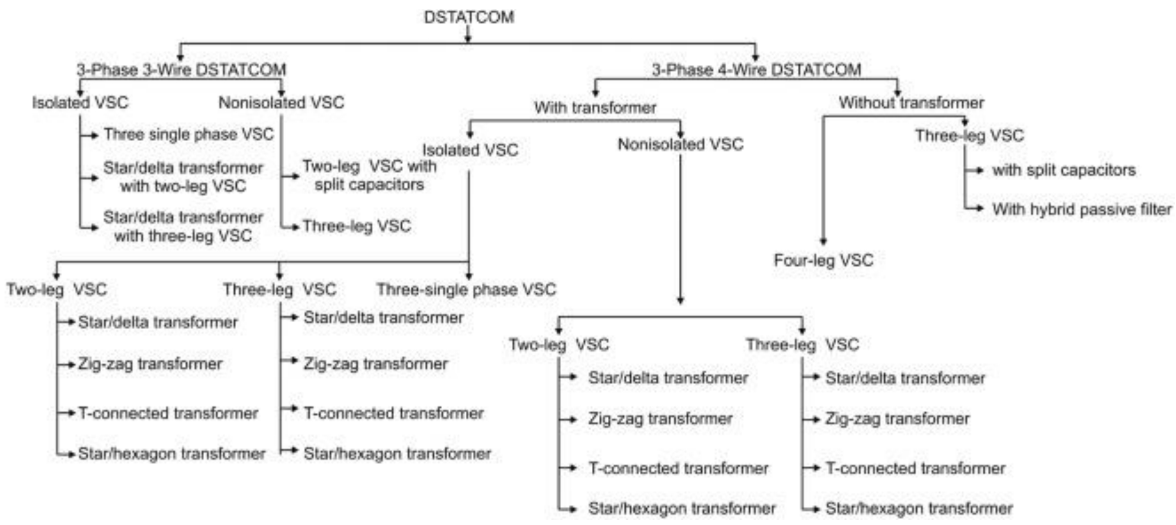

Fig.5. Topological classification of DSTATCOM.

topological diagrams the unbalanced/non-linear loads as well as supply source are not shown, only the converter topologies and transformer configurations are included for the sake of clarity.

3.1. Three-phase three-wire DSTATCOM

Three-phase three-wire DSTATCOMs are used for reactive Power compensation, harmonic elimination, PQ improvement and load balancing in 3P3W distribution system. The topologies for three-phase three-wire DSTATCOMs include isolated VSC and non-isolated VSC-based DSTATCOM.

3.1.1. Isolated VSC-based DSTATCOM

The VSC is isolated from supply system through a transformer. Isolated VSC-based three-phase three-wire DSTATCOM topology reported in [17] contains a bank of three single-phase VSC units connected to a common dc storage capacitor.

Each VSC unit is connected to the system supply through an isolating transformer which provides isolation between the converters. Transformer also prevents the dc capacitor storage being shorted through controlled switches in different converters. Controlled switch is a power semiconductor device and anti-parallel diode combination. Three-leg VSC and two-leg VSC-based isolated topologies of 3P3W DSTATCOM using star/delta transformer and transformer topology such as T-connected, zig-zag, and star/hexagon may also be used.

3.1.2. Non isolated VSC-based DSTATCOM

VSC is connected to the supply system through inductive reactor. This topology is classified into three-leg VSC or two-leg VSC with split capacitor. Three-leg VSC-based topology has three legs in the bridge each comprising of two IGBTs. The mid-point of each half bridge is connected at the point of common coupling(PCC)through an interface inductor. Three-phase loads are connected at the PCC. A three-phase star connected RC filter is used at PCC to absorb voltage switching ripple. The use of three leg DSTATCOM for reactive power, harmonics and unbalanced load current compensation of a diesel generator set for an isolated system. A nonlinear controller design for a three leg DSTATCOM connected to distribution system with distributed generation(DG) to regulate the voltage by reactive power compensation. The self supporting voltage of dc bus is used for mitigation of current harmonics and load balancing. Implementation of three leg VSC based DSTATCOM using self tuning filter (STF) based IRP control algorithm for PQ improvement.

4. CONTROL TECHNIQUES OF DSTATCOM

The reactive power needed by the load is provided by the DSTATCOM and only real power is supplied by the source such that source current remains at unity PF. Load balancing is achieved by making reference source current balanced. It has real fundamental frequency component of the load current and used to decide switching of the VSC and being extracted by control techniques. Different control strategies reported in the literature such as IRP theory, SRF theory, adaline-based control algorithm, PI con- troller for maintaining dc bus voltage. Some important and widely used techniques are detailed below in the subsections as follows.

4.1. Instantaneous reactive power (IRP) theory

IRP theory is also known as p–q theory and proposed by Akagi [99]. In this method, sensed three-phase voltage and load currents are transformed in to two-phase quantities in α–β frame using clark's transformation. The instantaneous active and reactive power is calculated in this frame. The reference currents in α–β frame are converted to abc frame using reverse clark's transformation.

4.2. Synchronous reference frame (SRF)theory

Synchronous reference frame theory (SRF) control technique is based on transformation of currents in synchronously rotating d-q frame. Sensed voltage signals are processed by phase locked loop to generate sine and cosine signals. Sensed current signals are transformed to d-q frame and filtered. The filtered currents are back transformed to abc frame and fed to hysteresis current controller for switching pulse generation.

4.3. Symmetrical component theory

The control algorithm is based on prime objective to obtain the balanced source currents for which the positive sequence voltage and currents are considere. Therefore the reference source currents can be considered as:

$$i_{sa}+i_{sb}+i_{sc} = 0$$

The power generated from the source is constant and equal to the dc value of the load power. The average load power is computed by using filter. The reference currents as well as sensed currents and voltages are shown in the block diagram. The switching signals generated are used for control of VSC [111].

5. SELECTION CONSIDERATIONS FOR SPECIFIC APPLICATION OF DSTATCOM

The selection of a suitable DSTATCOM topology and control technique for its use in specific application is an important task for users. The performance of DSTATCOM depends on the control algorithm used for extraction of reference current components. Comparative The kilo volt ampere (kVA) rating of the transformer is a major consideration for selection of the transformer for specific application. The star/delta transformer is natural choice because it is simple in design and commonly available in market but has disadvantage of higher rating. Zig-zag transformer has the lowest rating followed by T-connected transformer and with highest rating for star/delta and star/hexagon transformers. The converter topological considerations such as3P3W,3P4W, isolated and non isolated, with and without transformer are critical.

6. FUTURE WORK

The DSTATCOM is very much effective for improvement of both voltage and current related PQ problems such as harmonic elimination, load balancing, voltage regulation, power factor correction and neutral current compensation in distribution system. However, the present day cost of DSTATCOM is on higher side which is main hurdle for its implementation in the system.

Therefore, it is highly desirable to carry out extensive research to reduce the cost of DSTATCOM without affecting the efficiency and effectiveness in PQ improvement capability. Renewable energy(RE)penetration in to the electric utility grid is increasing day by day and intermittent nature of these resources affects the quality of supplied power. The weather conditions such as wind speed variations and variable solar insolation affect the power output of REsources. The DSTATCOM may be an effective solution for these problems, hence possibilities of implementation of DSTATCO in RE based power system are required to be explored.

7. CONCLUSIONS

A comprehensive literature review of the DSTATCOM is carried out. This paper presents a detailed survey on the topic of DSTATCOM used for PQ improvement in distribution system. Topologies used in both 3P3Wand 3P4W distribution systems are analyzed critically and a comparative study of different types of topologies is presented. The control techniques such as IRP,SRF, PI controller are analyzed and their performance is presented. A comparative study of transformers used in the DSTATCOM topologies is also presented. Selection considerations of DSTATCOM topologies and control techniques for specific applications have also been outlined. Finally, at the end of paper future scope for research to enhance the performance and suitability of DSTATCOM for specific purpose is
presented. According to the developed review, it can be concluded that DSTATCOM is an effective tool for PQ improvement in distribution system.
It is hoped that this Review on DSTATCOM will be beneficial to the users, designers, manufacturers, researchers and power engineers for enhancing the quality of power.

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