A Review of Various Topologies and Control Schemes of DSTATCOM Implemented on Distribution Systems

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ABSTRACT
Nowadays the demand for receiving the high quality electrical energy is being increasing as consumer wants not only reliable but also quality power .The usage of automated equipment are increasing and far more susceptible to disturbances compare to the prior generation equipment and information systems. With the deregulation of the electric power energy market, the awareness concerning the quality of power has been increased day by day among diverse categories of customers. Power quality has become an important topic to electricity consumers at all levels of usage. Power quality can be improved in distributed system by using shunt compensation device known as Distribution Static Compensator (DSTATCOM). This paper covers the different topologies of Distribution Static Compensators (DSTATCOMs) and the various control methodologies, and its selection for specific applications.

KEYWORDS: Index Terms, Distribution Static Compensator (DSTATCOM), Power Quality, Custom Power.

1. INTRODUCTION

Power Quality (PQ) is a term which generally refers to sustaining nearby sinusoidal waveform of power dispensation bus voltages at allowed voltage and frequency. Power Quality (PQ) linked issues are of most concern nowadays. The power quality is badly disturbed because of the using nonlinear and dynamic loads and various faults in power system broadly. Besides, the controlling equipment and electronic devices based on computer technology insist higher levels of power quality. This type of devices are sensitive to small changes of power quality, a short time change on PQ can cause great economical losses. Because of these reasons, no matter for the power business, equipment manufacturers or for electric power customers, power quality problems had become an issue of increasing interest. Under the situation of the deregulation of power industry and competitive market, as the main character of goods, power quality will affect the price of power directly in near future.

The main power quality terminologies defined by IEEE Standard 1159-1995 [5], are as follows:

Voltage dip, Voltage sag, Under voltage, Voltage swell, Over voltage, Voltage 'spikes', 'impulses' or 'surges', Harmonics and Flickers.

Custom power devices play a major role to overcome the power quality related problems occurring in the transmission and distribution network system. Custom power devices is a strategy which is normally targeted to sensitive equipped customers, and is introduced recently and designed primarily to meet the requirements of industrial and commercial customer [12]. One of the main advantages of custom power devices is to ensure a greater reliability and a better quality of power flow to the load centers in the distribution system by successfully compensating for voltage sags, dips, surges, swell, harmonic distortions, interruptions and flicker, which are the frequent problems associated with distribution lines [13].

Custom power devices overcome the major power quality problems by the way of injecting active and/or reactive power(s) into the system. The concept of custom power devices is to use solid state power electronic components or static controllers in the medium voltage distribution system aiming to supply reliable and high-quality power to sensitive users.

Power electronic valves are the basis of those custom power devices such as converter-based devices, which can be divided into three groups [9]:

-Series controllers (an example is Static Compensator: STATCOM),

- Shunt controllers (an example is Dynamic Voltage Restorer: DVR), and
-Combined Series-Shunt controllers (an example is Unified Power Quality Conditioner UPQC).

Among Custom power devices, the shunt controllers have shown feasibility in term of cost-effectiveness in a wide range of problem-solving from transmission to distribution levels. In this regard, Static Synchronous Compensator (STATCOM) is an effective solution of power quality problems [10]. STATCOM systems are used in distribution and transmission systems for different purposes. The STATCOM installed in distribution systems or near the loads to improve power factor and voltage regulation is called D-STATCOM. D-STATCOMs have faster response when compared with transmission STATCOMs [11].

Much research confirms several advantages of D-STATCOM compared to other custom power devices. These advantages include [16]:
- Size, weight, and cost reduction.
- Equality of lagging and leading output.
- Precise and continuous reactive power control with fast response.
- Possible active harmonic filter capability.

Distribution Static Compensator (DSTATCOM) has the ability to overcome the problem of limited bandwidth, higher passive element count which causes increased size and losses, and slower response of Static Var Compensators (SVC) and it is done by precise control and fast response during transient and steady state, with lower foot print and weight. The DSTATCOM has emerged as a promising device to provide solution for voltage related issues and also serving a host of other current related power quality problem's solutions such as voltage regulation, load balancing, reactive power compensation, power factor correction & improvement and current harmonic control [2].

In this paper, various topologies and different control techniques of DSTATCOM is demonstrated for voltage regulation or power factor correction by reactive power compensation along with harmonics elimination and load balancing. The paper is organized as follows: Section II describes the structure of DSTATCOM. Section III and IV provides the classifications and control techniques of DSTATCOM respectively and Section V gives conclusion and future work.

2. DISTRIBUTION STATIC COMPENSATOR

This is a shunt connected device that has the same structure as that of a STATCOM and connected to the point of common coupling (PCC) in distribution system having unbalanced and nonlinear loads and is shown in Fig. 1. This can perform load compensation, i.e., power factor correction, harmonic filtering, load balancing etc. when connected at the load terminals. 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 fly wheel is available on dc-side of the DSTATCOM [2], [3]

The various component of DSTATCOM is voltage source converter, dc bus capacitor, transformer and ripple factor. The VSC converts a dc voltage into 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 [6], [7].

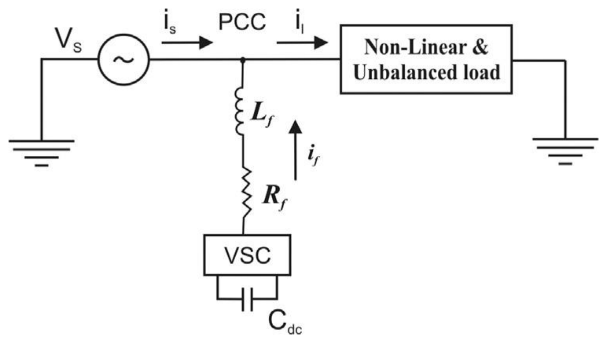


Fig. 1. The single line diagram of DSTATCOM

3. CLASSIFICATION OF DSTATCOM

The DSTATCOM can be classified on the bases of different topologies, number of switching devices and on the bases of neutral current compensation etc. These DSTATCOMs are developed to meet the requirements of different applications in distribution system. Two types of classification is discussed in this paper.

3.1. Converter Based Classification [15-18]

DSTATCOM utilizes either a voltage-source inverter (VSI) or a current-source inverter (CSI). Voltage source inverter use capacitive energy storage, while Current source inverter use inductive energy storage in their respective dc links for voltage and current [3]. However, the voltage source inverters are broadly used because of the less heat dissipated, smaller size, and the less cost of the capacitor compared to the inductor, used in the CSI, for the same power rating [4]. The VSI connected in shunt with the AC system provides multifunctional topology which can be used for different aims such as voltage regulation and compensation of reactive power, correction of power factor, and elimination of current harmonics [36]. Voltage source inverter (VSI) topology is popular because it can be expandable to multilevel, multistep & multichain topology to enhance the performance with lower switching frequency and increased power handling capacity. Various multilevel topologies are Diode clamp multilevel inverter, Cascaded H-bridge &

Flying capacitor multilevel inverter are as shown in Figs-2 a, 2b, 2c.

3.2.1. Diode-Clamped Multilevel Inverter:

The most commonly used multilevel topology is the diode clamped inverter, in this topology the diode is used as the clamping device to clamp the dc bus voltage so as to achieve steps in the output voltage [37]. Thus, the main concept of this inverter is to use diodes to limit the power devices voltage stress. The voltage over each capacitor and each switch is Vdc. An n level inverter needs (n-1) voltage sources, 2(n-1) switching devices and (n-1) (n-2) diodes. The quality of the output voltage can be improved and the voltage waveform becomes closer to sinusoidal waveform by increasing the number of voltage levels.

Fig. 2(a) shows a five-level diode-clamped converter in which the dc bus consists of four capacitors, C1, C2, C3, and C4. For dc-bus voltage Vdc, the voltage across each capacitor is Vdc/4 and each device voltage stress will be limited to one capacitor voltage level Vdc/4 through clamping diodes. The order of numbering of the switches for phase a is S1, S2, S3, S4, S1 ' , S2 ' , S3' and S4'.

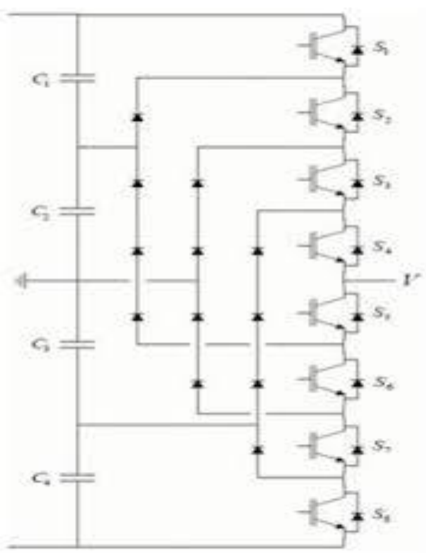


Fig. 2(a). The Diode-Clamped Multilevel Inverter Circuit Topologies (Five-level)

3.1.2. Cascade H -bridge multilevel inverter

In Cascaded H-bridge inverters separate dc sources (SDC's) are introduced. This new converter can avoid extra clamping diodes or voltage balancing capacitors. Fig. 2(b) Shows the basic arrangement of the 5-level cascaded-inverters with SDC's, shown in a single-phase configuration. Each SDC is related with a single-phase full-bridge inverter. To synthesize a multilevel waveform, the ac output of each of the different level H- bridge cells is connected in series. The number of output phase voltage levels in a cascaded inverter is defined by $m = 2H + 1$, where H = no. of H-bridges; while the relation between phase voltage and line voltages is same as diode –clamped inverter.

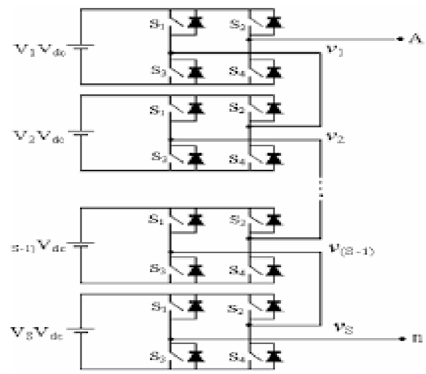


Fig. 2(b). The Cascaded H-bridge multilevel INVERTER,

3.1.3. Flying capacitor multilevel inverter

A quite well-known topology of multilevel inverter is Flying Capacitor Multilevel Inverter. It is quite similar to diode clamped multilevel inverter. The capacitor has to be pre-charged in this type of multilevel inverter. The topology consists of diodes, capacitors and switching devices as shown in fig. 2(c). This has been designed only up to six levels of voltage because of the practical restrictions. Each leg consists of switching devices which are in general transistors. Every inverter limb consists of cells connected in inward nested series. Every cell has two power switches and a single capacitor. Power switch is a combination of a transistor connected with an anti-parallel diode. Unlike diode clamped inverter, this topology uses capacitors for clamping [34]. An inverter with N cell will have 2N switches and N+1 different voltage levels including zero. We can also have negative voltage levels, and so all in all we can say that N cell multilevel inverter can give 2N+1 voltage levels. The voltage level is decreased as we move towards the load. The number of level depends upon the number of conducting switches in each limb. It is also known as Imprecated Cell Inverter. Since the capacitors floats with respect to earth's potential, they are called Flying Capacitor

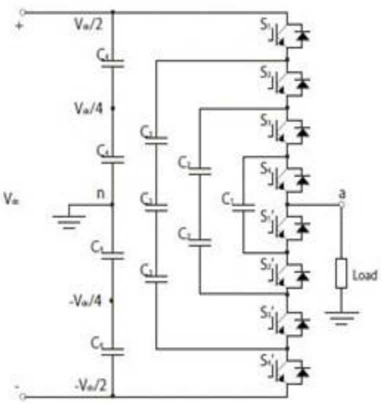


Fig. 2(c). The flying capacitor multilevel inverter

3.2. Topology Based Classification

Based on the various topologies of VSI (Voltage Source Inverter) DSTATCOM is classified as follows:

3.2.1. Three-Phase Three-Wire DSTATCOM [29]

The three phase three wire DSTATCOMs are used for compensation of consumer load by improving the power quality improvement in three-phase three-wire distribution system. Three phase Full bridge topology is shown in figure 3(a). For this topology the sum of current through its three legs must be zero [29]. The compensation for zero sequence current that might be folowing in the load will not be possible, nor can it eliminate any DC current flowing into the source from the load. This will result in distrortion in the source current.

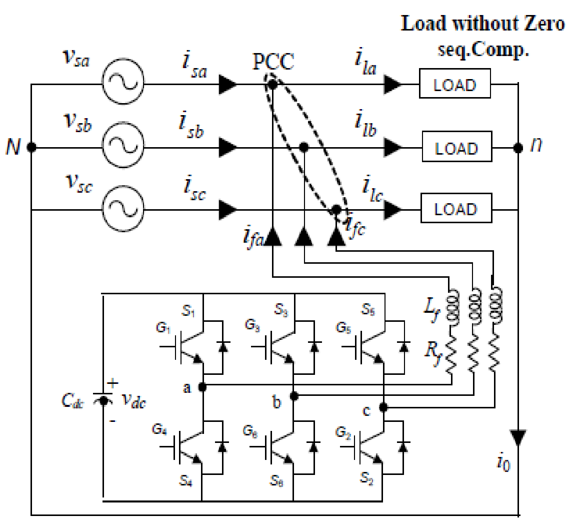


Fig. 3(a). The three phase Full bridge topology

3.2.2. H-Bridge VSI topology [4]

It contains three H Bridges VSIs which are connected to a common dc storage capacitor. In this figure each switch represents a power semiconductor devices and an anti-parallel diode combination. Each VSI is connected to the network through a transformer. Six output terminals of the transformer are connected in star. These six terminals can also be connected in delta to compensate a delta connected load. In this case, each transformer is connected in parallel with the corresponding load [1]. The purpose of including the transformer is to provide isolation between the inverter legs which prevents the dc storage capacitor from being shorted through switches in different inverters. The inductor L_f in this figure represents the leakage inductance of each transformer and additional external inductance. Copper loss of the connecting transformer is represented by a resistance R_f, but due to the presence of isolation transformers, this topology, however, is not suitable for compensation of the load currents containing dc components.

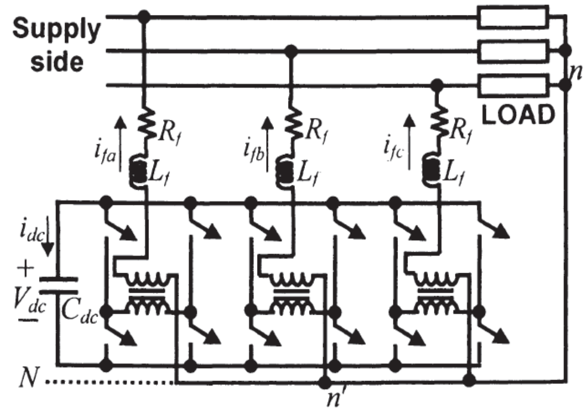


Fig. 3(b). The H bridge topology in which three VSIs are supplied from a common dc storage capacitor

3.2.3. Neutral-Clamped Three-Phase VSI topology [5]

This topology consist of a chopper circuit which is represented by the switches S_{chl} and S_{ch2} , a diode D_{ch1} and D_{ch2} in parallel and inductance and resistance which are denoted by Lp and Rp. The purpose of this chopper circuit is to balance the voltages in the two capacitors as shown in figure3(c).

Let the voltage across Cdc1 be Vdc1 and voltage across Cdc2 is Vdc2. Normally the two switches are left open and thus two voltages Vdc1 and Vdc2 are equal. Now suppose there is a voltage drop in Vdcl due to this there is rise of voltage in V dc2. Current is built up in the inductor Lp due to closing of switch Sch2 and once the current reaches a definite level, the switch Sch2 is opened, hence the inductor current get discharged through the diode D_{chl} to bring up the voltage V_{dcl} to the desired level.

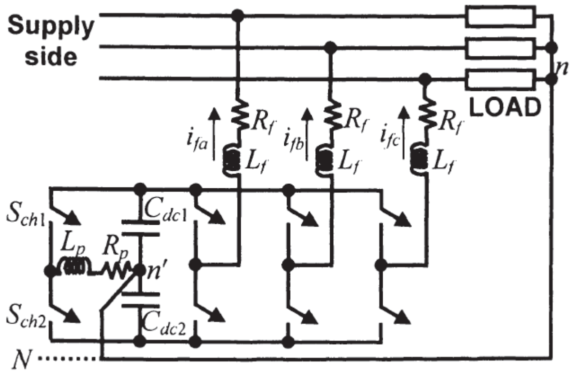


Fig. 3(c). The neutral clamped three phase VSI topology

Similarly, the charge can be transferred from the capacitor $C_{dc}1$ to the capacitor $C_{dc2}$by closing the switch S_{Chl} to build current in L_p and then charging C_{dc2} through the diode $D_{ch2}$by opening the switch S_{chl}.

3.2.4. Three phase four leg VSI topology [16]

Fig. 4 shows a VSI with four legs that are used and requires only one dc storage unit. Three of its legs are used for phase connection while the fourth leg is connected to the load neutral and the supply neutral, if available, through a reactance [6-8]. The reference current for the fourth leg is the negative sum of three phase load currents. This nullifies the effect of dc component of load current.

To maintain the adequate charge on dc-side capacitor a PI regulator is used to control the flow of real power from ac side towards dc side of the converter. When the compensator is working, zero sequence current is routed to path *n-n'* containing switching frequency harmonics. Using fourth leg of inverter, the negative of zero sequence current - *io*is is tracked. Certainly it needs a higher bandwidth VSI to track negative of neutral current (- i_o) as i_o contains harmonics due to non-linear loads. This increases the switching losses.
If this current is not tracked properly, it will leave high switching frequency current components in the *N-n* path, which is not desirable. The advantage of the topology is that it requires one less capacitor.

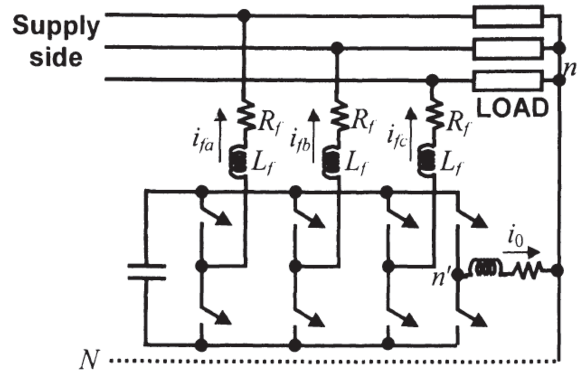


Fig. 4(a). A compensator structure which uses a four-leg VSI

3.2.5. Star connected three phase four wire topology [43]

The main problem in compensator topologies is voltage imbalance in capacitors when using two or more capacitor and this problem become critical when load contains a dc part. The compensator uses a current source, comprising of a voltage source inverter (VSI) with six switches (S1-S6) as shown in figure 5.

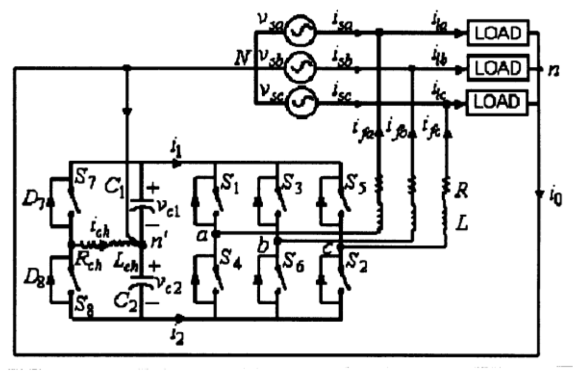


Fig. 5. The star-connected three-phase, four-wire distribution system

3.2.6. Three phase four wire VSI with two DC link capacitor [42]

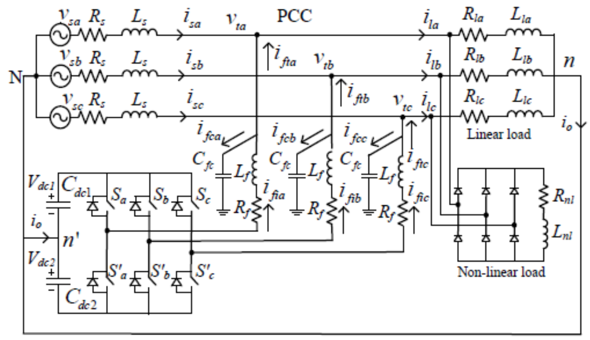
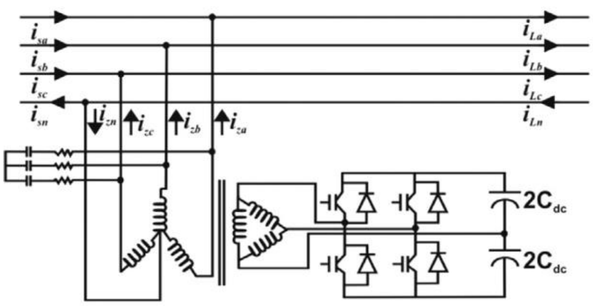


Fig. 6. The three phase four wire with two DC link capacitor

In Fig. 6 shows a DSATCOM is connected at point of common coupling (PCC). It is realized by using three-phase, four-wire VSI containing two dc link capacitors [43]. VSI and PCC is connected via LC filter. A shunt capacitor C_{fc} is connected across PCC which helps in elimination of high-switching frequency components and prohibits them to enter into the source [27]. A constant voltage Vdc is maintained across both DC capacitor $V_{dc1} = V_{dc2} = V_{dc}$. Source voltages, PCC voltages, load currents, source currents, and filter currents are v_{sj} , v_{lj} , i_{lj} , i_{sj} , and i_{ftj}, respectively with j = a, b, c for three phases.

3.2.7. Isolated two-leg VSC [41]

Two-leg VSC have a split capacitor with a transformer in the three-phase four-wire DSTATCOM. Transformer provides isolation from the system [15]. Two-leg three-phase four-wire DSTATCOM topologies using star-delta and, T-connected are shown in Fig 7; three-phase three-wire with two phase windings connected to the two legs of VSC and third phase winding connected to middle point of the split capacitor in VSC side winding of transformer. Three phases of the system side windings are connected to the three phases of the supply and neutral of the winding is connected with the neutral of the 3 phase 4wire supply system. Ripple filter is separately connected to the supply system [26].



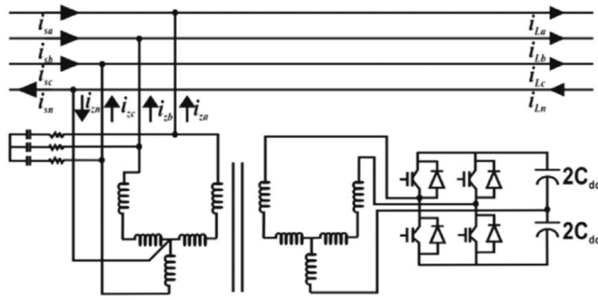


Fig. 7. The isolated two-leg VSC based 3 phase 4 wire DSTATCOM topology

3.2.8. No isolated VSC without transformer [11]

Non-isolated VSC-based DSTATCOM topologies using no transformer are classified as four-leg and three-leg VSC-based topology. The four-leg VSC-based 3P4W DSTATCOM topology is shown in Figure-8 and reported in [11]. An implementation of a four-leg VSC using an adaptive neural network-based control algorithm for compensation of linear/non-linear loads is presented in [12]. The application with PV for improvement of penetration level with low voltage distribution system is reported in [13] and PQ improvement is reported in [14].

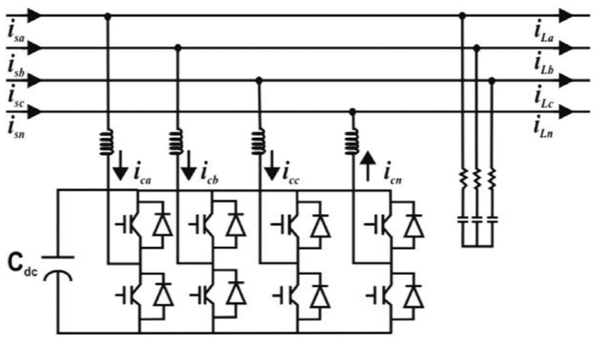


Fig. 8. The Non isolated VSC based 3phase 4 wire DSTATCOM

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 [40]. Different control strategies are reported in the literature such as IRP theory, SRF theory, Adaline-based control algorithm, PI controller for maintaining dc bus voltage. Some important and widely used techniques are detailed below in the subsections as follows.

4.1. Synchronous reference frame (SRF) based control strategy [35]

SRF control technique is based on transformation of current in synchronously rotating d-q frame [21-22]. The voltage signal is sensed and processed by phased lock loop (PLL) to generate sine and cosine signals as shown in figure 9. The sensed current signal then are transformed to d-q frame and filtered. After filtering the filtered currents are back transformed to *abc* frame and fed to hysteresis current controller for switching plus generation [23]. The mathematical transformation equations are described in [24]. The currents generated in α–β coordinates are transformed tod-q frame with the help of park's transformation using θ as transformation angle as

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (1)$$

With the help of low pass filter, the DC components, i_{ddc} and i_{qdc}, are extracted and are transformed back into α–β coordinates using reverse park's transformation as

$$\begin{bmatrix} i_{\alpha dc} \\ i_{\beta dc} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} i_{ddc} \\ i_{qdc} \end{bmatrix} \quad (2)$$

To obtain three-phase reference source currents in abc coordinates these currents are transformed as

$$\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{\alpha dc} \\ i_{\beta dc} \end{bmatrix} \quad (3)$$

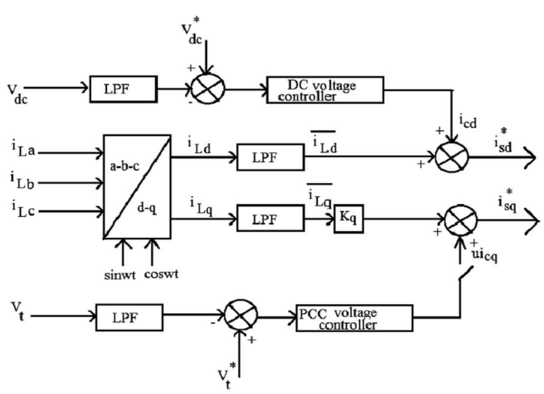


Fig. 9. The block diagram of synchronous reference control scheme

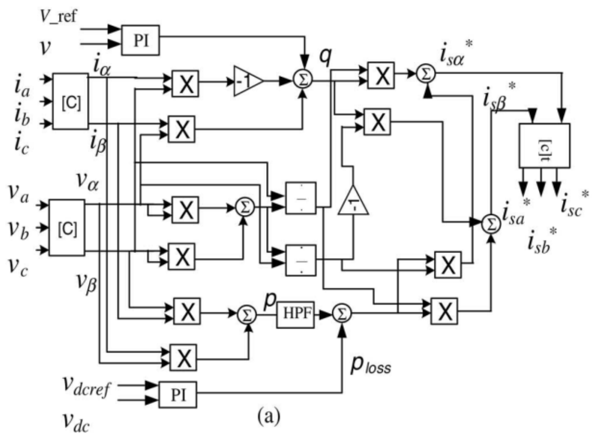


Fig. 10. The IRPT-based control of DSTATCOM

4.2. Instantaneous p–q Theory [21]

The control of DSTATCOM is implemented on the basis of instantaneous reactive power theory (IRPT) or p-q theory to calculate the desired compensation current. The block diagram for the control using IRPT is shown in Figure-10. In this method, the sensed three-phase PCC voltages and load currents are transformed into α-β-o axis using Clark's transformation. In addition, the source must deliver no zero-sequence active power (so that the zero-sequence component of the voltage at the PCC does not contribute to the source power). The reference source currents in the reference α-β-o frame are converted to the *abc* frame using the reverse Clark's transformation.

4.3. Neural Network Based Control System [25]

In this control algorithm, there is requirement of unit vector template corresponding to fundamental positive sequence component of current in phase with the phase voltage waveform. For proper estimation of components of load current, a undistorted unit voltage templates can be represented by:

$$V_p(t) = U\sin\omega t \quad (4)$$

To generate sinusoid (sincot) vector template, synchronized with ac mains, the zero crossing of phase voltage is detected in case of voltage being distorted.

$$i_p(t) = W_p v_p(t) \quad (5)$$

where weight (W_p) is estimated using Adaline. The weight can be represented in terms of voltage and current given as:

$$W_p = I_1\cos\varphi / U \quad (6)$$

To maintain minimum error, the scheme for estimating weights corresponding to fundamental frequency real component of current (for three-phase system), based on LMS algorithm tuned Adaline tracks the unit vector templates [14].

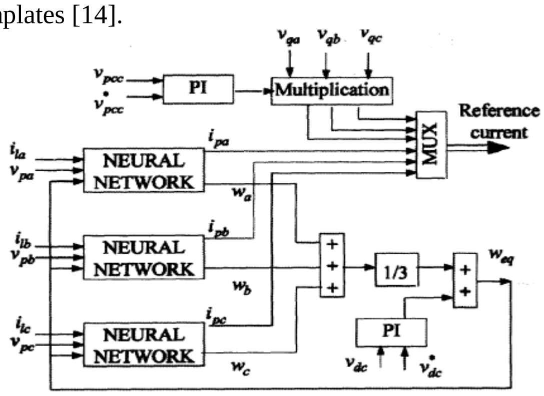


Fig. 11. The control scheme for voltage regulation mode of operation using ANN

The estimation of weight is given as per the following iterations:

$$W_p(k+l)=W_P(k)+n\{i_L(k)-W_p(k)v_p(k)\}v_p(k) \quad (7)$$

The value of n (convergence coefficient) decides the rate of convergence and accuracy of estimation. For proper estimation of reference signals, the weights are averaged to compute the equivalent weight for positive sequence and negative sequence current component in the decomposed form. Fig.11 shows the basic control scheme for ac voltage regulation mode of operation. The output signal given by PI controller is multiplied by the unit templates quadrature with phase voltage and added to the real reference current component calculated using neural network. The technique is demonstrated to selectively compensate the current harmonics, load unbalance, and reactive power based on priority [28].

4.4. Sliding Mode Control [19]

Sliding mode control (SMC) is a special type of Variable Structure Control (VSC) systems. VSC systems are articulated by a set of feedback control laws and a decision rule. The decision rule, namely the switching function, selects a particular feedback control in accordance with the systems behavior. In sliding mode control, VSC systems are designed to drive the system states to a particular surface in the state space, named sliding surface and once the sliding surface is attained, SMC keeps the states on the sliding surface. In general, SMC has mainly two parts to design. The first part involves the design of a switching function so that the sliding motion satisfies design specifications [34]. The second is concerned with the selection of a control law that will make the switching surface attractive to the system state. The sliding mode controller overcomes the uncertainties in the loads nearby the DSTATCOM and the loading conditions, therefore; a robust control can be achieved [38].

4.5. Symmetrical component theory [30]

The prime objective of the control algorithm is to obtain the balanced source currents for which the positive sequence voltage and currents are considered [30]. The reference source currents can be considered as

$$i_{sa}+i_{sb}+i_{sc} = 0 \quad (8)$$

With the help of block diagram in Figure-12, implementation of this control technique is explained 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 sensed currents as well as reference currents and voltages are shown in the block diagram. For controlling VSC, switching signals are generated and used [31]. Under non-ideal source voltage condition such as unbalanced and distorted source voltage conditions with linear as well as non-linear loads this technique fails [20].

4.6. Average unit power factor (AUPF) theory [33]

The source must supply the sinusoidal currents in phase with the voltages. The relation between source currents, voltages and average load power is given by the following relation [32]:

$$\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \frac{P_{lav}}{V^2} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$

where

$$P_{lav} = \frac{1}{T}\int (v_{sa}i_{La} + v_{sb}i_{Lb} + v_{sc}i_{Lc})\,dt$$
$$V^2 = \frac{1}{T}\int (v_{sa}v_{sa} + v_{sb}v_{sb} + v_{sc}v_{sc})\,dt \quad (9)$$

The compensator currents are derived as $i_c = i_l - i_s$.

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} - \frac{P_{lav}}{V^2} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (10)$$

The compensator reference currents are compared with actual compensator currents and passed through the hysteresis band controller which generates gate pulses for voltage source converter of DSTATCOM [33].

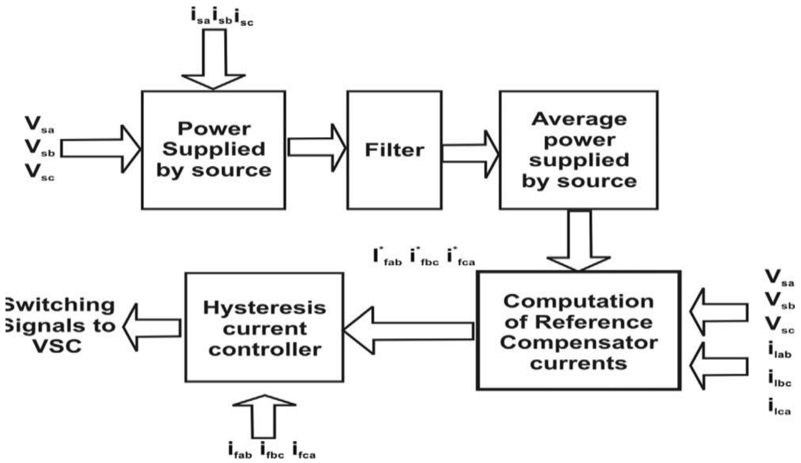


Fig. 12. The basic block diagram of symmetrical component theory

Table 1. The comparison of DSTATCOM control techniques performance of control technique

		SRF	IRP	NN	SMC	SC	AUPF
1	Reactive power compensation	Good	Partial	Good	Excellent	Excellent	Excellent
2	Harmonic mitigation	Good	Good	Good	Excellent	Better	Excellent
3	Load balancing	Average	Good	Excellent	Excellent	Excellent	Good
4	Source neutral current elimination	Good	Excellent	Good	Good	Good	Good
5	Computational complexity	Average	High	Simpler	High	Simpler	High

4. 7. Comparative study of control techniques

Based on critical reviews of publications a comparative study of control techniques is carried out. Table-1 shows a comparative study of different control schemes on the basis of performance and PQ improvement capability of DSTATCOM.

5. CONCLUSIONS AND FUTURE WORK

The DSTATCOM is very effective for improvement of power quality (PQ) problems related to both current and voltage such as load balancing, Harmonics elimination, power factor correction, voltage regulation and neutral current compensation in distribution system.

This paper presents a detailed survey on various topologies and control strategies of DSTATCOM used in both 3phase 3 wire and 3phase 4 wire distribution systems. The control techniques such as IRP, SRF, SMC, NN, and AUPF are analyzed. Comparative studies of various control schemes are also presented and from the Table-1 we analyzed that IRP, AUFC and SMC are much complex then the other schemes but excellent in harmonics mitigation. For the load balancing, IRP and NN control schemes are preferred and for reactive power compensation, SMC control scheme can be implemented. This comparative study will helps the users in selecting the particular topology and control technique of DSTATCOM that suits for specific application. Currently research is going on to reduce the cost of DSTATCOM without affecting the efficiency and effectiveness in PQ improvement capability.

Renewable energy (RE) penetration into the electrical utility grid is increasing day by day and affects the quality of supplied power. The weather conditions such as variable solar insolation and wind speed variations affect the power output of RE sources. The implementation of DSTATCOM in RE based power system is required to be explored as the DSTATCOM may be an effective solution for these problems.

REFERENCES

[1] Om PrakashMahela, Abdul GafoorShaik, **"A review of distribution static compensator",** *Renewable and Sustainable Energy Reviews,* Vol. 50, pp. 531–546, 2015.

[2] Iyer S, Ghosh A, Joshi A., **"Inverter topologies for DSTATCOM applications-a simulation study",** *Electric Power System Res,* Vol. 75(23), pp. 161–70, 2005.

[3] Eldery M, El-Saadany E, Salama M. **“Dstatcom effect on the adjustable speeddrive stability boundaries”,** *IEEE Trans Power Deliv* Vol. 22(2), pp.1202–9, 2007.

[4] Ghosh A, Joshi A. **“The concept and operating principles of a mini custompower park”,** *IEEE Trans Power Deliv*, Vol. 19(4), pp.1766–74, 2004.

[5] Gupta R, Ghosh A, Joshi A. **“Performance comparison of vsc-based shunt and series compensators used for load voltage control in distribution systems”,** *IEEE Trans Power Deliv* Vol. 26(1), pp. 268–78, 2011.

[6] Hussain S, Subbaramiah M. **“An analytical approach for optimal location ofdstatcom in radial distribution system”,** *In: 2013 International conference onenergy efficient technologies for sustainability (ICEETS)*, pp. 1365–9, 2013.

[7] Singh B, Arya S, Chandra A, Al-Haddad K. **“Implementation of adaptive filter indistribution static compensator”,** *IEEE Trans Ind Appl* Vol. 50(5), pp. 3026–36, 2014.

[8] Singh B, Jayaprakash P, Somayajulu TR, Kothari D, Chandra A, Al-Haddad K., **“Integrated three-leg vsc with a zig-zag transformer based three-phase four wire dstatcom for power quality improvement”,** *In: 34th annual conference of IEEE industrial electronics, IECON 2008*, pp. 796–801, 2008.

[9] A. Ghosh, G. Ledwich, **“Power Quality Enhancement Using Custom Power Devices”,** *Norwell, MA, USA*: 2002.

[10] Kasal G, Singh B., **“Voltage and frequency controllers for an asynchronousgenerator-based isolated wind energy conversion system”,** *IEEE Trans EnergyConvers*, Vol. 26(2), pp. 402–16, 2011.

[11] Rohani A, Joorabian M., **“Modeling and control of dstatcom using adaptivehysteresis band current controller in three-phase four-wire distribution systems”,** *In: 5th Power electronics, drive systems and technologies conference(PEDSTC)*, pp. 291–7, 2014.

[12] Singh B, Arya S, Jain C, Goel S., **“Implementation of four-leg distribution staticcompensator”,** *IET Gener, TransmDistrib* Vol. 8(6), pp. 1127–39, 2014.

[13] P. Wolfs, A. Oo, **“Improvements to lv distribution system pv penetration limitsusing a dstatcom with reduced dc bus capacitance”,** *In: Power and energy society general meeting (PES)*, Vancouver, BC: IEEE, pp. 1–5, 2013.

[14] Zaveri T, Bhalja B, Zaveri N., **“A novel approach of reference current generationfor power quality improvement in three-phase, three-wire distribution system using DSTATCOM”,** *International Journal of Electric Power Energy Syst*, Vol. 33(10), pp. 1702–10, 2011.

[15] Jayaprakash P, Singh B, Kothari D., **“Implementation of an isolated three-legvsc with star/hexagon transformer based three-phase four-wire DSTATCOM”,** *In: 2009 2nd international conference on emerging trends in engineeringand technology (ICETET)*, pp. 533–8, 2009.

[16] Mahesh K. Mishra, A. Ghosh, and A. Joshi, **“Operation of a DSTATCOM in voltage control mode,”** *Power Delivery, IEEE Transactions on*, Vol. 18, No. 1, pp. 258–264, 2003.

[17] G.F. Reed**,** M. Takeda, and I. lyoda, **“Improved power quality solution using advanced solid-slate switching and static compensation technologies”,** *IEEE Power Engineering Society.*

[18] S. P. Gawande, S. Khan and M. R. Ramteke **“Design Consideration for Configuration, Topology & Control Schemes of DSTATCOM Implemented on Distribution Systems”,** *Lecture Notes on Information Theory*, Vol. 1, No. 3, pp. 28-38, 2013.

[19] R. Gupta, A. Ghosh, **“Frequency-domain characterization of slidingmode control of an inverter used in DSTATCOM application,”** *IEEE Trans. Circuits Syst.*, Vol. 53, No. 3, pp. 662–676, 2006.

[20] Zaveri T, Bhalja B, Zaveri N. **“Comparison of control strategies for DSTATCOM in three-phase, four-wire distribution system for power qualityimprovement under various source voltage and load conditions”**, *Int J ElectrPower Energy Syst*, Vol. 43(1), pp. 582–94, 2012.

[21] Kumar P, Singh A, Kummari N. **“p-q theory based modified control algorithmfor load compensating using dstatcom”**, 2*014 IEEE 16th internationalconference on harmonics and quality of power (ICHQP)*, pp. 591–5, 2014.

[22] Bangarraju J, Rajagopal V, Jayalaxmi A. **“Unit template synchronous referenceframe theory based control algorithm for dstatcom”,** *J InstEng (India): Ser B2014*, Vol. 95(2), pp. 135-41, 2014.

[23] Jayaprakash P, Singh B, Kothari D. **“Reduction in rating of voltage sourceconverter of dstatcom using a zig-zag transformer”,** *In: 2012 IEEE internationalsymposium on industrial electronics (ISIE)*, pp. 1066–71, 2012.

[24] Sepulveda C, Munoz J, Espinoza J, Figueroa M, Melin P., **“All-on-chip dq-framebased d-statcom control implementation in a low-cost fpga”,** *IEEE Trans Ind Electron*, Vol. 60(2), pp. 659–69, 2013.

[25] B. Singh, V. Verma, and J. Solanki, **“Neural network-based selectivecompensation current quality problems in distribution system,”** *IEEE Trans. Ind. Electron.*, Vol. 54, No. 1, pp. 53–60, 2007.

[26] Singh B, Jayaprakash P, Kothari D. **“Isolated h-bridge vsc based 3-phase 4-wiredstatcom for power quality improvement”,** *In: IEEE international conference on sustainable energy Technologies*, ICSET 2008, pp. 366–71, 2008.

[27] Rohani A, JoorabianM., **“Modeling and control of dstatcom using adaptivehysteresis band current controller in three-phase four-wire distributionsystems”,** *5th Power electronics, drive systems and technologies conference(PEDSTC)*, pp. 291–7, 2014.

[28] Singh B, Dube S, Arya S, Chandra A, Al-Haddad K. **"A comparative study ofadaptive control algorithms in distribution static compensator",** *39th Annual conference of the IEEE industrial electronics society, IECON 2013*, pp. 145–50, 2013.

[29] S. B. Karanki, N. Geddada, M. K. Mishra, and B. Kalyan Kumar, **"A DSTATCOM topology with reduced DC-Link voltage rating for loadcompensation with nonstiff source,"** *IEEE Trans. Power Electron.,* Vol. 27, No. 3, pp. 1201-121, Mar. 2012.

[30] Kumar S, Singh B. **"Control of 4-leg vsc based dstatcom using modifiedinstantaneous symmetrical component theory",** *International conferenceon power systems, ICPS'0,* pp. 1–6, 2009.

[31] Zaveri T, Bhavesh B, Zaveri N. **"Control techniques for power quality improvementin delta connected load using dstatcom",** *2011 IEEE internationalelectric machines drives conference (IEMDC),* pp. 1397–402, 2011.

[32] Kummari N, Singh A, Kumar P. **"Comparative evaluation of dstatcom control algorithms for load compensation",** *2012 IEEE 15th international conferenceon harmonics and quality of power (ICHQP),* pp. 299–306, 2012.

[33] Sahu G, Mahapatra K. **"A novel control strategy of dstatcom for loadcompensation under distorted utility condition"**, *2014 International conferenceon advances in electrical engineering (ICAEE),* pp. 1–6, 2014.

[34] H. Akagi, Y. Kanazawa, and A. Nabae, **"Instantaneous reactive compensatorscomprising switching devices without energy storage components,"** *IEEE Trans. Ind. Appl.,* Vol. IA-20, No. 3, pp. 625–630, 1984.

[35] D. M. Divan, S. Bhatttacharya, and B. Banerjee, **"Synchronous frameharmonic isolator using active series filter,"** *in Proc. Eur. Power Electron.Conf.,* pp. 3030–3035, 1991.

[36] Sepulveda C, Munoz J, Espinoza J, Figueroa M, Melin P. **"All-on-chipdq-framebased d-statcom control implementation in a low-cost fpga",** *IEEE Trans IndElectron,* Vol. 60(2), pp. 659–69, 2013.

[37] Singh B, Arya S, Chandra A, Al-Haddad K. **"Implementation of adaptive filter indistribution static compensator",** *IEEE Trans Ind Appl Vol.* 50(5), pp. 3026–36, 2014.

[38] H. Fujita, H. Akagi, "**Voltage-regulation performance of a shunt active filter intended for installation on a power distribution system,"** *Power Electronics, IEEE Transactions on*, Vol. 22, No. 3, pp. 1046–1053, May 2007.

[39] A. S. De Morais and I. Barbi, "**Acontrol strategy for four-wire shunt activefilters using instantaneous active and reactive current method,"** *in Proc.32nd Ann. Conf. IEEE Ind. Electron. (IECON),* pp. 1846–1851, 2006.

[40] M. I. M. Montero, E. R. Cadaval, and F. B. González, "**Comparison ofcontrol strategies for shunt active power filters in three-phase four-wiresystems,"** *IEEE Trans. Power Electron*., Vol. 22, No. 1, pp. 229–236, 2007.

[41] Singh B, Jayaprakash P, Kothari D. **"New control approach for capacitorsupported DSTATCOM in three-phase four wire distribution system undernon-ideal supply voltage conditions based on synchronous reference frame theory",** *Int J Electr Power Energy Syst,* Vol. 33(5), pp. 1109–17, 2011.

[42] Bhim Singh, P. Jayaprakash, D. P. Kothari, AmbrishChandra, Kamal Al Haddad, **"Comprehensive Study of DSTATCOM Configurations"**, *IEEE transactions on industrial informatics*, Vol. 10, No. 2, may 2014.

[43] Chandan Kumar, Mahesh K. Mishra, "**Operation and Control of an Improved Performance Interactive DSTATCOM"**, *IEEE transactions on industrial electronics,* pp. 1-5, 2015.

[44] Chandan Kumar, Mahesh K. Mishra, **"A Control Algorithm for Flexible Operation of DSTATCOM for Power Quality Improvement inVoltage and Current Control Mode"**, *IEEE International Conference on Power Electronics,* Drives and Energy Systems December16-19, 2012, Bengaluru, India.