Mitigation of Power Quality Problems Using FACTS Controllers in an Integrated Power System Environment: A Comprehensive Survey

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DOI : 10.5963/IJCSAI0101001

***Abstract*-This paper presents a comprehensive survey on the mitigation of power quality problems such as low power factor, shortage of reactive power, poor voltage, voltage and current harmonics due to sudden change in field excitation of synchronous alternator, sudden increased in load, sudden fault occur in the system are solved by FACTS controllers such as STATCOM, DSTATCOM. This paper also presents current status of mitigation of power quality problems by FACTS controllers. The authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of power quality problems solved by FACTS controllers.**

Keywords-Flexible Alternating Current Transmission Systems (FACTS); FACTS Controllers; Static Synchronous Compensator (STATCOM); Distributed-STATCOM (DSTATCOM); Power Systems

I. INTRODUCTION

Power quality (PQ) issues, especially current harmonics, current unbalance and voltage unbalance, voltage sags, and poor power factor, have drawn much attention and much research work has been performed in this area. **V**OLTAGE sags are regarded as one of the most harmful power-quality (PQ) disturbances due to their costly impact on industrial processes.

Another PQ problem is a poor power factor to the incoming utility. This is caused by the proliferation of induction motors, thyristor rectifiers, and other nonlinear power electronics loads such as variable speed ac drives. Variation of load and diversity profiles over a day can result in wide variation in the reactive and harmonic VARs consumed by the plant. Most utilities have strict regulations concerning the plant's power factor, often requiring the use of switched shunt capacitor banks to improve the net power factor close to unity. Significant penalties are levied on plants that do not comply with the power factor requirements. The issue of harmonic pollution is more complex. While IEEE 519, first formulated in 1982, specifies maximum harmonic current levels at the point of common coupling (PCC), there is no movement to enforce it, unless it interferes with the neighboring loads. This is primarily because the cost of compliance has been fairly high. One means of correcting these power quality problems is to provide non-active power compensation by a parallel compensator.

FACTS technology is the application of power electronics in transmission systems. The main purpose of this technology is to control and regulate the electric variables (current, voltage, and impedance) and such effectively compensate mitigate voltage sag in the power systems. The use of power electronic-based apparatus at various voltage levels in electric energy systems is becoming increasingly widespread due to rapid progress in power electronic technology. The STATCOM is one such apparatus which can potentially be used in the context of FACTS at the transmission level and custom power controllers at the distribution level and in end users' electrical installations. Potential applications in these contexts include voltage regulation, power factor correction, load balancing, and harmonic filtering.

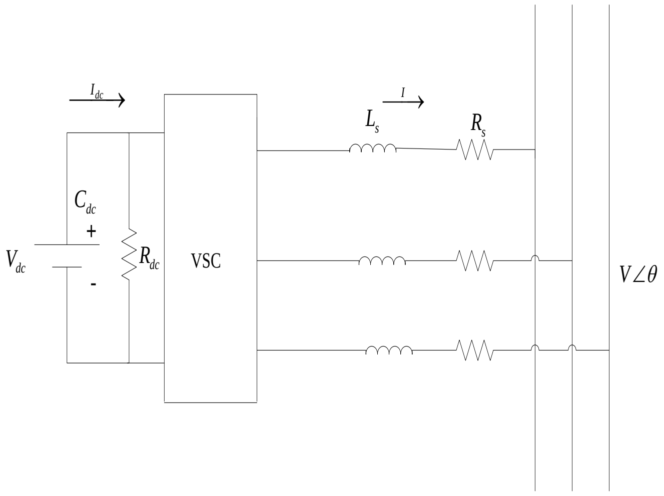
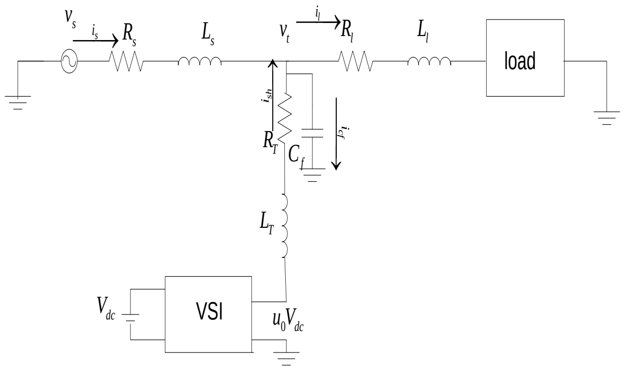


Fig. 1 STATCOM equivalent circuit

A DSTATCOM is a voltage source converter (VSC)-based power electronic device. Usually, this device is supported by short-term energy stored in a dc capacitor. The DSTATCOM filters load current such that it meets the specifications for utility connection. If properly utilized, this device can cancel the following:



- The effect of poor load power factor such that the current drawn from the source has a near unity power factor;
- The effect of harmonic contents in loads such that current drawn from the source is sinusoidal;
- The effect of unbalanced loads such that the current drawn from the source is balanced;
- The dc offset in loads such that the current drawn from the source has no offset.

II. MATHEMATICAL MODELING OF STATCOM AND DSTATCOM FOR POWER QUALITY PROBLEMS

A. Statcom

The following features followed by STATCOM:

- This device is connected to the line as a shunt mode.
- This device is based on voltage source inverter(VSI).
- In this device there is no chances of resonance phenomenon.
- Using this device the reactive power supported to the system or bus i.e. enhance voltage profile of the system.

$$\frac{1}{w_s}\frac{d}{dt}i_d = -\frac{R_s}{L_s}i_d + i_q + \frac{1}{L_s}(u_d V_{dc} - V_d) \quad (1)$$

$$\frac{1}{w_s}\frac{d}{dt}i_q = -\frac{R_s}{L_s}i_q - i_d + \frac{1}{L_s}(u_q V_{dc} - V_q) \quad (2)$$

$$\frac{C_{dc}}{w_s}\frac{d}{dt}V_{dc} = -\left(i_d u_d + i_q u_q + \frac{V_{dc}}{R_{dc}}\right) \quad (3)$$

Where i_d, i_q are the injected dq STATCOM currents, u_q is the voltage across the dc capacitor, R_{dc} represents the converter losses, R_s and L_s are the coupling transformer resistance and inductance respectively and the STATCOM RMS bus voltage is $V\angle\theta$ .The inputs u_d and u_q are given by

$$i_{ref,q} \quad (4)$$

$$u_q = k\sin(\alpha+\theta) \quad (5)$$

Where K and α are the modulation ratio and phase shift respectively, and

$$V_d = V\cos\theta \quad (6)$$

$$V_q = V\sin\theta \quad (7)$$

The STATCOM power balance equations at Bus i are

$$0 = V_i(i_d\cos\theta_i + i_q\sin\theta_i) - V_i\sum_{j=1}^{n} V_j Y_{ij}\cos(\theta_i - \theta_j - \phi_{ij}) \quad (8)$$

$$0 = V_i(i_d\sin\theta_i - i_q\cos\theta_i) - V_i\sum_{j=1}^{n} V_j Y_{ij}\sin(\theta_i - \theta_j - \phi_{ij}) \quad (9)$$

where the summation terms represent the power flow equations, $Y_{ij}\angle\phi_{ij}$ is the (i, j) element of the admittance matrix and n is the number of buses in the system.

$$\dot{x} = f(x) + \sum_{i=1}^{m} g_i(x)v_i \quad (10)$$

$$y = h(x) \quad (11)$$

where f, g are smooth vector functions that are continuous and differentiable, h is a smooth scalar function and m is the number of control variables. In the STATCOM model, $m = 2$ then state equation can be written as

$$\dot{x} = f(x) + g_1(x)u_1 + g_2(x)u_2 \quad (12)$$

$$f(x) = \begin{bmatrix} ax_1 + w_s x_2 - cV_d \\ ax_2 - w_s x_1 - cV_q \end{bmatrix} \quad (13)$$

$$g_1(x) = \begin{bmatrix} cx_3 \\ 0 \\ -dx_1 \end{bmatrix} \quad (14)$$

$$g_2(x) = \begin{bmatrix} 0 \\ cx_3 \\ -dx_2 \end{bmatrix} \quad (15)$$

where

$$x = [x_1\ x_2\ x_3]^T = [i_d\ \ i_q\ \ V_{dc}]^T$$

$$u = [u_1\ \ u_2]^T = [u_d\ \ u_q]^T$$

and

$$a = -\frac{R_s w_s}{L_s}$$

$$b = \frac{w_s}{C_{dc}R_{dc}}$$

$$c = \frac{w_s}{L_s}$$

$$d = \frac{w_s}{C_{dc}}$$

Where, the symbols have their usual meanings.

B. Dstatcom

The following features followed by DSTATCOM:

- It is modified form of STATCOM.
- It is having better control operational features as compared to STATCOM.
- This device is connected to the line as a shunt mode.
- This device is based on voltage source inverter (VSI).

- In this device there is no chance of resonance phenomenon.
- Using this device the reactive power supported to the system or bus, i.e. enhance voltage profile of the system.

(i)Voltage control

$$\frac{d}{dt}\begin{pmatrix} i_{dc} \\ i_{qc} \\ v_c \end{pmatrix} = A_{VC}\begin{pmatrix} i_{dc} \\ i_{qc} \\ v_c \end{pmatrix} - \begin{pmatrix} \frac{v_{sd}}{I_t} \\ \frac{v_{sq}}{I_t} \\ 0 \end{pmatrix} \quad (16)$$

$$A_{VC} = \begin{pmatrix} \frac{-R_t}{x_t} & 1 & -m\cos(\phi) \\ -1 & \frac{-Rt}{x_t} & -m\sin(\phi) \\ \frac{3m}{2C_{dc}}\cos(\phi) & \frac{3m}{2C_{dc}}\sin(\phi) & \frac{G_{dc}}{C_{dc}} \end{pmatrix} \quad (17)$$

Where ϕ and m are the modulating angle and the index of the SPWM, respectively.

(ii)Control Control

$$\frac{d}{dt}\begin{pmatrix} v_{dc} \\ v_{qc} \\ i_{dc} \\ i_{qc} \end{pmatrix} = A_{CC}\begin{pmatrix} v_{cd} \\ v_{cq} \\ i_{dc} \\ i_{qc} \end{pmatrix} + \begin{pmatrix} \frac{1}{C_{dc}} i_{ref,d} \\ \frac{1}{C_{dc}} i_{ref,q} \\ \frac{1}{x_t} v_{sd} \\ \frac{1}{x_t} v_{sq} \end{pmatrix} \quad (18)$$

$$A_{CC} = \begin{pmatrix} -\frac{G_{dc}}{C_{dc}} & 1 & \frac{1}{C_{dc}} & 0 \\ -1 & \frac{-G_{dc}}{C_{dc}} & 0 & \frac{1}{C_{dc}} \\ -\frac{1}{x_t} & 0 & -\frac{R_t}{x_t} & 1 \\ 0 & -\frac{-1}{x_t} & -1 & -\frac{R_t}{x_t} \end{pmatrix} \quad (19)$$

Where $i_{ref,d}$ and $i_{ref,q}$ are the reference dc and quadrature current signal respectively.

Where, the symbols have their usual meanings.

III. A LITRATURE SURVEY

A. Statcom

1) Voltage and Current Control Viewpoint

Hailian Xie *et al.* [1], the voltage at the point of common coupling (PCC) in a weak network is very sensitive to load changes. A sudden change in active load will cause both a phase jump and a magnitude fluctuation in the bus voltage (voltage at the PCC), whereas reactive load changes mainly affect the voltage magnitude. With the addition of energy storage to a STATCOM, it is possible to compensate for the active power change as well as providing reactive power support. Wei Qiao *et al.* [2], a novel interface neuro-controller (INC) is proposed for the coordinated reactive power control between a large wind farm equipped with doubly fed induction generators (DFIGs) and a STATCOM. The heuristic dynamic programming (HDP) technique and radial basis function neural networks (RBFNNs) are used in this literature to design this INC. It effectively reduces the level of voltage sags as well as the over-currents in the DFIG rotor circuit during grid faults, and therefore, significantly enhances the fault ride-through capability of the wind farm. K. Chatterjee *et al.* [3], a STATCOM-based var generator for medium power applications, utilizing one-cycle control is proposed. The control structure employs an integrator with a reset as its core component to control the pulse width of the converter devices so that the current drawn from the source is a precisely controlled reactive current leading or lagging the utility voltages as demanded by the system. Yu Liu *et al.* [4], a new feedback control strategy is discussed for balancing individual dc capacitor voltages in a three-phase cascade multilevel inverter-based STATCOM. S.O. Faried *et al.* [5], a novel and simple stochastic-based approach to determine the optimal sizing of multiple FACTS devices in a power system for steady-state voltage profile enhancement is presented. In this context, investigations have been conducted on a published test system taking into consideration the uncertainty of the system load and generator scheduling.

M. Saeedifard *et al.* [6], a space vector modulation (SVM)-based switching strategy for a five-level diode-clamped converter that is adapted as a STATCOM has been proposed. An Luo *et al.* [7], the control strategy for the STATCOM used in utility distribution systems is investigated, and a novel fuzzy-PI-based direct output-voltage (DOV) control strategy has been presented. Konstantin Borisov *et al.* [8], a novel reference signal generator (RSG) for voltage-source converters (VSCs) that enables the maximization of its functionality has been proposed. Andres E. Leon *et al.* [9], a new control strategy for STATCOMs operating under unbalanced voltages and currents has been presented. The proposed strategy adopts a state observer (software sensor) to estimate ac voltages at the STATCOM connection point. Ying-Yi Hong and Yi-Feng Luo [10], a novel technique for distributed generations (DGs) have attracted increasing attention due to considerations of environmental sustainability. Wind farms are one of the DGs, and they have intermittent characteristics. In this literature presented a method using wind generator voltages, STATCOM, and transformer taps as controllers to regulate the voltage profile for operation planning in a distribution system.

Byunghoon Chang *et al.* [11], the application schemes for a coordinated control system of multiple FACTS controllers are presented in this literature to enhance the voltage stability around the seoul metropolitan area. Atousa Yazdani *et al.* [12], electric arc furnaces (EAFs) are prevalent in the steel industry to melt iron and scrap steel. EAFs frequently cause large amplitude fluctuations of active and reactive power and are the source of significant power-quality (PQ) disturbances. STATCOMs provide a power-electronic based means of embedded control for reactive power support and PQ improvement. Juan Segundo-Ramírez and Aurelio Medina [13] in this contribution, two voltage-source converter (VSC) models based on Fourier series and hyperbolic tangent function are proposed. Marta Molinas *et al.* [14], a novel technique by which the transient torques during recovery after a grid fault can be smoothed in a wind farm with induction generators directly connected to the grid is proposed. A model based control technique using the quasi-stationary equivalent circuit of the system is suggested for controlling the torque with a STATCOM. Rajiv K. Varma *et al.* [15], a novel concept of utilizing photovoltaic (PV) solar farm (SF) as a FACTS-STATCOM, to regulate the point of common coupling voltage during nighttime when the SF is not producing any active power, has been proposed in this literature.

Bhim Singh *et al.* [16] demonstrated a simple electricity generating system that can supply electricity in remote areas such as seashores, hilly regions, etc. The proposed electricity generating system consists of SEIG and STATCOM based, voltage regulator. The STATCOM supplies variable reactive power to the SEIG and acts as a voltage regulator. Hailian Xie *et al.* [17], VSC has been widely utilized to provide instantaneous reactive power support to power systems, an application referred to as STATCOM. Integration of energy storage (ES) into a STATCOM makes it possible for the STATCOM to provide a certain amount of active power as well as reactive power support. Woei-Luen Chen *et al.* [18] a systematic approach based on eigen-structure assignment to determine the mode shape and transient response of a STATCOM utilized as an exciter for induction generators (IG) has been proposed. Vitaly Spitsa *et al.* [19], in this literature, a new approach to the problem of the STATCOM state feedback design is presented. Yogesh K.Chauhan *et al.* [20], in this literature dealing with the voltage-regulating (VR) schemes for SEIGs has been proposed, which suffer from poor voltage regulation even when driven by constant speed prime movers or fixed head hydro turbines. Nobuhiko Hatano and Toshifumi Ise [21], since STATCOM is often requested to operate under asymmetrical condition by power system faults, capacitor voltage balancing between phase clusters is particularly important. Solving this problem, a technique using zero-sequence voltage and negative-sequence current is proposed.

Mikhail N. Slepchenkov *et al.* [22], in this literature the effectiveness of reactive power compensation using a multilevel, hexagram-converter-based STATCOM with OCC for a wind farm with fixed-speed turbines, and the interaction with the power system network studies have been carried out. Li Wang and Chia-Tien Hsiung [23], the proposed literature has been presented a control scheme based on a STATCOM to achieve both voltage control and damping enhancement of a grid-connected integrated 80-MW offshore wind farm (OWF) and 40-MW marine- current farm (MCF). Yan Zhang and Jovica V. Milanovic [24], an approach to optimally select and allocate FACTS devices in a distribution network in order to minimize the number of voltage sags at network buses is proposed in this literature. Anish Prasai *et al*. [25], this literature has been proposed a dynamic capacitor (D-CAP) based on the family of inverter-less active filters that is able to provide a dynamically controllable capacitance with active harmonic filtering integrated into the same unit. Jovica V. Milanovic and Yan Zhang [26], FACTS devices or their subderivative custom power devices are efficient and often used and recommended power-electronics-based devices for mitigation of voltage sags in electrical power system. With FACTS devices installed, the overall system (and individual bus) sag performance could significantly change depending on the type of the device used. In order to assess this change in sag performance in realistic large power systems, the classical (essentially static) fault calculation procedure should be amended to incorporate the effects of these devices on bus voltages. This literature has been presented a new approach of quasi-static sag analysis using a system impedance (Z_{BUS}) matrix that incorporates FACTS devices.

Keyou Wang and Mariesa L. Crow [27], a new internal STATCOM control based on feedback linearization has been proposed. The feedback linearization controller has been developed without any simplifying assumptions to the STATCOM model. The proposed control is benchmarked against published results. Controllability issues associated with a singularity in the feedback linearization control (FBLC) coordinate transformation has been identified, and a solution has been provided to avoid instability. H. Mohammadi P. and M. Tavakoli Bina [28], a new transformerless four-leg topology has been suggested for shunt compensation, the modular multilevel converters (MMC) based on the half-bridge converters, to achieve higher performance as a STATCOM in a distorted and unbalanced medium voltage large-current (MV-LC) system. Anish Prasai and Deepak M. Divan [29], industrial plants are faced with stringent requirements by the utility to maintain a near unity power factor. These plants have traditionally utilized switched capacitor banks as a cost-effective means for power factor correction (PFC). However, if there is a significant level of harmonics present in the current that is disturbing the neighboring loads, then a separate unit for harmonic filtering is required as well. By the time a realistic system is configured, significant cost and complexity are encountered. The topology consists of taking an existing asset like a PFC capacitor, adding a pair of ac switches and small *LC* components per phase, and thereby realizing an asset with augmented functionalities has been proposed.

Y. Xu *et al.* [30], a three-phase insulated gate bipolar transistor (IGBT)-based STATCOM is used for voltage and/or current unbalance compensation. An instantaneous power theory is adopted for real-time calculation and control. Three control schemes – current control, voltage control and integrated control – are proposed to compensate the unbalance of current, voltage or both. H. Zhou G *et al.* [31], the control method for a new hybrid high-voltage dc (HVDC) connection for large wind farms with DFIGs has been presented. The hybrid HVDC system consists of a line-commutated converter plus a STATCOM on the rectifier side and a pulse-width modulation (PWM) current source inverter (CSI) on the inverter side. S.D.G. Jayasingha *et al.* [32], modulation and control of a cascade multilevel STATCOM configuration to improve the quality of voltage generated by wind power systems have been presented. Pinaki Mitra *et al.* [33], this literature has been explored the potential of a low-cost solution that utilizes the reactive power and voltage support capabilities of plug-in vehicles parked in charging stations (Smart-Parks) so that they can behave as virtual STATCOMs. Clark Hochgraf *et al.* [34], in this literature synchronous frame voltage regulator has been presented that works even when three phase symmetry is lost. This regulator addresses voltage imbalance by using separate regulation loops for the positive and negative sequence components of the voltage. The proposed regulator allows the STATCOM to ride through severe transient imbalance without disconnecting from the power system and, further, to assist in rebalancing voltages.

2) Performance Parameters of System Viewpoint

Wei Qiao *et al.* [35], this literature has been investigated the application of a STATCOM to assist with the uninterrupted operation of a wind turbine driving a doubly fed induction generators (DFIG), which has been connected to a power network, during grid faults. Qiang Song and Wenhua Liu [36], a control scheme for star-connected cascade STATCOMs operating under unbalanced conditions is proposed. The STATCOM has been assumed to be connected to an equivalent three-phase star-connected power supply. Mohamed S. El-Moursi *et al.* [37], this literature has been addressed the implementation issues associated with a novel damping control algorithm for a STATCOM in a series compensated wind park for mitigating sub-synchronous resonance (SSR) and damping power system oscillations. The intelligent shaft monitor (ISM) scheme with synthesized special indicator signals has been developed and examined in the STATCOM control structure. Ronny Sternberger and Dragan Jovcic [38], an analytical, state-space model of an indirect, voltage-controlled cascaded-type multilevel STATCOM with "square wave control" has been proposed. B. Ronner *et al.* [39], this literature has been pointed out the need for STATCOMs used in conjunction with wind parks.

Bishnu Sapkota, and Vijay Vittal [40], the impact of induction motors on voltage stability has been studied with the focus on trajectory sensitivity. The concept of trajectory sensitivity index has been proposed as a method to identify the location for dynamic VAr support to mitigate the short-term voltage instability problem caused by large disturbances. R. Saha and B. Singh [41], a modified three-level 48-pulse +100 MVAr STATCOM employing four pairs of elementary six-pulse neutral-point diode-clamped gate turn-off thyristor-based voltage source converters with fundamental frequency switching modulation has been realised using angle control methodology and pre-calculated dead angle (the duration in which converter-terminal voltage is clamped to zero) in d – q synchronous rotating frame. A.H. Kasem *et al.* [42], this literature has been introduced a methodology to enhance the quality of the power and voltage, and minimize the flicker produced from constant-speed direct-connected wind turbines. The method has been used an electrolyser/fuel cell combination to be connected to the point of common coupling via limited rating converters. Sharad W. Mohod and Mohan V. Aware [43], this literature study has been demonstrated the power quality problem due to installation of wind turbine with the grid. In this proposed scheme STATCOM has been connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. J. A. Barrado *et al.* [44], this literature has been presented a STATCOM with a self-oscillating bidirectional dc–dc converter for interfacing battery energy storage in a stand-alone induction generator system. Mohamed S. El Moursi *et al.* [45], this literature has presented a coordinated voltage control scheme for improving the network voltage profile and for minimizing the steady-state loading of the STATCOM to effectively support the system during contingencies.

3) Others Parameters View Point

S.R. Samantaray [46], a new approach for fault zone identification and fault classification for TCSC and UPFC line using decision tree (DT) has been presented in this literature.

Salman Mohagheghi *et al.* [47], a Mamdani-type fuzzy logic controller has been designed and implemented in hardware for controlling a STATCOM, which is connected to a ten-bus multi-machine power system has been prosed. B. Singh et al. [48], the development of STATCOM controller employing various solid-state converter topologies, magnetics configurations, control algorithms, switching techniques and so on, has been well reported in proposed literature with its versatile applications in power system. Chien-Hung Liu and Yuan-Yih Hsu [49], a self-tuning proportional-integral (PI) controller in which the controller gains adapted using the particle swarm optimization (PSO) technique has been proposed for a STATCOM. Wenchao Song, and Alex Q. Huang [50], this literature has proposed an effective fault-tolerant strategy by using H-bridge building block (HBBB) redundancy in CHMC-based STATCOM. Jon Are Suul *et al.* [51], this literature has proposed a control method for limiting the torque of grid-connected cage induction machines during the recovery process after grid faults, by using a STATCOM connected at the machine terminals. The presented concept is a model-based approach derived from a quasi-static equivalent circuit of the induction machine, the STATCOM and a thevenin representation of the power system.

Mohd. Hasan Ali, and Bin Wu [52], STATCOM, Pitch control system, Braking Resistor (BR), and Superconducting Magnetic Energy Storage (SMES) have recently been reported as stabilization methods for fixed-speed wind generator systems. Although the individual technologies have been well documented, a comparative study of these systems has not been reported so far. This literature aimed to fill in the gap, and provides a comprehensive analysis of these stabilization methods for fixed-speed wind generator systems. Jovica. V. Milanovic, and Yan Zhang [53], FACTS based devices have been proven to be an efficient mitigation solution for voltage sag prevention. The high cost of FACTS based devices often prohibited their wider deployment within power networks. This literature has presented an approach for comprehensively assessing the financial benefits to the network resulting from their use. S. Rahimzadeh *et al.* [54], a novel method based on genetic algorithm has been proposed to find the location, the operating point as well as the number of multi-type FACTS devices in the restructured environments simultaneously and optimally. Atousa Yazdani *et al.* [55], this literature has introduced an approach to detect the existence of the faulted switch, identify which switch is faulty, and reconfigure the STATCOM.

M. Jahangir Hossain *et al.* [56], a robust multivariable controller with the objective of enhancing the low-voltage ride-through (LVRT) capability of wind farms with fixed-speed induction generators has been presented in this literature. Mohamed Elsamahy *et al.* [57], in this literature, investigations have been carried out to explore the impact of a midpoint STATCOM on the coordination between the generator distance phase backup protection and the generator capability curves. M.S. El-Moursi [58], this literature has presented a new technique for improving the fault ride through (FRT) capability of self-excited induction generator (SEIG)-based wind parks by implementing fault current limiters (FCLs) using the electromagnetic transient program simulation program (PSCAD/EMTDC). The system performance has been tested in steady-state operation and in response to system contingencies, taking into account the impact of the short circuit ratios on the transient stability margin with and without FCLs.

M. Tavakoli Bina and D.C. Hamill [59], a practical 775kVAr STATCOM has been designed, in which the phase difference between the converter voltage and the AC system voltage is controlled over a small region to obtain a nearly linear reactive power control. The converter voltage has been synthesized using a PWM control with a fixed modulation index close to one. Bhim Singh and R. Saha [60], in this literature, a competitive topology with a fewer number of devices and reduced magnetics has been evolved to develop an 18-pulse, 2-level + 100MVAR STATCOM in which a GTO-VSC device has been operated at fundamental frequency switching gate control. S. A. Al-Mawsawi *et al.* [61], this literature deals with a modern approach of controlling the power flow in AC transmission lines. The control and distribution of power flow in two parallel transmission lines can be implemented by applying one of the FACTS, which is STATCOM device. The STATCOM device has been installed on one line of the two parallel transmission lines to design the controllers for such a system using Electromagnetic Transients Program (EMTP). The closed-loop STATCOM system as a terminal line voltage regulator has been designed with two types of controllers, PI with gain scheduling and fuzzy logic. The dynamic performance of the two controllers has been tested and compared.

B. Dstatcom

1) Voltage and Current Control Viewpoint

G. Ledwich and A. Ghosh [62], the topology and control have been discussed of a DSTATCOM that can be operated flexibly in the voltage or current control mode. In the voltage control mode, the DSTATCOM can force the voltage of a distribution bus to be balanced sinusoids. In the current control mode, it can cancel distortion caused by the load, such that current drawn by the compensated load is pure balanced sinusoid. Mahesh K. Mishra. *et al.* [63], this literature presents the operating principles of a DSTATCOM that has been used to maintain the voltage of a distribution bus. A three-phase, four-wire distribution system has been assumed in this literature. Arindam Ghosh and Avinash Joshi [64], the concept of a mini custom power park in which the voltage inside the park has been tightly regulated by a DSTATCOM is proposed. In the proposed concept DSTATCOM, backed by a diesel generator, will supply the most sensitive loads during the total line outages, thereby nearly making them both transient and interruption free. Rajesh Gupta and Arindam Ghosh [65], the commonly used switching schemes for sliding mode control of power converters has been analyzed and designed in the frequency domain. Particular application of DSTATCOM in voltage control mode has been investigated in a power distribution system.

Anshuman Shukla *et al.* [66], flying capacitor multilevel inverter (FCMLI) is a multiple voltage level inverter topology intended for high voltage and power operations with low distortion. It has used capacitors, called flying capacitors for clamping the voltage across the power semiconductor devices. In this literature, the implementation of a DSTATCOM using an FCMLI is presented. Anshuman Shukla *et al.* [67], in this literature, load compensation using multilevel inverter-based DSTATCOM has been presented. Anshuman Shukla *et al.* [68], this literature examines the application of a diode-clamped multilevel inverter (DCMLI)-based DSTATCOM connected to a three-phase, four-wire (3p4w) distribution system. Bhim Singh *et al.* [69], the proposed DSTATCOM has been employed for the compensation of reactive power, harmonics currents, neutral current, load balancing and the voltage regulation at the point of common coupling. Rajesh Gupta *et al*. [70], in this literature, a fixed-switching-frequency closed-loop modulation of a voltage-source inverter (VSI), upon the digital implementation of the modulation process has been analyzed and characterized. S. Srikanthan and Mahesh Kumar Mishra [71], this literature has proposed a carrier-based pulse-width modulation control for an inverter-chopper circuit in order to regulate the capacitor voltages to their reference values.

Alper Çetin and Muammer Ermis [72], this literature has described the design, implementation, and performance of a medium-size distribution-type DSTATCOM with the simplest two-level three-leg VSC topology. Reactive power control has been achieved by phase-shift-angle control, and VSC harmonics have been eliminated by selective harmonic elimination method (SHEM). Juan Segundo-Ramirez *et al.* [73], this literature has presented the stability analysis for a DSTATCOM that operates in current control mode based on bifurcation theory. Edward Song *et al.* [74], a flatness-based tracking control for the VSC has been used in this literature to improve performance where the nonlinear model is directly compensated without a linear approximation. Zhikang Shuai *et al.* [75], in this literature, a dynamic hybrid var compensator (HVC) for distribution grid has been proposed. The system is based on a combination of a small-capacity DSTATCOM and multi-group large-capacity thyristor switched capacitor (TSC).

Vincent Georg and Mahesh K. Mishra [76], this literature presents a detailed study on the design and analysis of user-defined constant switching (UDCS) frequency current-control-based four-leg DSTATCOM.

S. Srikanthan *et al.* [77], this literature has proposed an improved scheme of hysteresis current control for a three-level DSTATCOM application. Rajesh Gupta *et al.* [78], in this literature, a generalized multiband hysteresis modulation and its characterization have been proposed for the sliding-mode control of cascaded H-bridge multilevel-inverter (CHBMLI)-controlled systems. Mahesh K. Mishra and K. Karthikeyan [79], a proportional-integral (PI) controller has been used in this literature to maintain the dc-link voltage to the reference value. It has used deviation of the capacitor voltage from its reference value as its input. However, the transient response of the conventional PI dc-link voltage controller is slow. In this literature, a fast-acting dc-link voltage controller based on the energy of a dc-link capacitor has been proposed. Hazım Faruk Bilgin *et al.* [80], this literature deals with the design and implementation of the power stage of a forced-commutated current-source converter (CSC) for use in industry applications of D-STATCOM. Sunil Kumar *et al.* [81], in this literature, a neural-network (NN)-controlled DSTATCOM using a dSPACE processor has been implemented for power quality improvement in a three-phase four-wire distribution system. S.V Ravi Kumar, and S. Siva Nagaraju [82], a Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. This literature has presented work is to identify the prominent concerns in this area and hence the measures that can enhance the quality of the power have been recommended.

2) Performance Parameters of System Viewpoint

Gerard Ledwich and Arindam Ghosh [83], this literature has discussed load compensation using a DSTATCOM. It has been shown that the operation of a DSTATCOM assuming that it has been connected to a stiff source in such situations will result in distortions in source current and voltage at the point of common coupling. To avoid this, the DSTATCOM has been connected in parallel with a filter capacitor that allows the high frequency component of the current to pass. Walmir Freitas *et al.* [84], this literature has presented a dynamic study about the influences of ac generators (induction and synchronous machines) and DSTATCOM devices on the dynamic behavior of distribution networks. Mohamed A. Eldery *et al.* [85], in this literature, the dynamic models for adjustable speed drive (ASD) and DSTATCOM have been presented. Rajesh Gupta *et al.* [86], in this literature, the method of triangular carrier switching control of two-level inverters is extended to cascaded multilevel inverters using phase-shifted multicarrier unipolar PWM. The condition for smooth modulation is obtained using the Bessel's function representation of the PWM output and the switching condition of the multilevel inverter-controlled system.

Bhim Singh and Jitendra Solanki [87], in this literature, a DSTATCOM has been proposed for compensation of reactive power and unbalance caused by various loads in distribution system. An evaluation of three different methods has been made to derive reference currents for a DSTATCOM. These methods are an instantaneous reactive power theory, a synchronous reference frame theory, and a new Adaline-based algorithm. Pinaki Mitra and Ganesh Kumar Venayagamoorthy [88], this literature presents the application of a DSTATCOM to improve the power quality in a ship power system during and after pulse loads. References [87], [89], this literature presents the control of DSTATCOM for reactive power, harmonics and unbalanced load current compensation of a diesel generator set for an isolated system. The control of DSTATCOM has been achieved using least mean square-based adaptive linear element (Adaline). Rajesh Gupta *et al.* *[90]*, in this literature, the performance of voltage-source converter-based shunt and series compensators used for load voltage control in electrical power distribution systems has been analyzed and compared, when a nonlinear load has been connected across the load bus.

3) Others Parameters View Point

C. K. Sao et al. [91], a benchmark system for studying the sinusoidal pulse-width-modulated DSTATCOM has been proposed in this literature. A simple multifunction controller is provided to offer dc bus voltage control, power factor correction, and ac voltage control.

IV. RESULTS AND DISSCUSIONS

The summary of the paper as follows:

A. Statcom

1) Performance Parameters Wise Literatures Reviews Using STATACOM Viewpoint

TABLE 1 STATCOM

STATCOM	Total No. of Literatures Reviews out of 91 Literatures	% of Literatures Reviews out of 91 Literatures
Voltage and current control viewpoint	34	56
Performance parameters of system viewpoint	11	18
Others parameters view point	16	26

From above Table 1 it is concluded that the 56% of total literatures are reviewed based on voltage and current control viewpoint, 18% of total literatures are reviewed based on performance of system viewpoint, and the 26% of total literatures are reviewed on other parameters' viewpoint of systems using STATCOM.

From Fig. 1, it is also concluded that minimum number of literatures are reviewed based on performance parameters of system viewpoint, and maximum number of literatures are reviewed based on Voltage and current control viewpoint.

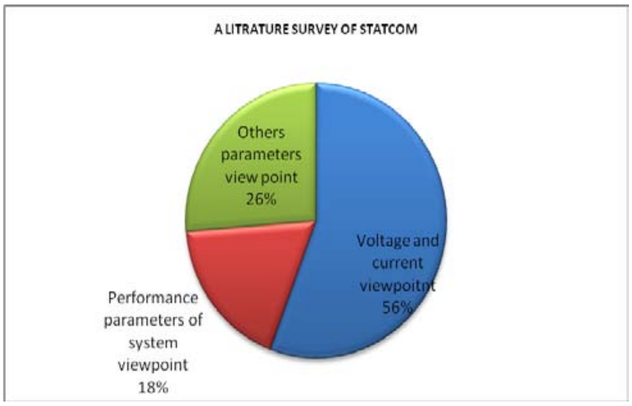


Fig.1 Pie chart for performance parameters viewpoint wise using STATCOM

2) Sessionwise Literatures Reviews Based on STATACOM Viewpoint

TABLE 2 NUMBER OF LITERATURES PER HALF OF DECADE YEARS OUT OF 61 LITERATURES

Years Range	No. of Literatures	% of Literatures Reviews out of 61 Literatures
1995-2000	1	2
2001-2005	2	3
2006-2010	47	77
2011	11	18

From above Table 2 it is concluded that the 77% of total literatures are reviewed in the session 2006-2010, 18% of total literatures are reviewed in the session 2011, and the 3% of total literatures are reviewed in the session 2001-2005.

From Fig. 2, it is also concluded that minimum number of literatures are reviewed in session 1995-2000, and maximum number of literatures are reviewed in session 2006-2010.

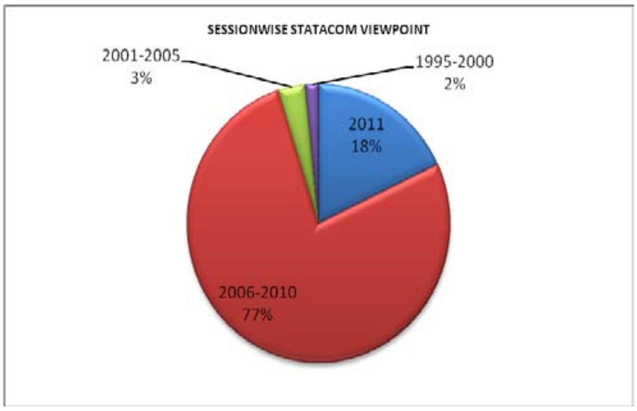


Fig. 2 Pie chart for Session wise literatures reviews based on STATACOM viewpoint

B. Dstatcom

1) Performance Parameters Wise Literatures Reviews Using DSTATACOM Viewpoint

TABLE 3. NUMBER OF LITERATURES PER HALF OF DECADE YEARS OUT OF 30 LITERATURES

DSTATCOM	Total No. of Literatures Reviews out of 91 Literatures	% of Literatures Reviews out of 30 Literatures
Voltage and current control viewpoint	21	70
Performance parameters of system viewpoint	08	27
Others parameters view point	01	03

From above Table 3 it is concluded that the 70% of total literatures are reviewed based on voltage and current viewpoint, 27% of total literatures are reviewed based on performance of system viewpoint, and the 03%of total literatures are reviewed on other parameters' viewpoint of systems using DSTATCOM.

From Fig. 3, it is also concluded that the minimum number of literatures are reviewed based on other parameters viewpoint, and maximum number of literatures are reviewed based on Voltage and current control viewpoint.

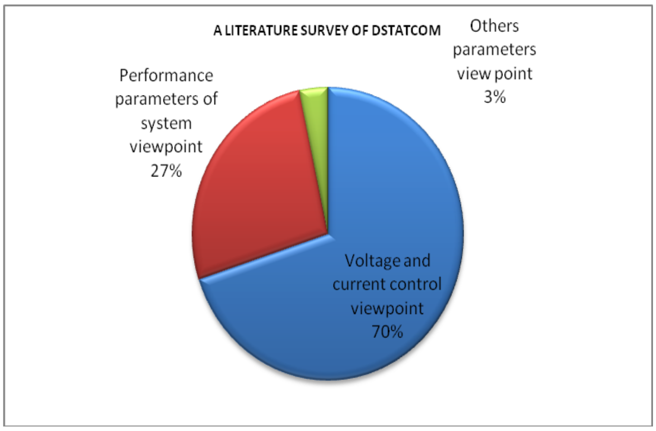


Fig.3 Pie chart for performance parameters viewpoint wise using STATCOM

2) Sessionwise Literatures Reviews Based on STATACOM Viewpoint

TABLE 4 NUMBER OF LITERATURES PER HALF OF DECADE YEARS OUT OF 30 LITERATURES

Years Range	No. of Literatures	% of Literatures Reviews out of 30 Literatures
2001-2005	26	20
2006-2010	21	70
2011	3	10

From above Table 4 it is concluded that the 70% of total literatures are reviewed in the session 2006-2010, 10% of total literatures are reviewed in the session 2011, and the 20% of total literatures are reviewed in the session 2001-2005.

From Fig. 4, it is also concluded that minimum number of literatures are reviewed in session 2011, and maximum number of literatures are reviewed in session 2006-2010.

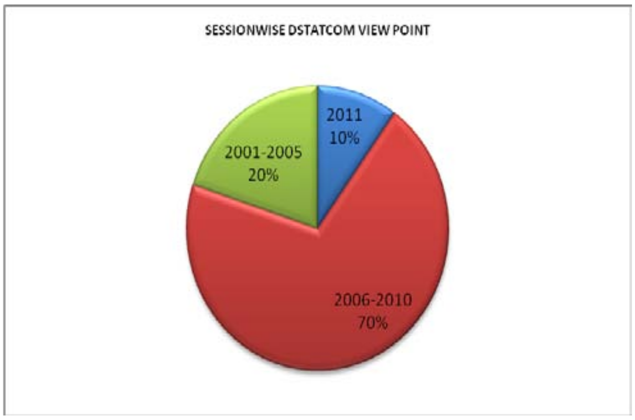


Fig. 4 Pie chart for Session wise literatures reviews based on DSTATACOM viewpoint

C. Comparison between STATCOM and DSTATCOM

1) Sessionwise Literatures Reviews STATACOM Plus DSTATCOM Viewpoint

TABLE 5 NUMBER OF LITERATURES PER HALF OF DECADE YEARS OUT OF 91 LITERATURES

Years Range	No. of Literatures
1995-2000	1
2001-2005	08
2006-2010	68
2011	14

Table 5 shows that the reviews status of STATCOM and DSTATCOM Session wise such as 2011,2010-2010,2005-2001, 2000-1995. From this pie-chart, it is concluded that the maximum paper are published in journals in session 2010-2006.

From Fig. 5, it is also concluded that minimum number of literatures are reviewed in session 1995-2000, and maximum number of literatures are reviewed in session 2006-2010.

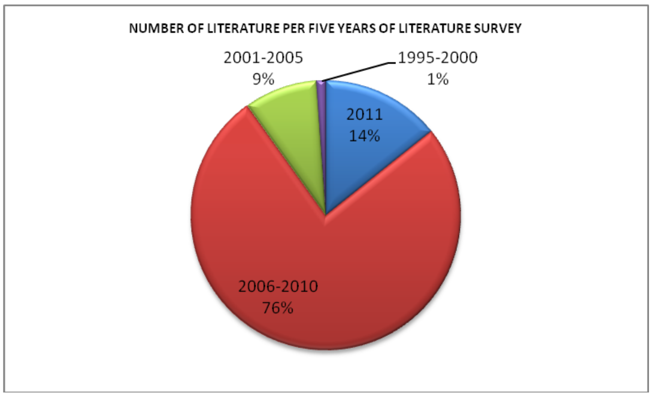


Fig. 5 Pie chart for Session wise literatures reviews based on STATACOM plus DSTATCOM viewpoint

2) Devicewise Literatures Reviews Based on STATACOM Plus DSTATCOM Viewpoint

TABLE 6 NUMBER OF LITERATURES BASED STATCOM AND DSTATCOM OUT OF 91 LITERATURES

Literatures survey	Number of literatures
STATCOM	61
DSTATCOM	30

Table 6 shows that the review status of STATCOM and DSTATCOM, it is concluded that maximum research has been carried out in the area of STATCOM.

From Fig. 6, it is also concluded that minimum number of literatures are reviewed based on DSTATCOM, and maximum number of literatures are reviewed based on STATCOM.

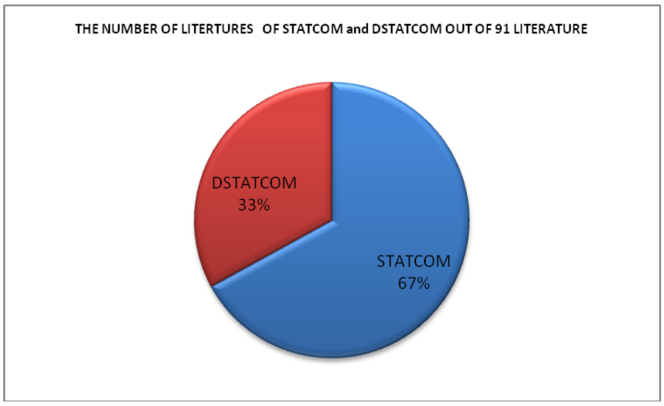


Fig. 6 Pie chart for device wise literatures reviews based on STATACOM plus DSTATCOM viewpoint

Finally it is concluded that maximum research work are carried out from STATCOM point of view. It observed that many researches are left regarding with DSTATCOM for placement and co- ordination of such devices.

V. CONCLUSION

This paper presents a comprehensive survey on the mitigation of power quality problems such as low power factor, shortage of reactive power, poor voltage, voltage and current harmonics due to sudden change in field excitation of synchronous alternator, sudden increased in load, sudden fault occur in the system are solved by FACTS controllers such as STATCOM, and DSTATCOM. This paper also presents current status of mitigation of power quality problems by FACTS controllers. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of power quality problems solved by FACTS controllers.

ACKNOWLEDGEMENT

The authors would like to thank Dr. K. S. Verma (Director), Prof.(Dr.) T. N. Shukla, Dr. S. K. Sinha (HOD EE Deptt.), Dr. A. S. Pandey, and Dr. Deependra Singh (Registrar), Kamla Nehru Institute of Technology, Sultanpur, for valuable discussions regarding with mitigation of power quality problems using FACTS controllers.

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