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A Comprehensive Review of DSTATCOM: Control and Compensation Strategies

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Abstract

Due to rapid increase in utilization of power electronics, appliances for energy distribution and generation is in demand. The traditional devices provide degraded performance, which pave the path for advanced compensated devices. Distribution Static Synchronous Compensator (DSTATCOM), which can be dynamically controlled and helps to improve power quality (PQ) problems. This paper discusses the various control methods required to improve dynamic capabilities of DSTATCOM for various applications.

INTRODUCTION

All electronics and electrical equipment suffers from power quality (PQ) issues, when connected to a distribution system. This leads to currents distortion and voltage collapse [1-2], resulting in poor performance of the equipment and power losses. The rapid growth in use of power electronics devices for utility grid and industries impose the providers to select a device carefully. Among all controllers, Distribution compensator is the most effective and powerful device device to address the issues associated with power quality. [3-10].

A Distribution compensator is the power device which is implemented in shunt configuration to improve the problems related to quality of the power. It provides stability in the voltage by controlling reactive power, suppresses flicker noise and also does compensation. The DSTATCOM can operate in two modes namely: *voltage* and *current*. The control algorithm which is used for voltage source inverter (VSI) switching [3] decides the effect of compensation. The DSTATCOM's performance depends upon the control algorithms which are generally used to generate source current. An overview of recent control techniques which are available in literature used for DSTATCOM is described in this paper.

The structure of the paper is described. The operation principle of shunt compensator is described in Section 2 and current control techniques in Section 3. Voltage current techniques are described in section 4. In section 5, the control techniques are compared. The conclusion of the literature reviewed in the paper is concluded in section 6.

CLASSIFICATION ACCORDING TO MITIGATED PQ PROBLEMS

The DSTATCOM is mainly used to compensate the PQ problems. This includes voltage and current quality, harmonics distortion and load unbalanced problems like currents reactive component, unbalance and neutral current at PCC. The DSTATCOM can be made to function in two modes: single and dual. In this paper, two modes of operation are used. The single mode provides compensation to any one of current or voltage while dual mode provides compensation for both current and voltage.

DSTATCOM and its Operating Principles

The DSTATCOM is one of power device which is connected to shunt. Its components are VSI, a DC-link device which is required for energy storage, a filter in output stage and with a coupling transformer as shown in Figure 1[11].

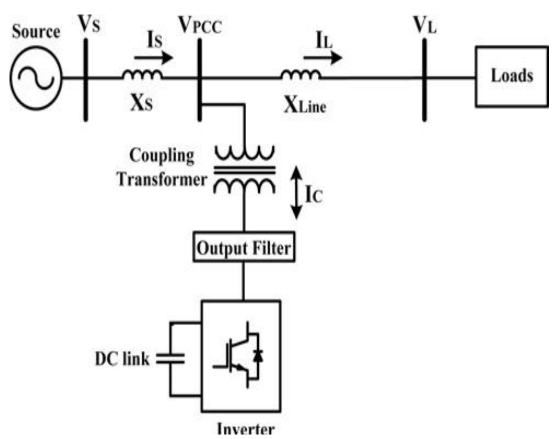

Figure 1: DSTATCOM Schematic diagram

A VSI is used to convert DC voltage stored in energy devices into output voltages, AC in three phases. The voltages which are generated are in phase with each other, using coupling transformer and connected to the utility grid. By using relevant setting of the magnitude and phase across output of the shunt compensator, the control of the active and reactive power flow between compensator and its grid [12-14] is provided.

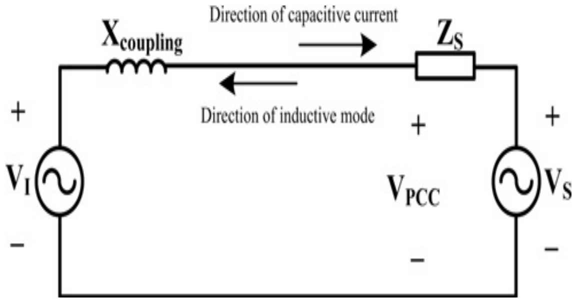

Figure 2: A DSTATCOM with a single phase power system.

Figure 2 shows the structure using single phase of a shunt compensator. Here V_1: inverter output voltage, $V_{Coupling}$: coupling impedance voltage drop, V_{PCC}: voltage of common coupling point (PCC) , V_S : voltage of the source. If V_1 = V_{PCC}, Shunt compensator will not exchange any reactive power with its utility grid, also reactive power is neither absorbed or generated by DSTATCOM. For V_1 > V_{PCC}, DSTATCOM behaves as if a reactance which is inductive in nature, is connected to its terminal. From transformer reactance of DSTATCOM, there is a flow of current in utility grid and power generated is capacitive. If V_1 < V_{PCC}, the DSTATCOM performs operation as if a reactance which is capacitive in nature, is connected to its terminal. In this condition [11, 15], the inductive power is absorbed by the device and the direction of flow of current is from the grid to the compensator.

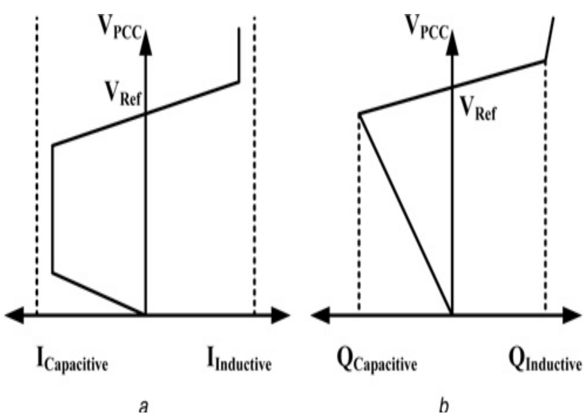

Figure 3: Shunt compensator operational characteristics (a) V-I (b) V-Q

In Figure 3, Voltage-current and V-Q characteristics of shunt compensator are shown, demonstrating the exchange of the reactive power between utility grid and compensator, where V_{ref} : the nominal voltage at PCC.

The phase angle between the voltages in utility grid and the distribution compensator output control the active power flow, which results in further reduction of the losses inside the inverter. It maintains charging of DC capacitor and adjusts magnitude of DSTATCOM output voltage. The Distribution compensator representation of vector at the fundamental frequency is shown in Figure 4, showing an inductive to the capacitive mode transition and vice versa.

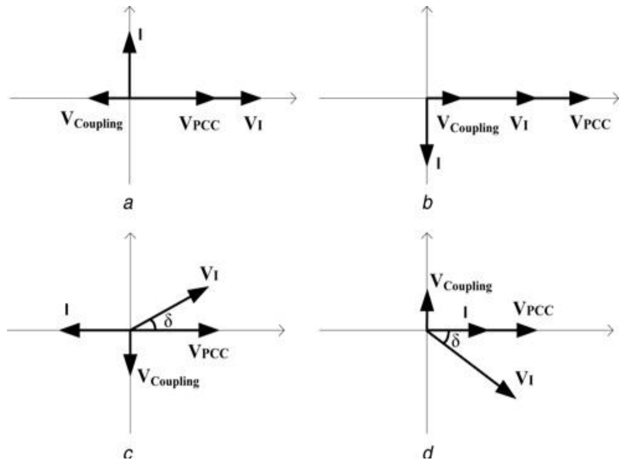

Figure 4: DSTATCOM different modes vector diagrams (a) Capacitive mode (b) Inductive mode (c) Active power release(d) Active power absorption.

By changing angle δ= 0 to δ= positive value, the switching from an inductive mode to capacitive mode is achieved. The power which is active, from the utility grid is transferred using a DC capacitor, which also brings drop in DC link. When angle "δ" is varied to a negative value from zero, there is a mode change from an inductive to the capacitive mode. There is an increase in DC link voltage, when there is a transfer of active power to the capacitor from the utility grid [16].

The active power (P) and reactive power (Q) variation between shunt compensator and its grid can be shown as follows in (1) and (2).

$$P = \frac{V_{PCC}V_1}{X_{Coupling}} \sin\delta \tag{1}$$

$$Q = \frac{V_{PCC}^2}{X_{Coupling}} - \frac{V_{PCC}V_1}{X_{Coupling}} \cos\delta \tag{2}$$

CONTROL AND COMPENSATION

Voltage control Strategies

A voltage control strategy which uses multiple DSTATCOMs applied to a low voltage (LV) network in order to anticipate

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voltage support. The multiple DSTATCOMs shared the required reactive power; the approach is promising as it requires minimum reactive power [17**]**.

A voltage controlled hybrid DSTATCOM of reduced rating, multiple features and with the ability of a single shunt compensator to alleviate several PQ problems are investigated in [18]. There is a connection of an external inductor between source and the load, which reduces the current requirement for mitigation of voltage sag and enhances the DSTATCOM voltage regulation bandwidth. An algorithm is proposed which is multi- functional and has an indirect control of the source currents while operating normally in order to mitigate PQ problems arise due to current and load terminal voltage. It is constant at the instances of voltage disturbances.

A stiff source connected load using a DSTATCOM is likely to have voltage disturbances. This is done by joining source, an external inductance and the load of suitable value in series. A multiple feature DSTATCOM with stiff source and which operates in voltage control mode. Also, it provides fast regulation of voltage at the time when disturbance in voltage appear across load terminals defined in [19]. It protects critical loads and during normal operating conditions, source currents can also be controlled by generated reference load voltages. In order to achieve source power factor to unity, DSTATCOM also provides the load current reactive and harmonic components. The outcomes are able to address PQ issues related to voltage and current.

A resilient voltage support strategy which uses multiple DSTATCOMs based on distributed coordination is given in [20]. It is applied to a low voltage (LV) networks accompanied by Photo Voltaic which acts as the renewable source for consumers. A DSTATCOMs share the required reactive power taking into account their effectiveness on voltage support and also matches its operation with the neighboring DSTATCOM by using its state information. The resilient voltage support strategy requires less reactive power as compared to other voltage support strategies.

For application in low voltage distribution grids, a voltage regulator using DSTATCOM is proposed in [21] .The low pass filter (second order) is used to connect the DSTATCOM. Its control structure provides active damping with the help of the two dc bus loops and three output voltage loops. The DSTATCOM is forced to operate with minimum power due to introduction of new idea to bring no compensation in certain conditions or in other words Minimum Power Point Tracking (MPPT). These three output voltage loop reduces apparent power processed by converter to nearly about 32 % and with the use of light load (95 %).

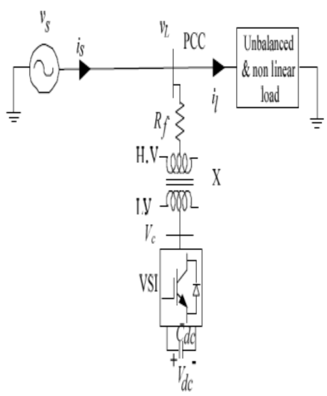

Figure: 5 DSTATCOM structure for HV distribution system [28]

In order to produce DSTATCOM reference voltage in voltage control mode operating condition, a new control scheme is proposed in [22]. There are several advantages of this scheme over existing DSTATCOM, which is voltage controlled, DSTATCOM for which 1.0 p.u is taken randomly as the reference voltage. The injection of lower currents in compensator and at the load terminal, unity power factor (UPF) under normal condition can be achieved. The later leads to reduce losses of the feeder and VSI. An uphold in the DSTATCOM rating is achieved resulting in increase of its ability in mitigating voltage sag. The scheme has advantages of providing correction in power factor, elimination in harmonics, balancing loads and regulation of voltage proportional to the load requirement.

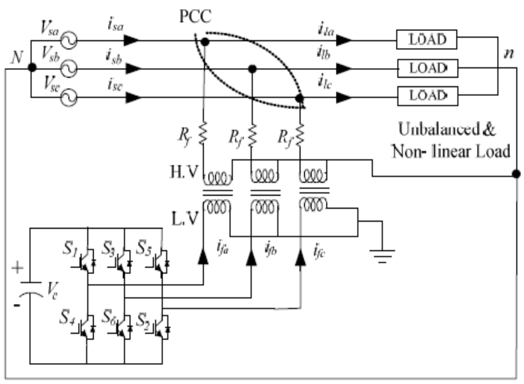

Figure 6: DSTATCOM (Three leg three phase inverter with a single dc capacitor) [28]

A three phase DSTATCOM which is based on modular multilevel converters (MMC), uses voltage control strategy, is described in [23]. The method to solve the unknown modulation index and circulation current of the electrical quantities is also illustrated in this paper. The sets of phase messages are used as compared to output current across each in voltage control loop which leads in reduction of number in data communication resources and current sensors. It is advantageous as number of MMCs module increases in the actual engineering application.

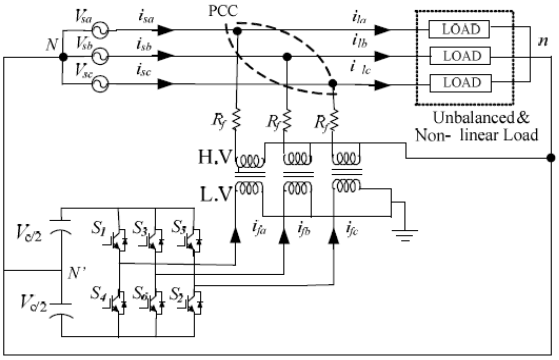

Figure 7: Split capacitor based DSTATCOM [28]

An adaptive control system is developed in [24] for a standalone power generation system (distributed) fed by a induction generator (self-excited). This is applied to regulate voltage. A four-leg shunt compensator is connected to the AC bus, used to perform the voltage regulation. The proposed adaptive controller provides voltage regulation with respect to parameters variations like connecting and disconnecting of load, also variation of induction generator's parameters.

The paper in [25] proposes a control system which brings voltage regulation using an induction generator (self-excited) in generation systems which are standalone. It’s a hybrid technology of four wires which contains capacitor banks that are switchable and DSTATCOM. Switchable capacitor banks supplies the reactive power which is required for voltage regulation and the reactive power which is remained is accumulated from the control of DSTATCOM to bring balance of IG currents and also to compensate harmonics which are present in load currents. The proportional resonant derivative (PRD) controller when liked with proportional integral controller, used to compensate currents control and is done by shunt compensator. The generator voltages and currents are in sinusoidal form with less distortion in harmonics, which is desirable for generator safety. This allows the use of voltage source converter (VSC) for low power rate.

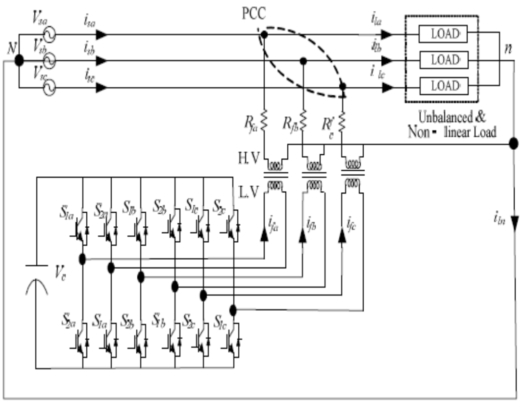

Figure 8: 3-independent single phase inverter with single dc capacitor based DSTATCOM

The paper in [17, 20] uses multiple DSTATCOMs to share the reactive power and for providing the voltage control. Multiple feature DSTATCOM are proposed in [18-19] which provides both voltage and current source control in order to mitigate PQ problems and voltage control for three phase is provided in [23] using single DSTATCOM to generate reference of a voltage controlled [22] source. The voltage regulation generated in [17, 20-21] is applied to a low voltage grid. The voltage regulation of stand-alone generation systems is provided in [24-25].

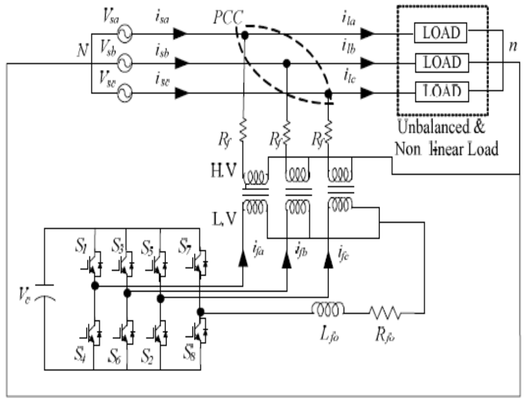

Figure 9: Three phase four leg inverter based DSTATCOM [28]

Current Control Strategies

An *id-iq* based control algorithm is proposed in [26] for the active and the reactive power control in time varying environment. The load fluctuations are compensated by DSTATCOM. This scheme of control algorithm enhances steady state performance and useful elimination of PQ disturbances. In order to regulate time varying active and reactive power control, an extra current control loop system is used under the fluctuations of load.

A DSTATCOM (3-phase 4-wire) configuration in current control mode containing an inverter andneutral points (three level) clamped is proposed in order to compensate load and to enhance the PQ [27]. The synchronous detection method is used to analyze the shunt compensator characteristics. This scheme provides complete sinusoidal source currents, in presence of distorted conditions. All three different approaches are analyzed for both unbalanced and non-linear load conditions with equal power, equal current and modified equal current. This modified equal current approach is better as compared to others even in the presence of highly distorted and unbalanced source voltages.

Inverter Technologies for DSTATCOM

The paper in [28] and [29] implements different inverter topologies under non-linear load conditions for high voltage distribution system shown in Figure 5. The high voltage and low voltage distribution system using single dc capacitor are not capable of providing full compensation with three phase and three legs VSI as shown in Figure 6. This drawback is overcome by using neutrally clamped DC capacitor topology. It still suffers from unbalanced capacitor that brings the requirement of an extra circuit for balancing and affects the overall cost of compensator cost given in Figure 7. An alternative solution to the problem is using three single phase inverter which are independent along with single DC capacitor which is given in Figure 8,that suffers from requirements of more switches which in turn again increases cost. The load neutral current is compensated using a 3-phase 4-leg VSC with the requirements of coordination between third leg and fourth leg as shown in Figure 9.

The DSTATCOM, five level inverter configuration uses a fuzzy logic controller that improves the PQ as done in [30]. The inverter with five level switching signals is generated using space vector modulation (SVM) method. The fuzzy controller uses operator’s knowledge which is different from conventional controller that uses mathematical equations that significantly increases the stability of power system.

Voltage and Current Control Strategies

The linear sinusoidal tracer (ILST) control algorithm is improved in [31] to achieve the reactive compensation of power for the linear and the nonlinear loads. The compensation of parameters like elimination of harmonics, correction of power factor, and regulation of voltage, which uses adaptive theory for hardware implementation of three phases DSTATCOM is achieved. The digital signal processor is used to compare performance analysis of DSTATCOM model. The DSTATCOM with both PCC and DC bus voltages are regulated while using unbalanced loads.

For power conditioning applications [32], an efficient control algorithm is used to implement three phase DSTATCOM, this proves to be an effective way for suppressing harmonics and balancing of loads. The scheme makes the uses of a double toned filter, a zigzag transformer, rectifiers and DSTATCOM’s with VSC. In the presence of voltage distortion, this derives the fundamental component of current.

Artificial Neural Networks

An excellent hybrid control approach [33] which uses an artificial neural network (ANN) with a zigzag transformer and hysteresis current controllers (HCC) for a DSTATCOM is proposed. The power factor and reduction in line current harmonics of the network is reduced using a hybrid controller. To push the source current into a sinusoidal one and tries to be in phase with line voltage the controller is used in the network. It provides two controls estimation of weighting factor of three phase load current and hysteresis switching algorithm for driving the VSC of DSTATCOM. The compensator is optimized using an ANN with suitable learning rate.

The adaptive neuro-fuzzy inference system which is least-mean-square based (ANFIS-LMS) is proposed in [34]. This algorithm is used to implement a three phase DSTATCOM in order to compensate PQ problems related to current. This algorithm addresses many problems like harmonics compensation, correction of power factor, balancing of loads, and regulation of voltage. In order to estimate supply currents using the proposed algorithm, active and the reactive power components are extracted from non-sinusoidal load currents. The voltage regulation modes under varying load conditions are also achieved.

A 3MVA DSTATCOM controller based on fuzzy logic is proposed which is used for improvement of the PQ and to stabilize the distribution power system [35]. The grey wolf optimization (GWO) algorithm is used to tune the controllers (fuzzy logic) scaling factor. When the voltage sag and load variations at grid end occurs, the DSTATCOM controllers are evaluated. It improves dynamic response and hence improves PQ.

Fuzzy logic controller (FLC) Takagi Sugeno (TS) [36] based on DSTATCOM is proposed which is used for elimination of harmonics, correction of power factor, balancing of loads and voltage regulation. The requirement of a mathematical model is eliminated as this controller uses linguistic variables. In place of DSTATCOM, a voltage source converter which is current controlled (CC-VSC) and is 3- phase insulated gate bipolar transistors (IGBTs) based, is used. The control algorithm uses two FLCs. The DSTATCOM DC link and phase voltages amplitudes are the FLC’s input signals. The TS-FLC is made using only two functions of membership which results in less complexity. This algorithm addresses and performs as a good harmonic eliminator, a voltage regulator and a load balancer.

It brings needed dynamic voltage control in DSTATCOM. A fuzzy logic approach is used in order to improve PQ problems and the stability in distribution power system. The Genetic Algorithms (GA) is used to optimize the FLC scaling factors. [37].

CONCLUSION

The paper is a comprehensive review on the DSTATCOMs in order to improve the PQ problems. The DSTATCOM offers many advantages and addresses many issues. The review of DSTATCOM papers in literature are valuable to reduce both current and voltage generated PQ problems. The voltage strategies, control strategies, voltage and control both are reviewed. The ANN based control strategies are reviewed.

Evolution of control strategies and their execution with multiple function compensation potential are the areas on which research can be focused in future to mitigate the various PQ problems using DSTATCOMs. In order to provide supply of electricity with better quality and reliability, the research on DSTATCOMs can solve the problems in grids and industrial units. New control strategies, switching methods and to bring compensation of flicker and harmonics simultaneously on DSTATCOMs, etc. can be done in future.

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