ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Power Quality Improvement by using DSTATCOM for Distribution System

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ABSTRACT:
Maximum AC loads consumes reactive power, it causes poor power quality in power system. The DSTATCOM is a compensating device which is used to control the flow of reactive power in the distribution systems. The complete background of the compensating devices and power electronic application in compensating devices is presented in this paper and also the compensation using the DSTATCOM modeling is also discussed. The detailed modeling and simulations of different control strategies are presented and implemented along with the necessary equations in the MATLAB simulink using the simpower systems tool boxes. The PI controllers are used for the implementation of the models and are discussed. Simulation results are we discussed and various case studies applied depending on the various loads like resistive, inductive and capacitive on the DSTATCOM simulink models and the simulation results are studied.

Keywords:
Reactive power compensation, DSTATCOM, dqmodel, power control and power quality.

1. INTRODUCTION
In the early days of power transmission in the late 19th century problems like voltage deviation during load changes and power transfer limitation were observed due to reactive power unbalances. Most of the AC loads are consuming reactive power due to presence of reactance. Heavy consumption of reactive power causes poor voltage quality. Today these Problems have even higher impact on reliable and secure power supply in the world of Globalization and Privatization of electrical systems and energy transfer.

The development in fast and reliable semiconductors devices (GTO and IGBT) allowed new power electronic Configurations to be introduced to the tasks of power Transmission and load flow control. The FACTS devices offer a fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. On the other hand the custom power is for low voltage distribution, and improving the poor quality and reliability of supply affecting sensitive loads. Custom power devices are very similar to the FACTS. Most widely known custom power devices are DSTATCOM, UPQC, DVR among them DSTATCOM is very well known and can provide cost effective solution for the compensation of reactive power and unbalance loading in distribution system.

The causes of power quality problems are generally complex and difficult to detect. Technically speaking, the ideal AC line supply by the utility system should be a pure sine wave of fundamental frequency (50/60Hz).Different power quality problems, their characterization methods and possible causes are discussed above and which are responsible for the lack of quality power which affects the customer in many ways. We can therefore conclude that the lack of quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained. This project demonstrates that the power electronic based power conditioning using custom power devices like DSTATCOM can be effectively utilized to improve the quality of power supplied to the customers.

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The aim of the paper is shows to implement DSTATCOM with control strategies in the MATLAB, simulink using Simpower systems tool box and to verify the results through various case studies applying different loads and study them in detail

2. POWER QUALITY AND RELIABILITY:

Power quality and reliability cost the industry large amounts due to mainly sags and short-term interruptions. Distorted and unwanted voltage wave forms, too. And the main concern for the consumers of electricity was the reliability of supply. Here we define the reliability as the continuity of supply. As shown in Fig.1, the problem of distribution lines is divided into two major categories. First group is power quality, second is power reliability. First group consists of harmonic distortions, impulses and swells. Second group consists of voltage sags and outages. Voltage sags is much more serious and can cause a large amount of damage. If exceeds a few cycle, motors, robots, servo drives and machine tools cannot maintain control of process.

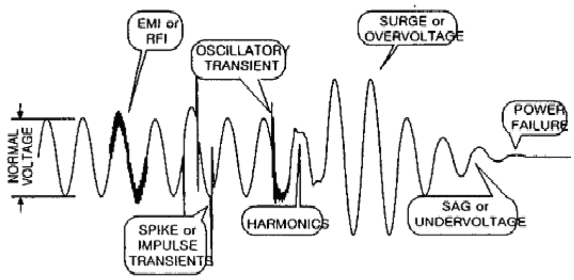

Fig.1. power quality and reliability

Both the reliability and quality of supply are equally important. For example, a consumer that is connected to the same bus that supplies a large motor load may have to face a severe dip in his supply voltage every time the motor load is switched on. In some extreme cases even we have to bear the black outs which is not acceptable to the consumers. There are also sensitive loads such as hospitals (life support, operation theatre, and patient database system), processing plants, air traffic control, financial institutions and numerous other data processing and service providers that require clean and uninterrupted power.

In processing plants, a batch of product can be ruined by voltage dip of very short duration. Such customers are very wary of such dips since each dip can cost them a substantial amount of money. Even short dips are sufficient to cause contactors on motor drives to drop out. Stoppage in a portion of process can destroy the conditions for quality control of product and require restarting of production. Thus in this scenario in which consumers increasingly demand the quality power, the term power quality (PQ) attains increased significance. Transmission lines are exposed to the forces of nature. Furthermore, each transmission line has its load ability limit that is often determined by either stability constraints or by thermal limits or by the dielectric limits. Even though the power quality problem is distribution side problem, transmission lines are often having an impact on the quality of the power supplied. It is however to be noted that while most problems associated with the transmission systems arise due to the forces of nature or due to the interconnection of power systems, individual customers are responsible for more substantial fraction of the problems of power distribution systems.

3. DISTRIBUTED STATIC COMPENSATOR (DSTATCOM)

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator (similar in many respects to the DVR) that is used for the correction of bus voltage sags. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. The major components of a DSTATCOM are shown in Fig. 2. It consists of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, and a

PWM control strategy. In this DSTATCOM implementation, a voltage-source inverter converts a dc voltage into a three-phase ac voltage that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (ac filter).

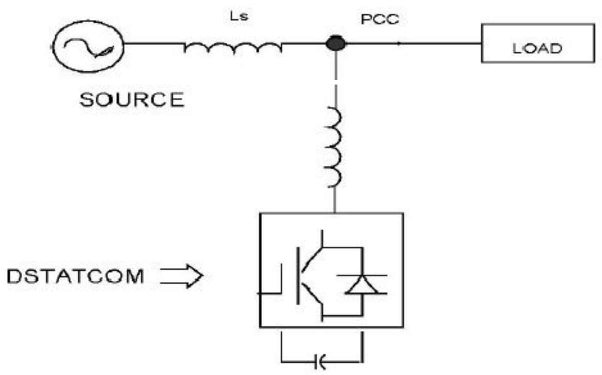

Fig.2.block diagram of DSTATCOM circuit

DSTATCOM components: DSTATCOM involves Mainly three parts IGBT or GTO based dc-to-ac inverters:

These inverters are used which create an output voltage wave that's controlled in magnitude and phase angle to produce either leading or lagging reactive current, depending on the compensation required.

L-C filter:

The LC filter is used which reduces harmonics and matches inverter output impedance to enable multiple parallel inverters to share current. The LC filter is chosen in accordance with the type of the system and the harmonics present at the output of the inverter.

Control block:

Control block is used which switch Pure Wave DSTATCOM modules as required. They can control external devices such as mechanically switched capacitor banks too. These control blocks are designed based on the various control theories and algorithms like instantaneous PQ theory, synchronous frame theory etc.. All these different algorithms are discussed in the next chapter.

4. BASIC OPERATING PRINCIPLE

Basic operating principle of a DSATCOM is similar to that of synchronous machine. The synchronous machine will provide lagging current when under excited and leading current when over excited. DSTATCOM can generate and absorb reactive power similar to that of synchronous machine and it can also exchange real power if provided with an external device DC source.

1) Exchange of reactive power:- if the output voltage of

the voltage source converter is greater than the system voltage then the DSATCOM will act as capacitor and generate reactive power(i.e.. provide lagging current to the system)

2) Exchange of real power: as the switching devices are not loss less there is a need for the DC capacitor to provide the required real power to the switches. Hence there is a need for real power exchange with an AC system to make the capacitor voltage constant in case of direct voltage control. There is also a real power exchange with the AC system if DSTATCOM id provided with an external DC source to regulate the voltage incase of very low voltage in the distribution system or in case of faults.

And if the VSC output voltage leads the system voltage then the real power from the capacitor or the DC source will be supplied to the AC system to regulate the system voltage to the =1p.u or to make the capacitor voltage constant. Hence the exchange of real power and reactive power of the voltage source converter with AC system is the major required phenomenon for the regulation in the transmission as well as in the distribution system. For reactive power compensation, DSTATCOM provides reactive power as needed by the load and therefore the source current remains at unity power factor (UPF). Since only real power is being supplied by the source, load balancing is achieved by making the source reference current balanced.

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The reference source current used to decide the switching of the DSTATCOM has real fundamental frequency component of the load current which is being extracted by these techniques. A STATCOM at the transmission level handles only fundamental reactive power and provides voltage support while as a DSTATCOM is employed at the distribution level or at the load end for power factor improvement and voltage regulation. DSTATCOM can be one of the viable alternatives to SVC in a distribution network. Additionally, a DSTATCOM can also behave as a shunt active filter, to eliminate unbalance or distortions in the source current or the supply voltage as per the IEEE-519 standard limits.

Since a DSTATCOM is such a multifunctional device, the main objective of any control algorithm should be to make it flexible and easy to implement in addition to exploiting its multi functionality to the maximum. The main objective of any compensation scheme is that it should have a fast response, flexible and easy to implement. The control algorithms of a DSTATCOM are mainly implemented in the following steps:

- Measurements of system voltages and current and
- Signal conditioning
- Calculation of compensating signals
- Generation of firing angles of switching devices

Generation of proper PWM firing is the most important part of DSTATCOM control and has a great impact on the compensation objectives, transient as well as steady state performance. Since a DSTATCOM shares many concepts to that of a STATCOM at transmission level, a few control algorithms have been directly implemented to a DSTATCOM, incorporating Pulse Width Modulation (PWM) switching, rather than Fundamental Frequency switching (FFS) methods. This project makes attempt to Compare the following schemes of a DSTATCOM for reactive power compensation and power factor correction based on:

1. Phase Shift Control
2. Decoupled Current Control

The performance of DSTATCOM with different control schemes have been tested through digital simulations with the different system parameters. The switch on time of the DSTATCOM and the load change time are also mentioned.

Phase Shift Control

In this control algorithm the voltage regulation is achieved in a DSTATCOM by the measurement of the rms voltage at the load point and no reactive power measurements are required. Fig.3 shows the block diagram of the implemented scheme.

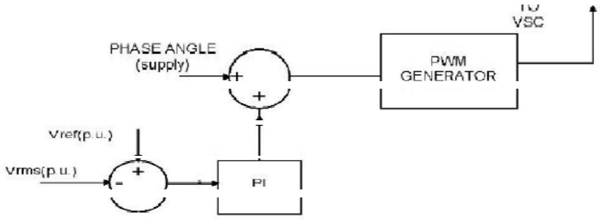

Fig.3. Block diagram of phase shift control

Sinusoidal PWM technique is used which is simple and gives a good response. The error signal obtained by comparing the measured system rms voltage and the reference voltage, is fed to a PI controller which generates the angle which decides the necessary phase shift between the output voltage of the VSC and the AC terminal voltage. This angle is summed with the phase angle of the balanced supply voltages, assumed to be equally spaced at 120 degrees, to produce the desired synchronizing signal required to operate the PWM generator. In this algorithm the D.C. voltage is maintained constant using a separate dc source.

Decoupled Current Control p-q theory

This algorithm requires the measurement of instantaneous values of three phase voltage and current. Fig.4. shows the block diagram representation of the control scheme. The compensation is achieved by the control of id and iq. Using the definition of the instantaneous reactive power theory for a balanced three phase three wire system, the quadrature component of the voltage is always zero, the real (p) and the reactive power (q) injected into the system by

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the DSTATCOM can be expressed under the dq reference frame as:

$$p = v_d i_d + v_q i_q$$
$$q = v_q i_d - v_d i_q$$

Since vq=0, id and iq completely describe the instantaneous value of real and reactive powers produced by the DSTATCOM when the system voltage remains constant. Therefore the instantaneous three phase current measured is transformed by abc to dqo transformation. The decoupled d axis component id and q axis component iq are regulated by two separate PI regulators. The instantaneous id reference and the instantaneous iq reference are obtained by the control of the dc voltage and the ac terminal voltage measured. Thus, instantaneous current tracking control is achieved using four PI regulators.

A Phase Locked Loop (PLL) is used to synchronize the control loop to the ac supply so as to operate in the abc to dqo reference frame. The instantaneous active and reactive powers p and q can be decomposed into an average and an oscillatory component. Where _p and q are the average part and ~p and ~q are oscillatory part of real and reactive instantaneous powers. The compensating currents are calculated to compensate the instantaneous reactive power and the oscillatory component of the instantaneous active power. In this case the source transmits only the non-oscillating component of active power. Therefore the reference source currents is and is in α-β coordinate are expressed as:

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ 0 \end{bmatrix}$$

These currents can be transformed in a-b-c quantities to find the reference currents in a-b-c coordinate

$$\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}$$

Where io is the zero sequence components which is zero in 3-phase 3-wire system

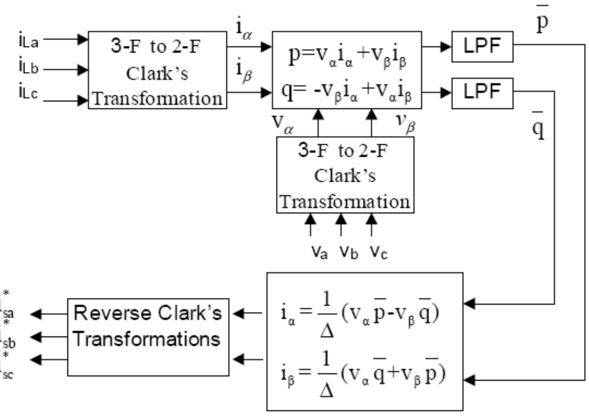

Fig.4. block diagram of decoupled theory based control of DSTATCOM

5. SIMULATION RESULTS

In this work, the performance of VSC based power devices acting as a voltage controller is investigated. Moreover, it is assumed that the converter is directly controlled (i.e., both the angular position and the magnitude of the output voltage are controllable by appropriate on/off signals) for this it requires measurement of the rms voltage and current at the load point. The DSTATCOM is commonly used for voltage sags mitigation and harmonic elimination at the point of connection.

The DSTATCOM employs the same blocks as the DVR, but in this application the coupling transformer is connected in shunt with the ac system, as illustrated in Fig.8. The VSC generates a three-phase ac output current which is controllable in phase and magnitude. These currents are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. Active and reactive power exchanges between the VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1) Voltage regulation and compensation of reactive power;
2) Correction of power factor
3) Elimination of current harmonics.

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With DSTATCOM compensation:

Case: 1 (an inductive load is applied .2seconds after the start of the simulation) Considering that the DSTATCOM is connected in shunt with the line. Initially there is a fixed inductive load is connected to the line. After 0.2 seconds the circuit breaker is closed an inductive load is applied, but in both the cases we observe that there is no drop in the terminal voltage due to the injection of reactive power by the DSTATCOM. .Therefore the load is maintained at unity power factor. The top window shows that there is no change in the voltage waveform and it is maintained at unity power factor. The second window shows the variations in the currents when inductive loads are applied at different instances of the Simulation. The simulation block and corresponding results for this case are shown in Fig.17 and Fig.18 respectively and the real and reactive powers are shown in Fig.19.

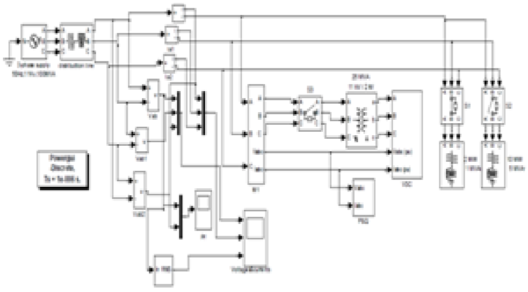

Fig.17. Simulink model of compensated lines with inductive load

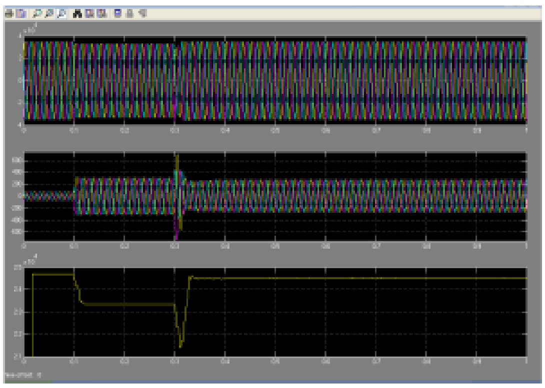

Fig.18. Load voltage, load current & load voltage magnitude respectively with Inductive load in the compensated line

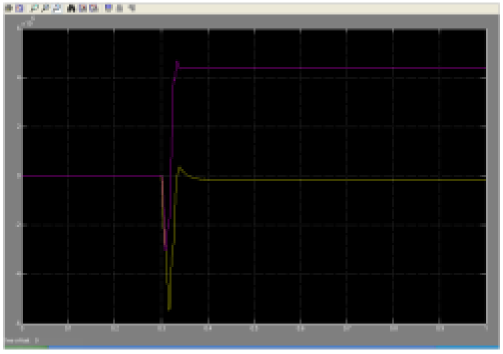

Fig.19. Reactive power of compensated lines with inductive load

Case: 2 (an capacitive load is applied at .2seconds after the start of the simulation) Considering that the DSTATCOM is connected in shunt with the line. Initially there is a fixed inductive load is connected to the line. After 0.2 seconds the circuit breaker is closed a capacitive load is applied, but in both the cases we observe that there is no rise in the terminal voltage due to the absorption of reactive power by the DSTATCOM. Therefore the load is maintained at unity power factor. The top window shows that there is no change in the voltage waveform and it is maintained at unity power factor. The second window shows the variations in the currents when inductive loads are applied at different instances of the simulation. The simulation block and corresponding results for this case are shown in Fig.20 and Fig.21 respectively and the real and reactive powers are shown in Fig.22.

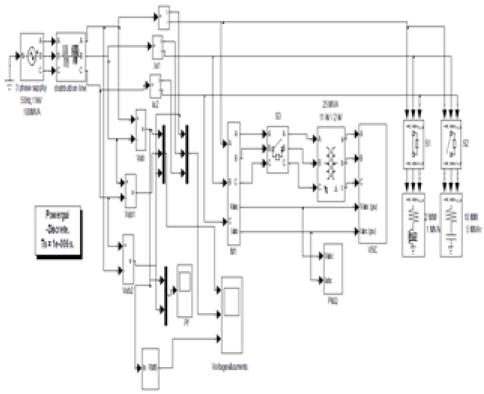

Fig.20. Simulink model of compensated lines with capacitive load

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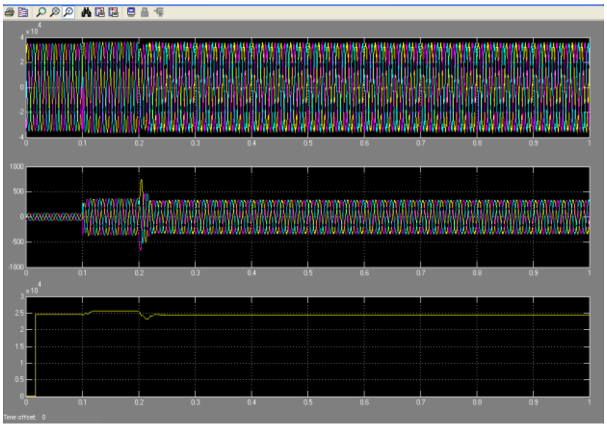

Fig.21. Load voltage, load current & load voltage magnitude respectively with Capacitive load in the compensated line

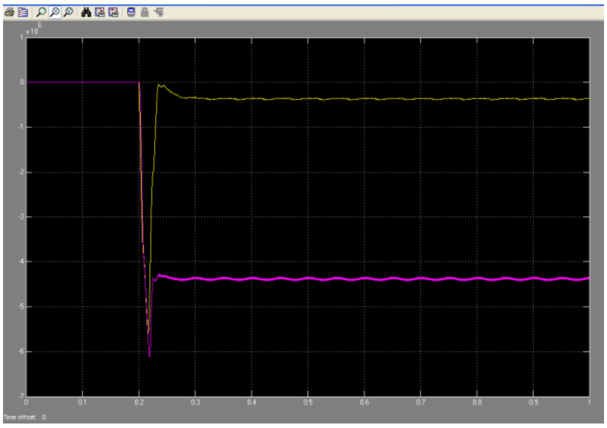

Fig.22. Reactive power of compensated lines with capacitive load

6. Conclusions

Custom Power (CP) devices can be used, at reasonable cost, to provide high power quality and improved power service. Detailed modeling is presented and results are discussed with different case studies. These Custom Power devices provide solutions to power quality at the medium voltage distribution network level. This project presents the detailed modeling of one of the custom power products, DSTATCOM is presented using instantaneous PQ theory, used for the control of DSTATCOM are discussed. These control algorithms are described with the help of simulation results under linear loads. The control scheme maintains the power balance at the PCC to regulate the dc capacitor voltages. PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. The control scheme was tested under a wide range of operating conditions, and it was observed to be very robust in every case. Extensive simulations were conducted to gain insight into the impact of capacitor size on DSTATCOM harmonic generation, speed of response of the PWM control and transient overshooting. It was observed that an undersized capacitor degrades all three aspects. On the other hand, an oversized capacitor may also lead to a PWM control with a sluggish response but it will reduce DSTATCOM harmonic generation and transient Overshooting. It is concluded that a DSTATCOM though is conceptually similar to a STATCOM at the transmission level; its control scheme should be such that in addition to complete reactive power compensation, power factor correction and voltage regulation the harmonics are also checked, and for achieving improved power quality levels at the distribution end.

FUTURE WORK:

This project presents a detailed modeling and analysis of one of the custom power device DSTATCOM. Instantaneous Decoupled Current Control or instantaneous p-q theory is discussed in detailed and verified through detailed simulations by developing the models in MATLAB simulink using the sim power system control tool boxes. Now we are posing a challenge to complete If the remaining control strategies which includes the synchronous frame theory, regulation of Bus and DC link voltage, and ANN based Adaline theory .these control strategies are implemented and studied in detail through various simulations then it would be of immense help for the real time implementation of the DSTATCOM across all over the globe. If thrown light on other custom power devices like the Dynamic voltage Regulator (DVR), and Unified power quality conditioner (UPQC), applying different strategies then we can bring a revolution in the control of power in the distribution system.

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