Compensation Of AC And DC Loads Of A Three-Phase DSTATCOM By Using A Fast-Acting DC-Link Voltage Controller

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Abstract

The DSTATCOM consists of a current-controlled Voltage-Source Inverter (VSI) which injects current at the Point of Common Coupling (PCC) through inductor. The operation of VSI is supported by a dc storage capacitor with proper dc voltage across it.

The transient response of the (DSTATCOM) is very important while compensating rapidly unbalanced and nonlinear loads. Any change in the load affects the dc-link voltage directly .The sudden removal of load would result in an increase in the dc-link voltage above the reference value, where as sudden increase in load would reduce the dc-link voltage below its reference value. The proper operation of DSTATCOM requires variation of the dc-link voltage controller within the prescribed limits. Conventionally, a Proportional-Integral (PI) controller is used to maintain the dc-link voltage to the reference value. It uses deviation of the capacitor voltage from its reference value as its input. However the transient response of the conventional PI dc-link controller is slow.

To maintain the dc-link voltage at the reference value, the dc-link capacitor needs a certain amount of real power, which is proportional to the difference between the actual and reference voltages. To overcome the disadvantage of the conventional PI dc-link voltage controller, a fast-acting dc-link voltage controller is proposed. To maintain the dc-link voltage of fast acting controller reference value is proportional to the difference between the squares of the actual and reference voltages. Mathematical equations are given to compute the gains of the conventional controller based on fast-acting dc-link voltage controllers to achieve similar fast transient response. The value of the dc-link capacitor can be selected based on its ability to regulate the voltage under transient conditions..

The efficiency of the proposed controller over the conventional dc-link voltage controller has been developed in MATLAB environment, simulated and obtained related waveforms.

Keywords— DSTATCOM, Voltage-Source Inverter (VSI), Proportional-Integral (PI) controller, MATLAB.

INTRODUCTION

Now a days due to different types of power electronic based equipment, nonlinear and unbalanced loads, has improving the power-quality problems in the power distribution network. They cause excessive neutral currents, overheating of electrical apparatus, poor power factor, voltage distortion, high levels of neutral-to-ground voltage, and interference with communication systems. The literature records the evolution of different custom power devices to mitigate the above power-quality problems by injecting voltages/currents or both into the system.

To avoid these type of problems the shunt-connected custom power device, called the Distribution static compensator (DSTATCOM), injects current at the point of common coupling (PCC). The newly presented A Three phase DSTATCOM to Compensating AC and DC Loads with A Fast-Acting DC-Link voltage controller [1]. So that harmonic filtering, power factor correction, and load balancing can be achieved. The DSTATCOM consists of a current-controlled voltage-source inverter (VSI) which injects current at the PCC through the interface inductor. The operation of VSI is supported by a dc storage capacitor with proper dc voltage across it. This process is called the compensation. For this compensation process is a dc-link voltage controller is should be used, which will regulate the dc voltage to the reference value.

POWER QUALITY PROBLEMS

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.2.1, 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.

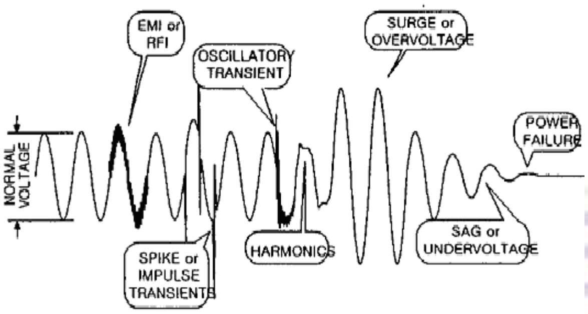

Fig.1 Power quality problems

If exceeds few cycles, motors, robots, servo-drives and machine tools cannot provide control. 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. Some of the power quality disturbance wave forms are shown in Fig 1. 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.

FACTS CONTROLLERS AND CONVERTERS

The most advanced solution to compensate reactive power is the use of a Voltage Source Converter (VSC) incorporated as a variable source of reactive power. These systems offer several advantages compared to standard reactive power compensation solutions. Reactive power control generated by generators or capacitor banks alone normally is too slow for sudden load changes and demanding applications, such as wind farms or arc furnaces. Compared to other solutions a voltage source converter is able to provide continuous control, very dynamic behavior due to fast response times and with single phase control also compensation of unbalanced loads. The ultimate aim is to stabilize the grid voltage and minimize any transient disturbances.

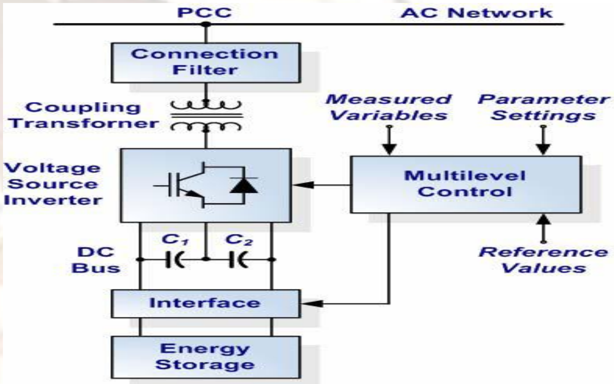

Fig.2 Basic STATCOM configuration

STATCOM converters are designed to mitigate the described phenomena with solutions based on Power Converter System (PCS) platforms providing the following control features:

Power factor correction (cosΠ control).

- Voltage control.
- Active harmonics cancellation.
- Flicker mitigation.
- Unsymmetrical load balancing.

STATCOM solutions can be implemented alone or in combination with switched capacitor banks.

DISTRIBUTION STATIC COMPENSATOR

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator 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. 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). The shunt-connected custom power device, called the distribution static compensator (DSTATCOM), injects current at the Point of Common Coupling (PCC) so that harmonic filtering, power factor correction, and load balancing can be achieved. The DSTATCOM consists of a current-controlled Voltage-Source Isnverter (VSI) which injects current at the PCC through the interface inductor. The operation of VSI is supported by a dc storage capacitor with proper dc voltage across it.

The shunt voltage controller is a voltage source converter connected in parallel with the load bus bar through a transformer or a reactor, Fig.4.5. The difference between the DVR and the SVC is that instead of injecting a voltage, the current through the reactance is controlled. The shunt voltage controller is normally used for power factor correction, voltage flicker, active filtering, etc., rather than voltage mitigation. For faults originated close to the SVC, on the same voltage level or close to the load, the impedance seen by the SVC will be very low. Since the contribution to the bus bar voltage equals the injected current multiplied by the impedance, a very high reactive current will be drawn during such a fault.

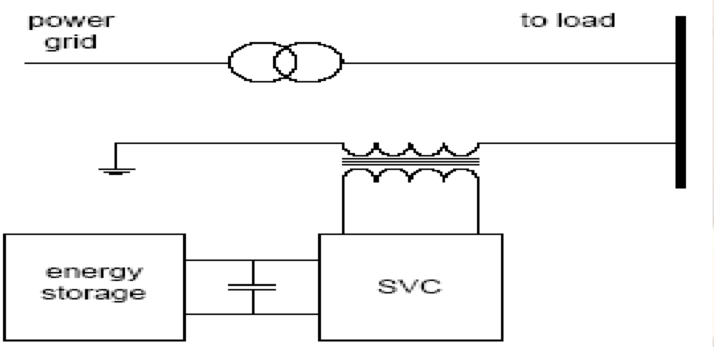

Fig.3 Example of a standard configuration for DSTATCOM

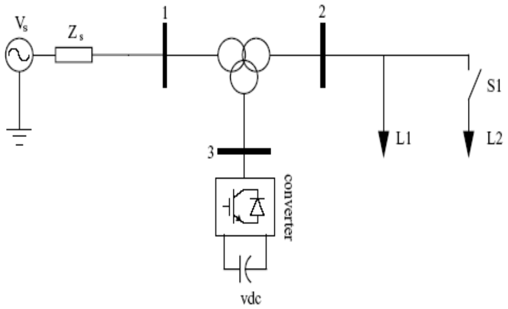

Fig.4 Single-line diagram of the test system for D-STATCOM

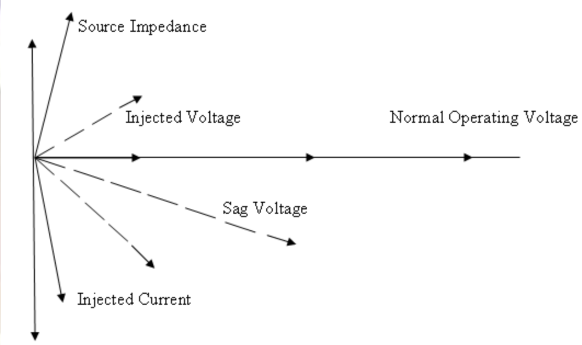

Fig.5 Phasor Diagram for Shunt Voltage Controller

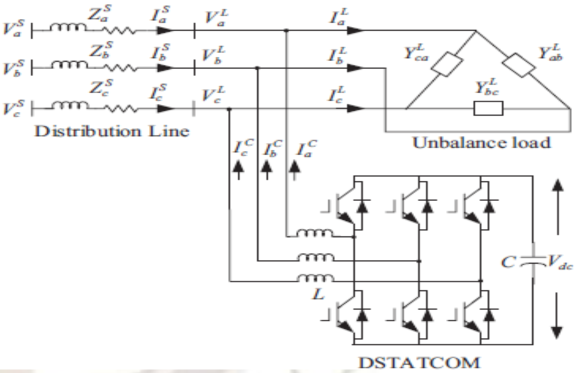

Fig.6 A radial distribution system with an unbalance load and a DSTATCOM

Dc-Link Voltage Controllers:

As mentioned before, the source supplies an unbalanced nonlinear ac load directly and a dc load through the dc link of the DSTATCOM, as shown in Fig. 1. Due to transients on the load side, the dc bus voltage is significantly affected. To regulate this dc-link voltage, closed-loop controllers are used. The Proportional-Integral-Derivative (PID) control provides a generic and efficient solution to many control problems. The control signal from PID controller to regulate dc link voltage is expressed as

$$P_{dc}= K_p(V_{dcref}-V_{dc})+ K_i \int(V_{dcref}-v_{dc})dt+k_d(V_{dcref}-V_{dc})/dt$$

k_p,ki and K_d are Proportional,Iintegral, and Derivative gains of the PID controller, respectively. The proportional term provides overall control action proportional to the error signal. An increase in proportional controller gain reduces rise time and steady-state error but increases the overshoot and settling time. An increase in integral gain reduces steady state error but increases overshoot and settling time. Increasing derivative gain will lead to improved stability. However, practitioners have often found that the derivative term can behave against anticipatory action in case of transport delay. A cumbersome trial-and-error method to tune its parameters made many practitioners switch off or even exclude the derivative term. Therefore, the description of conventional and the proposed fast-acting dc-link voltage controllers using PI controllers are given in the following subsections.

Conventional DC-Link Voltage Controller:

The conventional PI controller used for maintaining the dc-link voltage is shown in Fig.4.9 To maintain the dc-link voltage at the reference value, the dc-link capacitor needs a certain amount of real power, which is proportional to the difference between the actual and reference voltages. The power required by the capacitor can be expressed as follows

$$P_{dc}= K_p(V_{dcref}-V_{dc})+ K_i \int(V_{dcref}-v_{dc})dt$$

The dc-link capacitor has slow dynamics compared to the compensator, since the capacitor voltage is sampled at every zero crossing of phase supply voltage. The sampling can also be performed at a quarter cycles depending upon the symmetry of the dc-link voltage waveform. The drawback of this conventional controller is that its transient response is slow, especially for fast-changing loads. Also, the design of PI controller parameters is quite difficult for a complex system and, hence, these parameters are chosen by trial and error. Moreover, the dynamic response during the transients is totally dependent on the values of K_p and K_i when P_{dc} is comparable to P_{lavg} .

Fast-Acting DC Link Voltage Controller:

To overcome the disadvantages of the aforementioned controller, an energy-based dc-link voltage controller is proposed. Which is proportional to the difference between the squares of the actual and reference voltages, the power required by the capacitor can be expressed as follows

$$P_{dc} = K_p(V^2_{dcref} -V^2_{dc})+K_i \int(V^2_{dcref} -V^2_{dc})dt$$

k_p and ,ki are proportional and integral gains of the PI controller. The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required.

An error signal is obtained by comparing the reference voltage with the voltage measured at the load point. The PI controller process the error signal and generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

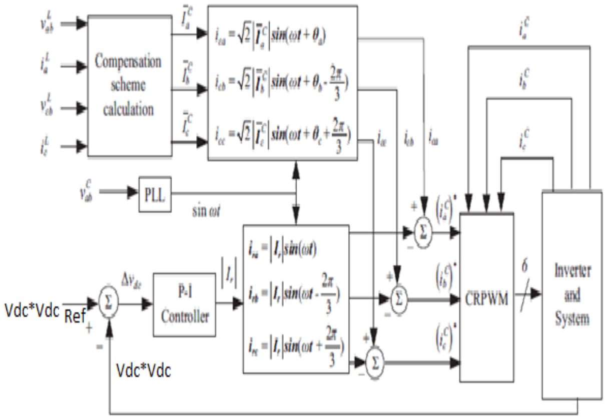

Fig.7 Block diagram of the Fast acting DC-Link proposed DSTATCOM controller

The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle.

i.e., $V_A = \text{Sin } (\omega t +\delta)$

$V_B = \text{Sin } (\omega t +\delta-2\pi/3)$

$V_C = \text{Sin } (\omega t +\delta+2\pi/3)$

Selection of DC-Link Capacitor:

The value of the dc-link capacitor can be selected based on its ability to regulate the voltage under transient conditions. Let us assume that the compensator in Fig.5.1 is connected to a system with the rating of X kilovolt amperes. The energy of the system is given by X×1000 J/s. Let us further assume that the compensator deals with half (i.e.X/2) and twice (i.e.2X,) capacity under the transient conditions for n cycles with the system voltage period of T s. Then, the change in energy to be dealt with by the dc capacitor is given as

$$\Delta E=(2X -X/2)nT$$

Now this change in energy should be supported by the energy stored in the dc capacitor. Let us allow the dc capacitor to change its total dc-link voltage from $1.4V_m$ to $1.8V_m$ during the transient conditions where V_m is the peak value of phase voltage. Hence, we can write

$$1/2C_{dc}[(1.8V_m)^2 -(1.4V_m)^2]= (2X -X/2)nT$$

Which implies that

$$C_{dc}= 3XnT/(1.8V_m)^2 -(1.4V_m)^2$$

For example, consider a 10-kVA system (i.e., X=10 kVA), system peak voltage V_m=325.2 V, n=0.5, and T= 0.02 s. The value of computed using is 2216μF. Practically, 2000μF is readily available and the same value has been taken for simulation and experimental studies.
For computing proportional controller gain

$K_p= C_{dc}/2T_c$

Where T_c =Capacitor voltage ripple period as 0.01Sec

Then Kp computed as kp=0.11

$K_i=K_p/2$

Therefore K_i=0.055.

SIMULATION RESULTS AND ANALYSIS

Simulation Results:

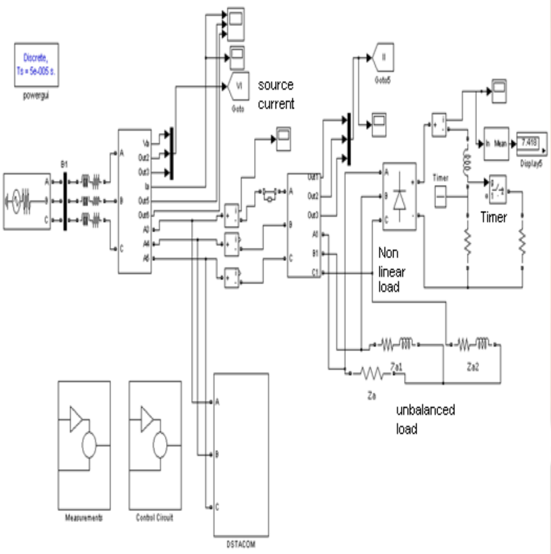

Fig.8 Simulation Diagram of Three-phase compensated system by using STATCOM

Basic simulation diagram is same in both the methods conventional and fast acting dc-link controlling methods. The difference is at input given to the PI-controllers.It consists of 400 volts supply for the circuit operation, Unbalanced load Z_a=25Ω, Z_b=44+j25.5Ω and Z_c=50+j86.6Ω,Non-linear load drawing a current of 5A.Timer is used to half the load between 0.4sec to 0.8sec the load is and 0.8 onwards its again Full load for observing setting time and transient response of the system.

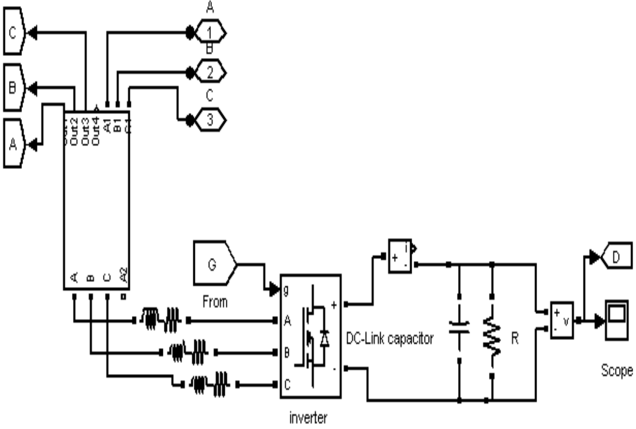

Fig.9 Simulation Diagram of VSI based DSTATCOM

In the above figure DC-Link capacitor2000$μ_F$, Here DC-Link capacitor regulate the voltage for operate the VSI for inverting DC to AC. Here Scope is used to Observing the DC-link capacitor voltage in both methods.

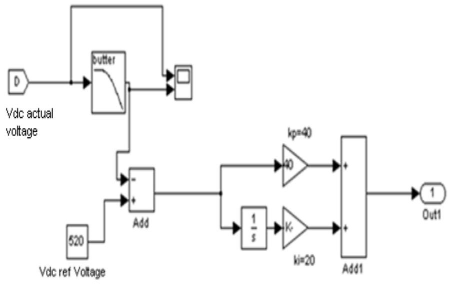

Fig.10 Simulation Diagram of Conventional PI-Controller

It was comparing and subtract the V_{dc} reference Voltage V_{dc} actual Voltages and error is computed by PI controller. Here proportional gain K_p=40 and integral gain k_i=20.

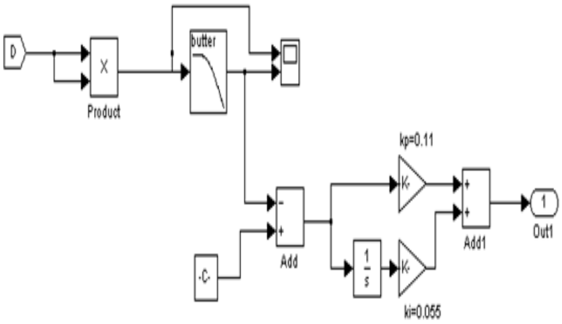

Fig.11 Simulation Diagram of Fast-acting PI-Controller

It was comparing and subtract the V^2_{dc} reference Voltage V^2_{dc} actual Voltages and error is computed by PI controller. Here proportional gain K_p=0.11and integral gain k_i=0.055.

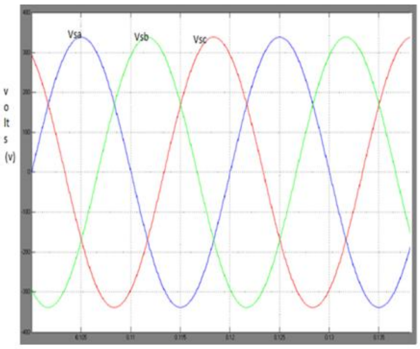

Fig.12 Supply Voltages

Above figure shows the supply voltages in the 3-phase compensated system. These voltag are denoted by V_{sa}, V_{sb} and V_{sc}.The supply voltages are 325 volts.

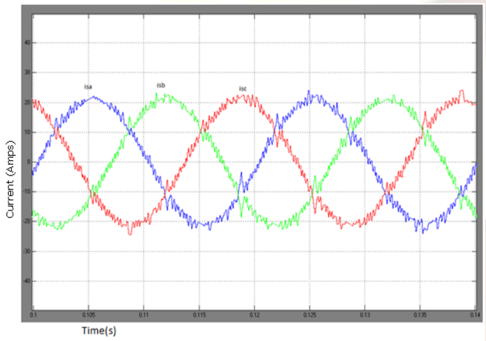

Fig.13 Compensated Source currents

Above figure shows the source currents in 3-phase compensated system. These currents are denoted by i_{sa}, i_{sb} and i_{sc}.The source currents in Three phases is 22amperes

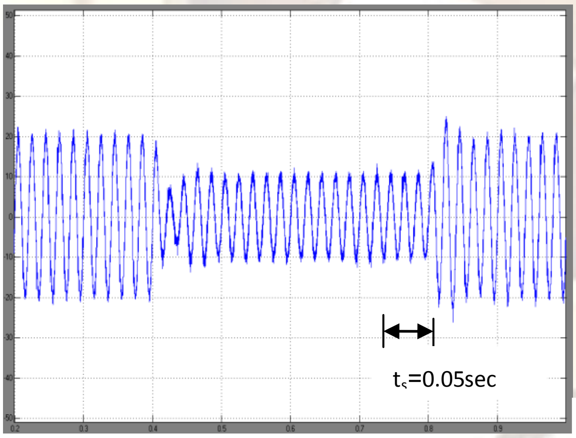

Fig.14 Transient response of Conventional controller Compensated Source Current in Phase 'a'.

From 0.4sec to 0.8sec the load is halved from 0.8 onwards again Full load. Whenever load changes occur fluctuations are generated. These fluctuations are settle down to take some time. This time is called settling time. The settling time of the system by using conventional controller, t_s=0.05sec is observed.

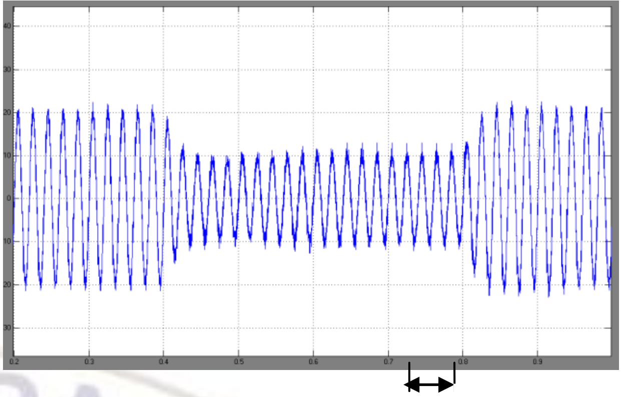

Fig.15 Transient response of] t_s=0.03 sec controller Compensated Source Current in Phase 'a'

Compared to conventional method settling time of the system reduced to t_s=0.03sec by using fast acting DC link controller is observed.

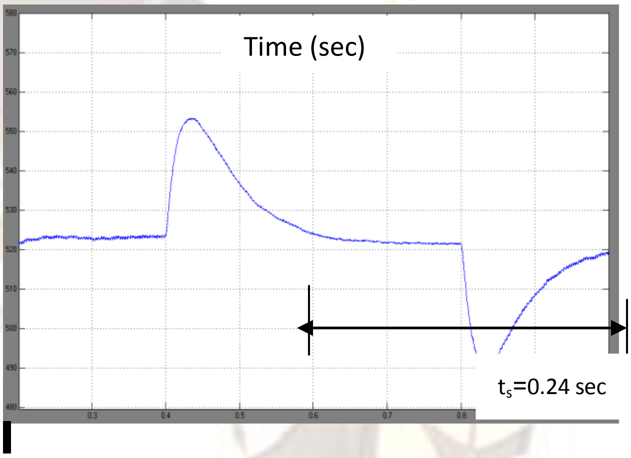

Fig.16 Transient response of Conventional controller DC-Link voltage

From 0.4sec to 0.8sec the load is halved whenever load is halved the dc link voltage is increases. It takes some time settle down this is called Settling time. From 0.8 onwards again Full load. The settling time of the system by using conventional controller, t_s=0.24sec.

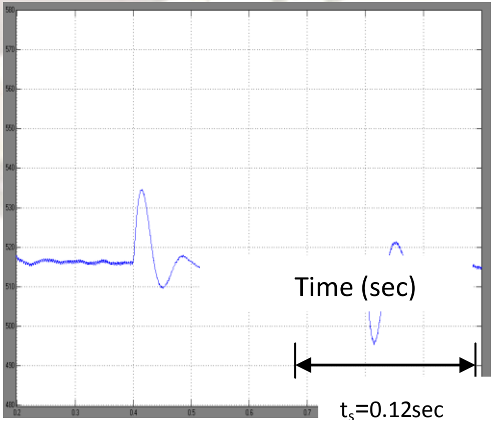

Fig.17 Transient response of Fast-acting controller DC-Link voltage

Compared to conventional method the settling time of the system is reduced to t_s=0.12sec by using fast acting DC link controller is observed.

CONCLUSIONS AND FUTURE SCOPE

CONCLUSIONS:

The control of DSTATCOM are discussed and also presented the power quality problems, consequences, and mitigation techniques, and the design and application of custom power device, D-STATCOM. The control scheme maintains the power balance at the PCC to regulate the dc capacitor voltages. A new PI control scheme has been implemented to control the VSI used in the D-STATCOM. The dc bus voltage of the DSTATCOM has been regulated to the reference dc bus voltage under varying loads.

The simulation results carried out showed that the D-STATCOM provides voltage regulation capabilities. It was also observed that the capacity for power compensation and voltage regulation of D-STATCOM depends on the rating of the dc storage device. In this Project an attempt was made to simulate the performance of D-STATCOM system for various power quality problems. Principle of Fast acting DC link control is described. Matlab/Simulink base model is developed and simulation results are presented. From the results, the transient response by the conventional controller t_s=0.05sec for current and t_s= 0.24sec for DC link voltage, where the transient response by using fast acting DC link controller is t_s=0.03sec for current and t_s=0.12sec for voltage. Finally, it is concluded that by fast acting DC-link control the settling time for DC link capacitor is reduced.

6.2 FUTURE SCOPE:

Application of same principle for AC voltage regulation during faults conditions. Application of same principle for other FACTS devices. Real time implementation of Fast Acting DC link voltage control scheme. The scope for further work is to minimize the power injection of D-STATCOM for compensation of the voltage sags by using FUZZY and combined NEURO-FUZZY control.

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