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Power Control Scheme of D-Statcom

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Abstract
This paper presents an instantaneous power control scheme of D-STATCOM for power factor and harmonic compensation. The control strategy has been introduced in order to enhance some steady-state performances and elimination of power quality disturbances. Power factor and harmonic current of a controlled feeder section are two vital roles in steady-state power distribution system operation. In this paper, a control scheme with constant power and sinusoidal current compensation is exploited. And the proposed control scheme is designed to correct the power factor. In order to correct the power factor, a power factor control loop is required and therefore included in the control block. The DC voltage across the DC link capacitor must be large enough and kept constant at that value to stabilize the compensation. Therefore, DC link voltage regulator must be added to the control loop. Simulation is performed in two cases. The first case was the control scheme introduced by [2]. Whereas, the second case was the proposed control scheme given in this paper. Both test cases were assigned to be operated with the same instruction. The test system was started from zero initial conditions with only the rectifier load. At t = 0.2 s, the DSTATCOM was connected to the system via the point of coupling connection. At t = 0.5 s, the RL load was switched on to increase the system loading .To verify the use of the control scheme in order to correct power factor and compensate harmonic current, a 22- kV power distribution feeder with three-phase rectifier load was tested. Real powers, reactive powers and DC link voltages of each case were observed and then compared.

I. INTRODUCTION

Electric power distribution network have become more increasingly important and plays an essential role in power system planning. This type of power systems has a major function to serve distributed customer loads along a feeder line; therefore under competitive environment of electricity market service of electric energy transfer must not be interrupted and at the same time there must provide reliable, stable and high quality of electric power [3-4]. To complete this challenge, it requires careful design for power network planning. There exist many different ways to do so. However, one might consider an additional device to be installed somewhere in the network. Such devices are one of capacitor bank, shunt reactor, series reactors, and automatic voltage regulators and/or recently developed dynamic voltage restorers, distribution static compensator (DSTATCOM), or combination of them [5-8]. The DSTATCOM [9-10] is a voltage source converter (VSC) based custom power technology which can perform as a reactive power source in power systems. The D-STATCOM can regulate magnitude of voltage at a particular AC bus, at the point where it is connected, via generating or absorbing reactive power from the system.

From D-STATCOM literature, a majority of research works have been conducted in order to enhance electric power quality due to distribution voltage variations, e.g. voltage sags or swells. Apart from these voltage variations, the-STATCOM is capable to enhance steady-state performances such as power factor and harmonic of a particular feeder portion. In this paper, a control scheme with constant Power and sinusoidal current compensation [2] is exploited. In order to correct the power factor additionally, a power factor control loop is required and therefore included in the control block.

II. STATIC SYNCHRONOUS COMPENSATOR

The improvement of electrical energy transmission efficiency has long been realized using passive power factor compensators containing shunt capacitors. Shunt capacitors are relatively inexpensive to install and maintain. Installing shunt capacitors in the load area or at the point where compensation is necessary increases the voltage stability. However, shunt capacitors have the problem of poor dynamics, poor voltage regulation and, beyond a certain level of compensation, a stable operating point is unattainable. Furthermore, the reactive power delivered by the shunt capacitor is proportional to the square of the terminal voltage; during low voltage conditions reactive power support drops, thus compounding the problem. In addition, shunt capacitor compensators may suffer from resonances with distributed inductances of the utility grid.

Nevertheless, in practice shunt capacitors have proven to be sufficiently effective, provided that the line voltage is sinusoidal. However due to proliferation of different power electronic converters amongst industrial and household equipment, which often draw explicitly on-sinusoidal current, in some cases the grid voltage quality is affected considerably. This being the case, the application of passive capacitive power factor compensators becomes problematic, since capacitor's reactance is decreased for higher voltage harmonic components leading to excessively increased capacitor currents. A typical industry solution for this problem is the application of tuned filter reactors in series with each compensation capacitor bank. This solution, however, significantly increases the required capacitance and rated voltage of the capacitors, as well as the cost of the whole compensator. This justifies application of more advanced techniques like SCR based dynamic power factor compensators or STACOM (Static Synchronous Compensator) converters, which can cope with all the problems mentioned above.

By definition, STATCOM is a static converter operated as a parallel connection static reactive power compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. In addition to system voltage control, which typically is the main task of the STATCOM, it may also be employed for additional tasks such as damping of power system oscillations, which results in improvement of the transmission capability.

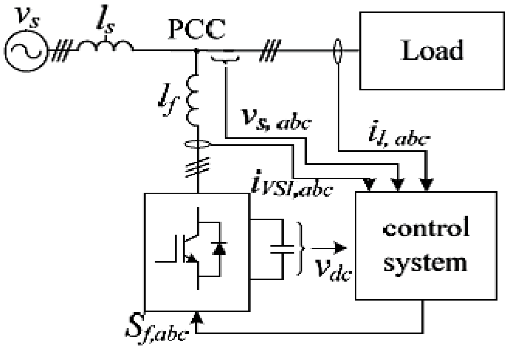

Fig.1. Basic structure of a STATCOM system

Structurally STATCOM is a voltage-source inverter (VSI) based device (Fig.1), which converts a DC input voltage into an AC output voltage in order to compensate the reactive power and improve power factor in the system. In case the system voltage drops sufficiently to force the STATCOM output to its ceiling, still its reactive power output is not affected by the grid voltage magnitude. Therefore, it exhibits constant current characteristics when the voltage is low. STATCOM can provide instantaneous and continuously variable reactive power in response to grid voltage transients, enhancing the grid voltage stability. The STATCOM operates according to voltage source principles, which together with unique PWM (Pulsed Width Modulation) switching of power switches gives it unequalled performance in terms of effective rating and response speed. This performance can be dedicated to active harmonic filtering and voltage flicker mitigation, but it also allows providing displacement power factor compensation of the load, thus improving the power factor.

III. INSTANTANEOUS POWER THEORY

The instantaneous power theory [2] is based on a definition of instantaneous real and reactive powers in time domain. To illustrate the theory, consider a set of instantaneous three phase quantity, for example v_a, v_b and v_c . It starts with transforming a set of three-phase variables in the abc into $\alpha\beta 0$ coordinates. This transformation is so-called as the Clark transformation as described follows. The below figure shows the Clarks transformation.

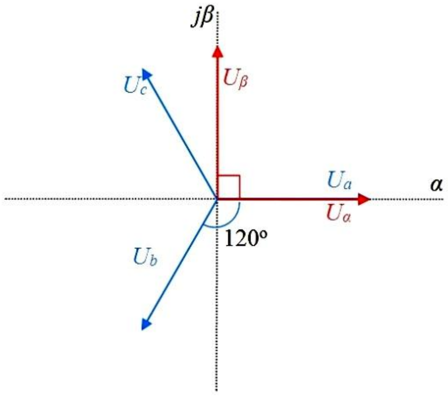

Fig.2.Clark Transformation

$$\begin{pmatrix} v_0 \\ v_\alpha \\ v_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \quad \text{----- (1)}$$

$$\begin{pmatrix} i_0 \\ i_\alpha \\ i_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \quad \text{----- (2)}$$

In three-phase, three-wire systems, there is no zero sequence components. If v_0 *and* i_0 are both neglected. The instantaneous complex power is useful. It can be applied for transient or steady-state analysis. The following equation is a compact form for the instantaneous real and reactive power definition and its inversion.

$$\begin{pmatrix} p \\ q \end{pmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} \quad \text{------- (3)}$$

These two powers can be separated into average components ($\overline{p}$ and $\overline{q}$) and oscillating components ($\tilde{p}$ and $\tilde{q}$) as shown in below equations..

$$p = \overline{p} + \tilde{p} \quad \text{--- (4)}$$

$$q = \overline{q} + \tilde{q} \quad \text{--- (5)}$$

The average values of both p and q agree with conventional real and reactive powers in AC circuits. The oscillating terms that naturally produce a zero mean give additional oscillating power flow without contribution of the energy transfer neither from the source to the load nor from the load to the source.

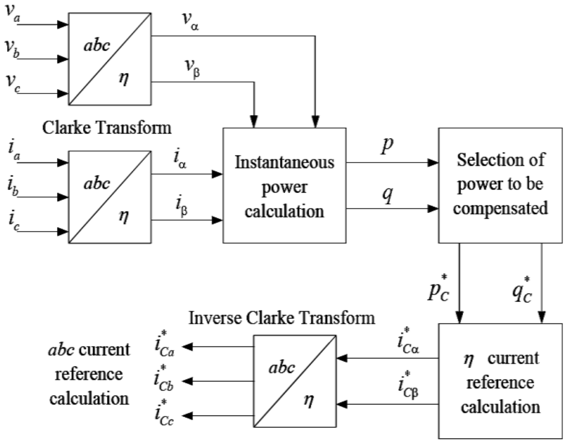

Fig.3.Control block of shunt current compensation based on the instantaneous power theory

$$\begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} = \frac{1}{{v_\alpha}^2 + {v_\beta}^2} \begin{pmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{pmatrix} \begin{pmatrix} p \\ q \end{pmatrix} \quad \text{----- (6)}$$

One important application of the instantaneous power theory is the shunt current compensation. The powers to be compensated can be simply determined by eliminating the oscillating real and reactive power components. The research conducted in this section aimed to compensate the source current become purely sinusoidal and deliver the minimum average real power to the load. The shunt current compensation based on the instantaneous power theory described in this section.

IV. DEVELOPED STATCOM CONTROL SYSTEM

The power compensation by D-STACOM can have various functions such as elimination of power oscillation; improvement of power factor elimination of harmonic current etc .power factor correction of a protected load can be included in the control scheme by zeroing reactive power supplied by the source. The compensator must supply the oscillating power components to the load. In order to compensate the oscillating power flow by means of PWM converters. The DC voltage across the DC link capacitor must be large enough and kept constant at that value to stabilize the compensation. Therefore, DC link voltage regulator must be added to the control loop

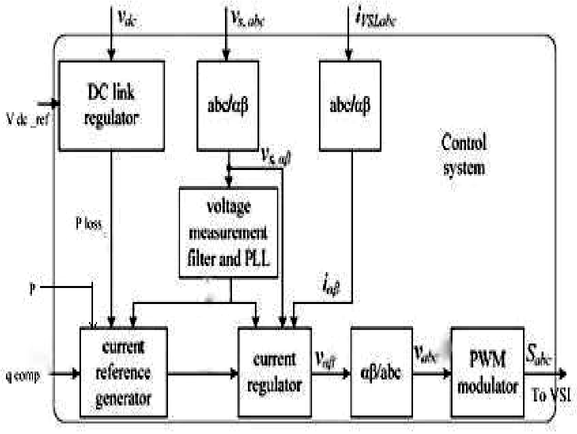

Fig.4.Overall control scheme

The overall control scheme is shown in the above figure. To separate the oscillating real power components a low-pass filter is used. Together with the switching and ohmic losses of the PWM converter, the instantaneous real power reference is formed. Similarly, the instantaneous reactive power reference can be set as zero to achieve unity power factor. With this power factor correction, the reactive power regulator is also added to the loop. The reference signals for generating the switching pattern to drive IGBT gates the current equations are

$$\begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} = \frac{1}{{v_\alpha}^2 + {v_\beta}^2} \begin{pmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{pmatrix} \begin{pmatrix} \widetilde{\overline{-p}} + \overline{p_{loss}} \\ -q \end{pmatrix} \quad \text{-- (7)}$$

The αβ current is transformed back to the abc coordinate for switching pattern generation as described by below equations

$$\begin{pmatrix} i_{ca} \\ i_{cb} \\ i_{c_c} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{c\alpha} \\ i_{c\beta} \end{pmatrix} \quad \text{------ (8)}$$

With this power factor correction, the reactive power regulator is also added to the loop the overview of the proposed control scheme can be depicted as shown in Fig.4. The regulation of DC link voltage and power factor correction achieved by using this control scheme.

V. SIMULATION RESULTS

To verify the use of the proposed control scheme in order to correct power factor and compensate harmonic current, a 22-kV power distribution feeder with three-phase rectifier loading as shown in Fig. 5 was employed. Table I gives information of the test system and D-STATCOM.

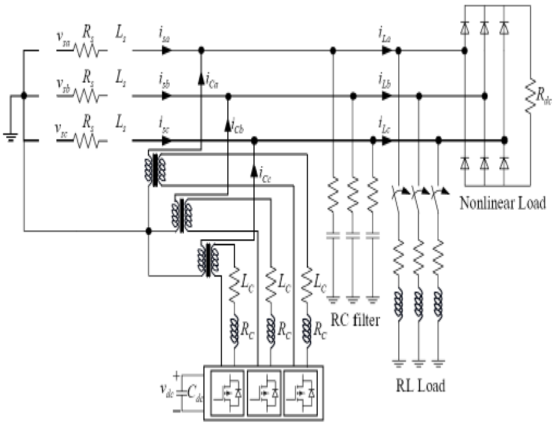

Fig.5. 22-kV power distribution feeder with three-phase rectifier loading

TABLE 1
PARAMETERS OF SYSTEM

Test system parameters	values
RL balanced load	R=50Ω,L=100mH
Non linear load	3-phase full wave rectifier load
Supply voltage	22KV,50HZ
DC capacitor	300μF
Reference Dc link voltage	9.5KV
Interface inductor	L_C=2mH.R_c=0.1Ω
RC filter	R=50Ω,C=1μF
RL source load	R=1Ω,L=4mH
Non linear load resistance	R_{dc}=300Ω

The test was divided into two cases. The first case was used the control scheme introduced by [2]. Whereas, the second case was the proposed control scheme given in this paper. Both test cases were assigned to be operated with the same instruction. The test system was started from zero initial conditions with only the rectifier load. At t = 0.2 s, the DSTATCOM was connected to the system via the point of coupling connection. At t = 0.5 s, the RL load was switched on to increase the system loading.

A. Case 1:

With the control strategy proposed by [2], the system response without D-STACOM in the time interval 0 – 0.2s was shown in Fig.6. At t = 0.2 – 0.5 s, the D-STATCOM was connected to compensate the non-linear load as responses shown in Fig. 7. It can be seen that the source current was shaped to be nearly sinusoidal. However, due to the PWM operation of the D-STATCOM, higher-order harmonic components were inevitably experienced. At t ≥0.5 s when the RL load switched, the source current was lagged the voltage at the point of coupling connection by21.6 degree corresponding to 0.9298 power factor lagging. This can be seen in Fig. 8.

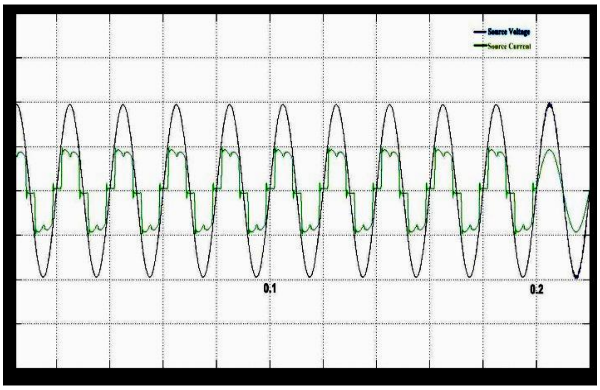

Fig.6. Response during t = 0 – 0.2 s for case 1

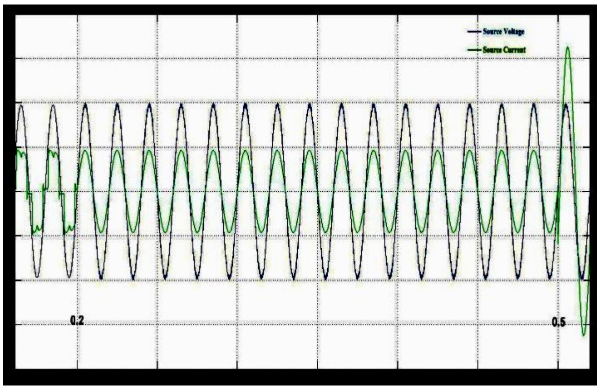

Fig.7. Response during t = 0.2 – 0.5 s for case 1

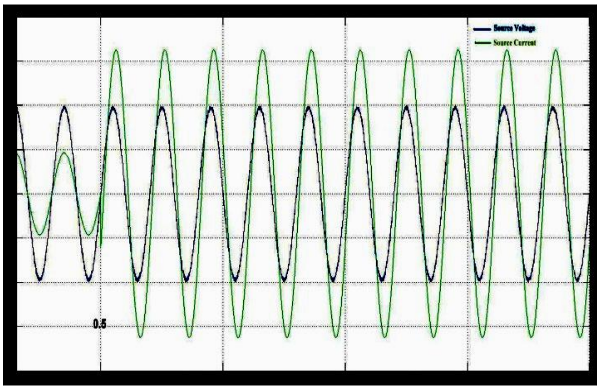

Fig.8. Response during t ≥ 0.5 s for case 1

B. Case 2:

With the control strategy proposed in this paper, the system response without D-STACOM in the time interval 0 – 0.2 s was shown in Fig.9. At t = 0.2 – 0.5 s, the D-STATCOM was connected to compensate the non-linear load as responses shown in Fig.10. It can be seen that the source current was shaped to be nearly sinusoidal. However, due to the PWM operation of the D-STATCOM, higher-order harmonic components were inevitably experienced. At t ≥ 0.5 s when the RL load switched, the source current that was previously lagged the voltage at the point of coupling connection in case1 was resumed to in-phase with the voltage waveform. This described the success of power factor correction by their active power control scheme made in this paper. This can be seen in Fig.11.

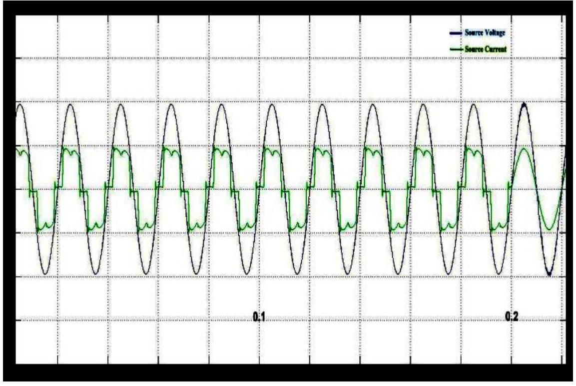

Fig.9. Response during t = 0 – 0.2 s for case 2

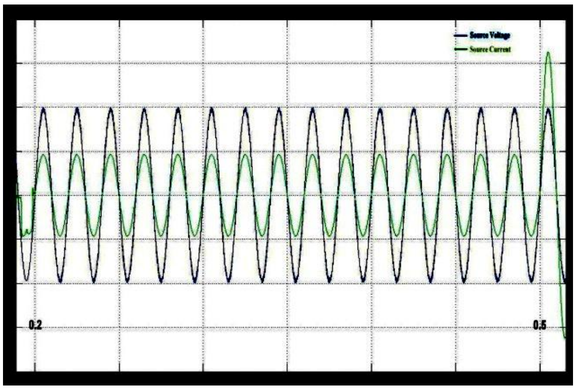

Fig.10. Response during t = 0.2 – 0.5 s for case 2

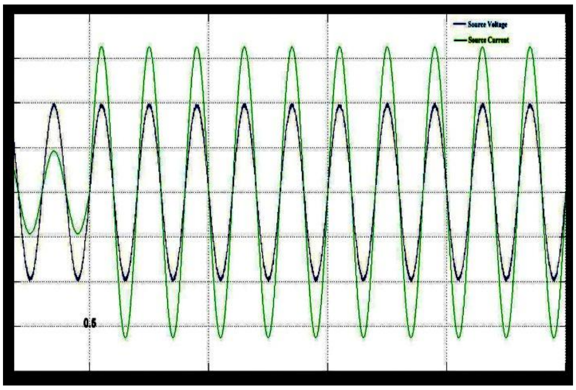

Fig.11. Response during t ≥ 0.5 s for case 2

C. Comparison:

This section gives comparison between the results from both cases. Real powers, reactive powers and DC link voltages of each case were observed and then compared. Figs12 – 14 present the comparison of which for real power, reactive power and DC link voltage, respectively. The response of the observed reactive powers clearly confirmed that during the overall operation, the proposed control scheme can well perform the function of power factor correction. This can be seen with the zero reactive power for case 2 in Fig. 13

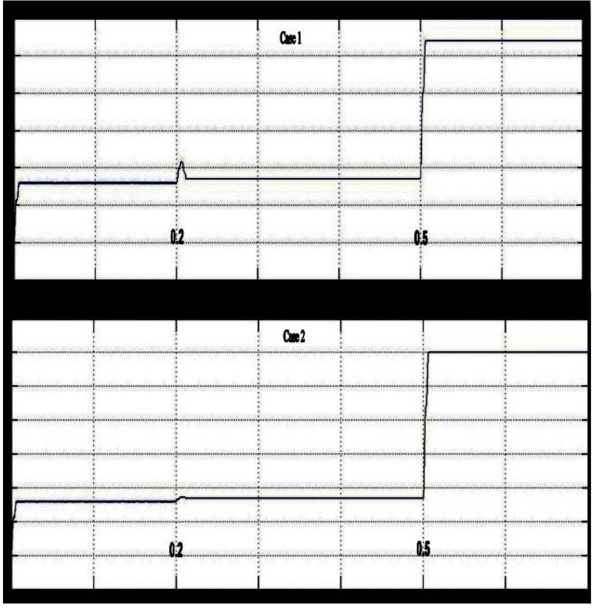

Fig.12. Comparison of instantaneous real power regulation

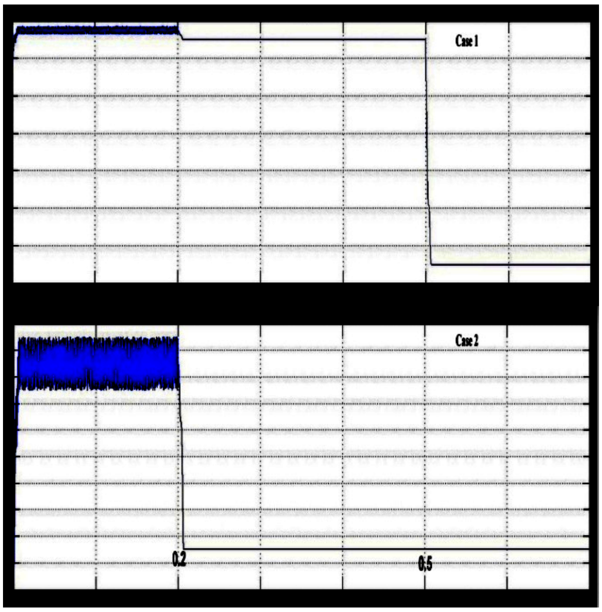

Fig.13. Comparison of instantaneous reactive power regulation

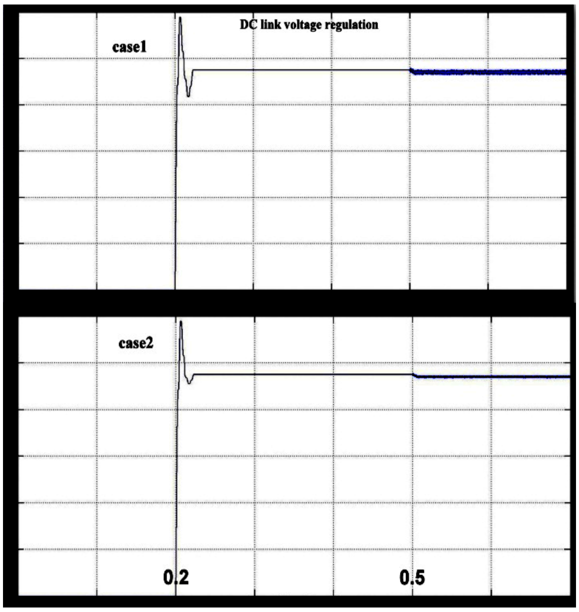

Fig.14. Comparison of DC link voltage regulation

VI. CONCLUSION

This paper presents a modified control scheme to compensate a distribution feeder loading with non-linear loads. The compensation consists of three main objectives that are a) Regulation of real powers delivering to loads, b) Regulation of DC link voltage to ensure PWM converter operation, and iii) correction of power factor. Modification of the control scheme made in this paper is to add the reactive power regulation into the control loop. With zero reactive power reference, unity power factor can be achieved. As a result, the modified control scheme can regulate DC link voltage and real power delivery at specified level while reactive power drawn from the load was cancelled by that injected from D-STATCOM.

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