Overview of SVC and statcom for instantaneous power control and power factor improvement

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Abstract: The main aim of this paper is to represents a modified instantaneous power control scheme of SVC and STATCOM for power factor and harmonic compensation. The proposed control strategy has been introduced in order to enhance some steady state performances besides its functional 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. Utilizing an already installed SVC and STATCOM to achieve these additional control objectives can help system operators to maximize overall system performances. Otherwise SVC and D-STATCOM both FACTS devices are used for power quality enhancement and harmonic reduction in the power system but the proposed control strategy provides additional objectives for system performance improvement. In this paper a control scheme with constant power and sinusoidal current compensation has been explained. In order to correct the power factor, a power factor control loop is required and therefore included in the control block. To verify the use of SVC and STATCOM for given system there is power distribution feeder with a three-phase rectifier load was tested. The simulation results showed that integration of the proposed reactive power control loop can correct the power factor of the controlled feeder to be better power factor.

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. To complete this challenge, it requires careful design for power network planning. Nowadays the most used charging devices for EV/HEV are unidirectional, that means they allow having power flow from grid to the vehicle battery, but many research institutions are trying to apply bidirectional charging devices, with battery to grid power flow. Some solutions have the battery, or some other energy source, like super capacitors or flywheels, included directly in the charging stations or UPS systems. Usually super capacitors in EV/HEV applications are used as hybrid energy sources together with other energy storage devices. In comparison with batteries the charging/discharging times of super capacitors are significantly shorter, which makes them an ideal solution for the devices that use electric motors to smooth the start-up current and voltage peaks. Battery energy storage system (BES) has the following features: modularity, environmentally benign, high efficiency, quick response. In that case using EV/HEV batteries could be reasonable. The ratio of the real power flowing to the apparent power in the circuit called power factor shows the amount of useful power transferred in an electric power system. With a power factor close to 1 the real power flow is highest and the grid does not contain reactive currents. The higher reactive currents increase the energy lost in the power system, and require larger wire cross section and other equipment, what increase the cost of full system. Different devices are used for power factor correction. The main principle of compensating device to produce the reactive current, that is opposite to reactive current source. Power factor compensating device needed to be putted as close as possible to the reactive power source to absorb reactive power near the load. 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, static compensator (STATCOM), or combination of them. The STATCOM is a voltage source converter (VSC) based custom power technology which can perform as a reactive power source in power systems. The 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 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 D-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 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. SVC

Fig. 1 shows a schematic diagram of a static var compensator. The compensator normally includes a thyristor controlled reactor (TCR), thyristor-switched capacitors (TSCs) and harmonic filters. It might also include mechanically switched shunt capacitors (MSCs), and then the term static var system is used. The harmonic filters (for the TCR-produced harmonics) are capacitive at fundamental frequency. The TCR is typically larger than the TSC blocks so that continuous control is realized. Other possibilities are fixed capacitors (FCs), and thyristor switched reactors (TSRs). Usually a dedicated transformer is used, with the compensator equipment at medium voltage. The transmission side voltage is controlled, and the Mvar ratings are referred to the transmission side.

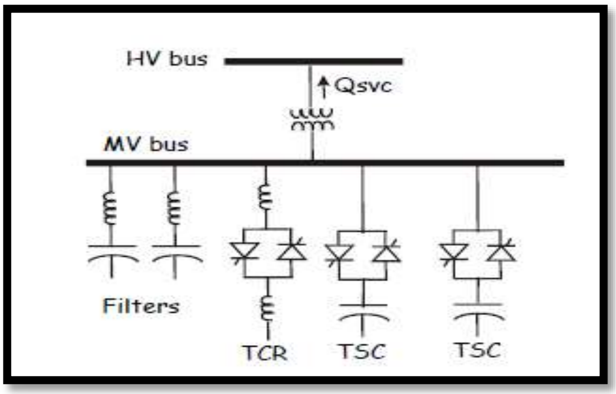

Fig. 1. Schematic diagram of an SVC

The rating of an SVC can be optimized to meet the required demand. The rating can be symmetric or asymmetric with respect to inductive and capacitive reactive power. As an example, the rating can be 200 Mvar inductive and 200 Mvar capacitive, or 100 Mvar inductive and 200 Mvar capacitive.

III. MODELING OF SVC

This section describes the appropriate models for dynamic studies: An SVC is in principle a controlled shunt susceptance. The voltage measurement converts the fundamental three phase waveforms to a RMS value. The conversion and filtering can be represented by an analog lag with around 10 ms time constant. The voltage regulator determines a value for Bref to make the error signal zero in the steady state. The voltage regulator is often purely integral control. The current may be obtained by multiplication of Bref and Vmeas. The susceptance regulator limits are determined by the physical size of the SVC (Bmin and Bmax). Today, the controls are digital so that various strategies can be implemented. For example, the "other signals" inputs to summing junction could be damping control.

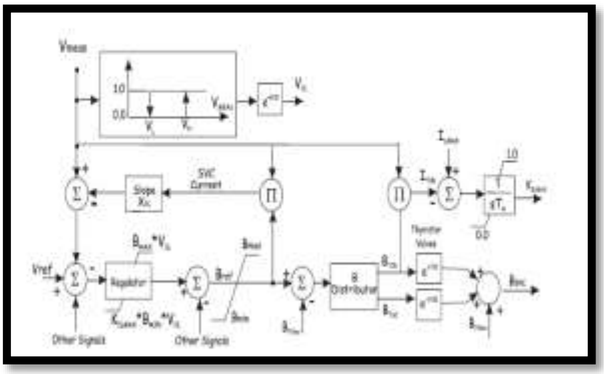

Fig. 2 SVC model for dynamic studies

The slope is defined as the ratio between the change of voltage and the change of the SVC current over the whole control range. It determines the steady-state operating point and is normally set between 2–5%. The thyristor susceptance control module is normally modelled by a time delay (Td2) of about 4 ms. An SVC might include a under voltage strategy which forces the susceptance to the lowest level to prevent contribution of the SVC to overvoltage following fault clearing. (In Fig. 2 the parameter VCL can become zero based on the selected values for VL and VH). A current limiter is normally provided to reduce the TCR current within a predefined time (T4 is about 1 second).

IV. STATCOM

The voltage-sourced converter (VSC) is the basic electronic part of a STATCOM, which converts the dc voltage into a three-phase set of output voltages with desired amplitude, frequency, and phase. Fig. 3 shows the simplest implementation of a STATCOM.

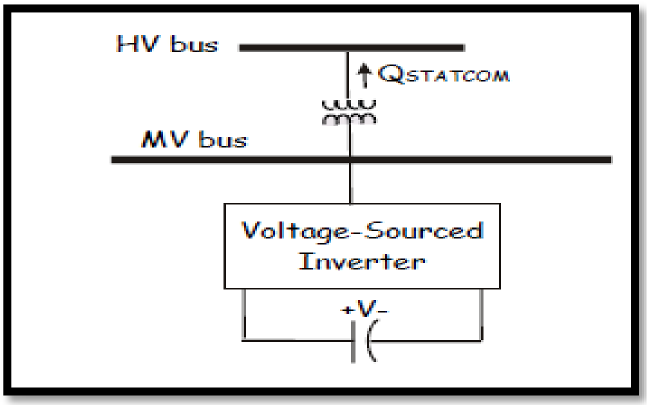

Fig.3 Schematic diagram of a basic STATCOM

There are different methods to realize a voltage-sourced converter for power utility application. Based on harmonics and loss considerations, pulse width modulation (PWM) or multiple converters are used. Inherently, STATCOMs have a symmetrical rating with respect to inductive and capacitive reactive power. For example, the rating can be 100 Mvar inductive and 100 Mvar capacitive. For asymmetric rating, STATCOMs need a complementary reactive power source. This can be realized for example with MSCs.

Modeling of STATCOM

Fig. 4 shows the STATCOM model for transient stability studies. STATCOM is in principle a controlled voltage source. In a real installation, the magnitude of the source voltage is controlled through dc voltage across the capacitor. Since this loop is very fast, the dc capacitor does not need to be modelled for dynamic stability studies. The regulator keeps the STATCOM current within the current limit (IMAX).

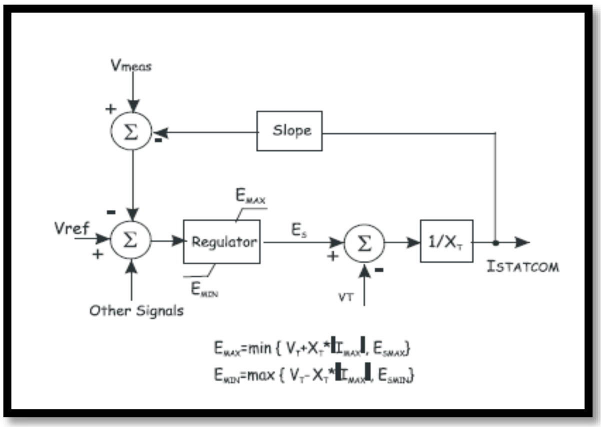

Fig. 4 STATCOM model for dynamic studies

Voltage Source Converter

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the „missing voltage". The „missing voltage" is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics. A special gate unit and voltage divider across each IGBT maintain an even voltage distribution across the series connected IGBTs. The gate unit not only maintains proper voltage sharing within the valve during normal switching conditions but also during system disturbances and fault conditions. A reliable short circuit failure mode exists for individual IGBTs within each valve position. Depending on the converter rating, series-connected IGBT valves are arranged in either a three-phase two-level or three level bridges. In three-level converters, IGBT valves may also be used in place of diodes for neutral point clamping. Each IGBT position is individually controlled and monitored via fiber optics and equipped with integrated anti parallel, free-wheeling diodes. Each IGBT has a rated voltage of 2.5 kV with rated currents up to 1500 A. Each VSC station is built up with modular valve housings which are constructed to shield electromagnetic interference (EMI). The valves are cooled with circulating water and water to air heat exchangers. PWM switching frequencies for the VSC typically range between 1-2 kHz depending on the converter topology, system frequency and specific application.

Energy Storage Circuit

Energy storage circuit is connected in parallel with the DC capacitor. The circuit carries the input ripple current of the converter and it is the main reactive energy storage element. The DC capacitor could be the charged by the battery source or could be recharged by the converter itself.

Controller

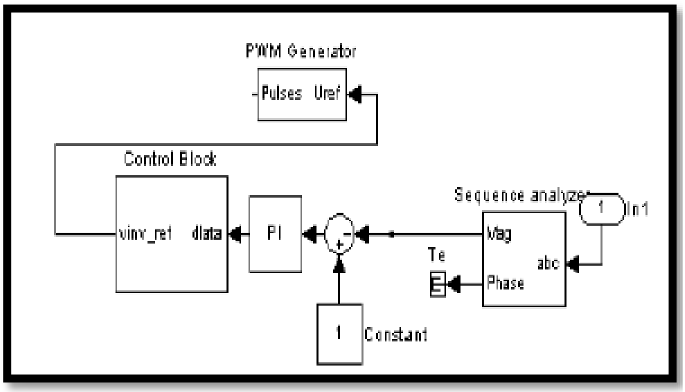

Figure-5 shows the block diagram of Controller system

The controller system is partially part of distribution system. Proportional-integral controller (PI Controller) is a feedback controller, which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value. In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit. PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves.

Control Strategy

Instantaneous Power Theory:-

As the name implied, the instantaneous power theory is based on a definition of instantaneous real and reactive powers in time domain. It is very useful not only in the steady-state but also in the transient state analysis for both three-phase systems with or without a neutral conductor. To illustrate the theory, let consider a set of instantaneous three phase quantity, for example Va, Vb and Vc. It starts with transforming a set of three-phase variables in the abc into αβ0 coordinates. This transformation is so-called as the Clark transformation as described follows.

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

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

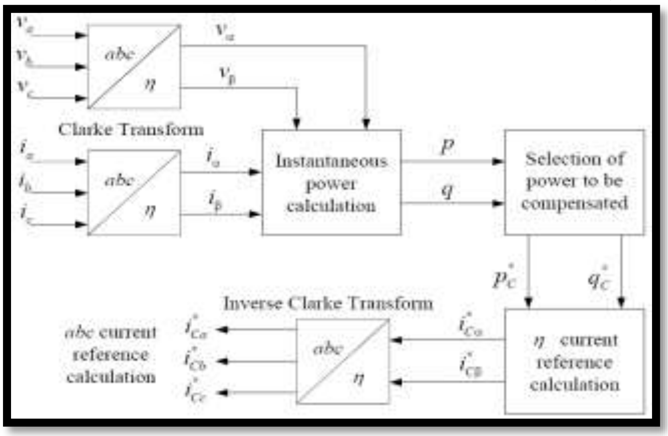

Fig. 6 Control block of shunt current compensation based on the instantaneous power theory

V. MODELLING AND SIMULATION

Modeling of 3-phase system without SVC & STATCOM

In the 3-phase system the power factor and active, reactive power parameters are very important as discussed in the above sections of this project. Now in the proposed system first of all we take a 3-phase system in which we create the 3-phase fault and check the values of power factor, line voltage, and line current and also check the effect on active and reactive power values. This is shown in the fig 7 below with the simulation results.

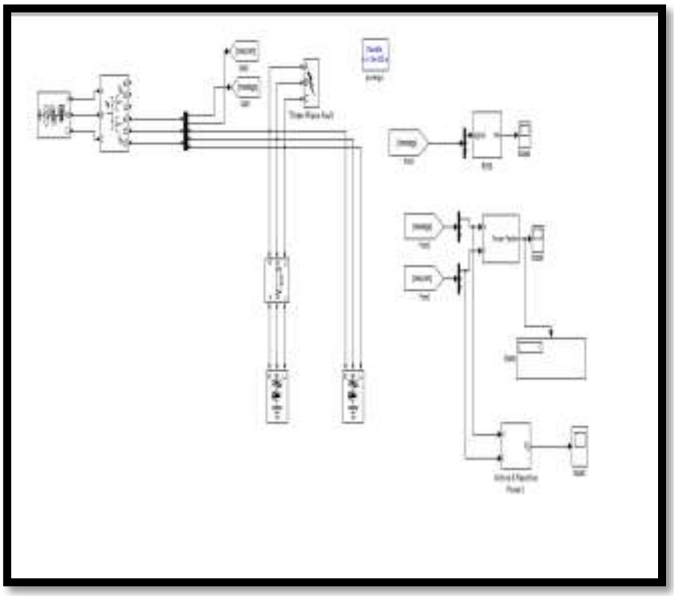

Fig 7-three phase system with the 3-phase fault and measurements block

VI. SIMULATION RESULTS:-

The simulation results in these sections shows the fluctuation in the value of power factor and it also shows the distortion and effect on active and reactive power also.

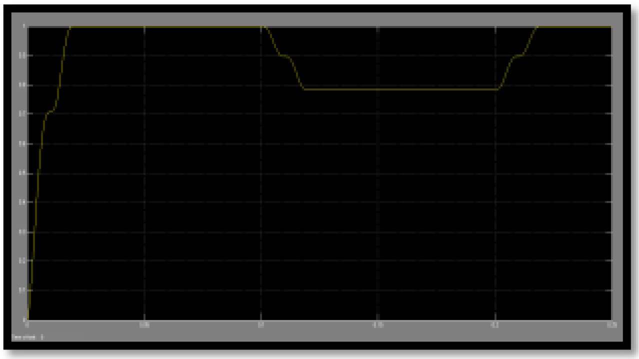

Fig 8-Distortion in line voltage Value

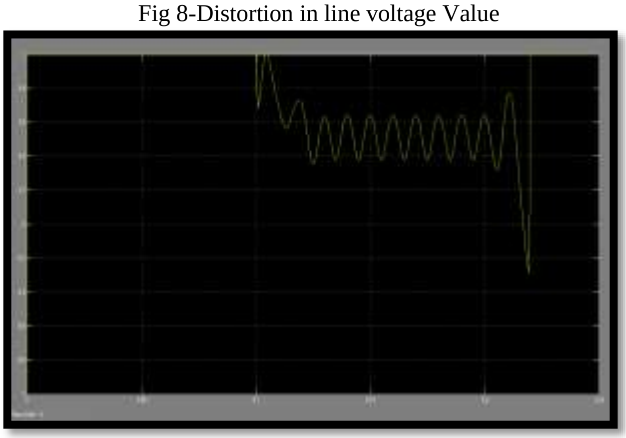

Fig 9-Fluctuation in power factor value

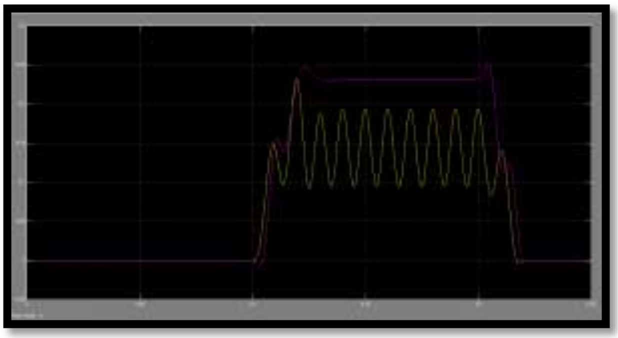

Fig 10-Active and Reactive Power value Fluctuation

Modeling of 3-phase system with STATCOM

Now we will provide STATCOM in the above proposed system with PI control strategy which will mitigate the distortion and fluctuation from the proposed system. Fig 11 below shows the 3-phase system with STATCOM and Control strategy of the proposed system with instantaneous power control theory which improves power factor and also provides control for active and reactive power value in the system.

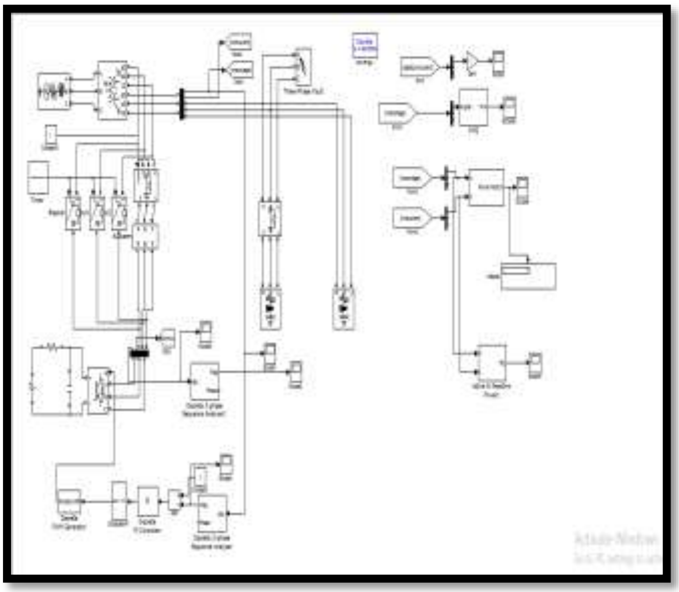

Fig 11-Proposed System with STATCOM connected

Simulation results after connection of STATCOM

Now after the proposed control strategy and simulation the STATCOM improves the power factor value and also shows that distortion and fluctuation are remove from the system. These are shown in the simulation results of fig bellows:-

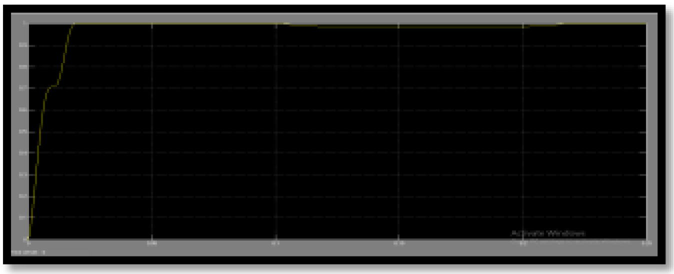

Fig 12 Line Voltage after STATCOM connection

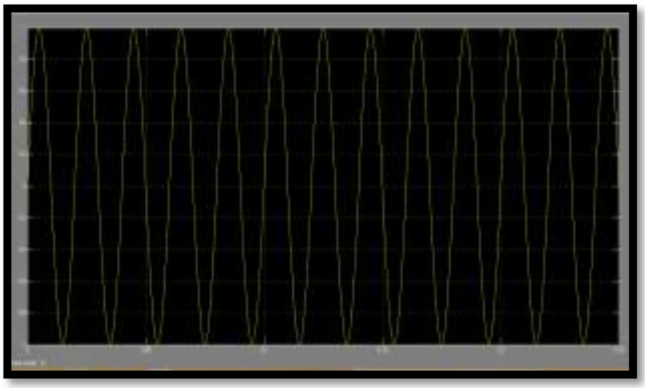

Fig 13-STATCOM current pure sinusoidal

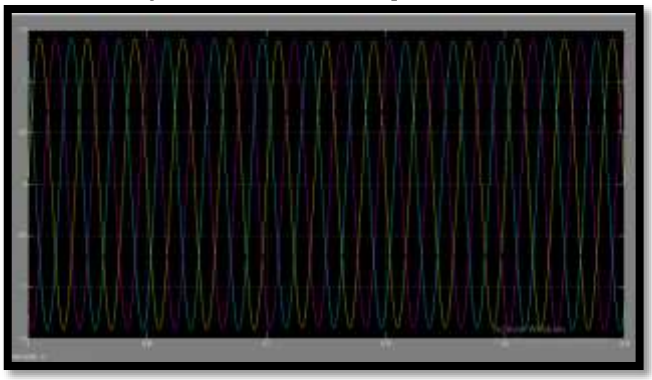

Fig 14-Three phase system output pure sinusoidal

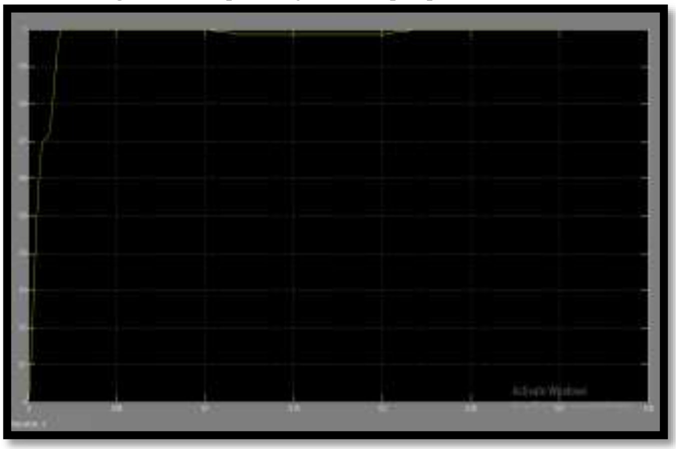

Fig 15-Improvement in power factor

VII. 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 i) regulation of real powers delivering to loads, ii) 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 STATCOM.

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