

## A Voltage Controlled Dstatcom for Power Quality Improvement

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**Abstract:** Due to increasing complexity in the power system, voltage sag is becoming one of the most significant power quality problems. Voltage sag is a short reduction voltage from nominal voltage, occurs in a short time. If the voltage sags exceed two to three cycles, then manufacturing systems making use of sensitive electronic equipments are likely to be affected leading to major problems. It ultimately leads to wastage of resources (both material and human) as well as financial losses. This is possible only by ensuring that uninterrupted flow of power is maintained at proper voltage levels. This project tends look at the solving the sag problems by using custom power devices such as Distribution Static compensator (D-STATCOM). Proposed scheme follows a new algorithm to generate reference voltage for a distribution static compensator (DSTATCOM) operating in voltage-control mode. The proposed scheme ensures that unity power factor (UPF) is achieved at the load terminal during nominal operation, which is not possible in the traditional method. Also, the compensator injects lower currents therefore, reduces losses in the feeder and voltage-source inverter. Further, a saving in the rating of DSTATCOM is achieved which increases its capacity to mitigate voltage sag. Nearly UPF is maintained, while regulating voltage at the load terminal, during load change. The state-space model of DSTATCOM is incorporated with the deadbeat predictive controller for fast load voltage regulation during voltage disturbances. With these features, this scheme allows DSTATCOM to tackle power-quality issues by providing power factor correction, harmonic elimination, load balancing, and voltage regulation based on the load requirement.

**Keyword:-** Distribution Static compensator; Pulse Width Modulation; Active Power Filters; Battery Energy Storage Systems; Distribution STATIC Synchronous Compensators; Distribution Series Capacitors; Distribution static compensator; Surge Arresters; Super-conducting Magnetic Energy Systems; Static Electronic Tap Changers; Solid State Transfer Switches; Solid State Fault Current Limiter; Static Var Compensator; Thyristor Switched Capacitors; Uninterruptible Power Supplies.

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### I. Introduction

Both electric utilities and end users of electrical power are becoming increasingly concerned about the quality of electric power. The term power quality has become one of the most prolific buzzword in the power industry. The issue in electricity power sector delivery is not confined to only energy efficiency and environment but more importantly on quality and continuity of supply or power quality and supply quality. Electrical Power quality is the degree of any deviation from the nominal values of the voltage magnitude and frequency. Power quality may also be defined as the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment. From a customer perspective, a power quality problem is defined as any power problem manifested in voltage, current or frequency deviations that result in power failure or disoperation of customer equipment. Power quality is certainly a major concern in the present era, it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage swells, harmonics, flickers, interruptions and notches.

### II. Power Quality Problems

#### 2.1 Voltage SAG

A Voltage Sag is a momentary decrease in the root mean square (RMS) voltage between 0.1 to 0.9 per unit, with a duration ranging from half cycle up to 1 min. It is considered as the most serious problem of power quality. It is caused by faults in the power system or by the starting of large induction motor.

#### 2.2 Voltage Swell

Voltage swell is defined as an increase in the root mean square (RMS) voltage from 1.1 to 1.8 per

unit for duration from 0.5 cycles to 1 min. Voltage swells are not as important as voltage sags because they are less common in distribution systems. The main causes for voltage swell are switching of large capacitors or start/stop of heavy loads.

### 2.3 Harmonics

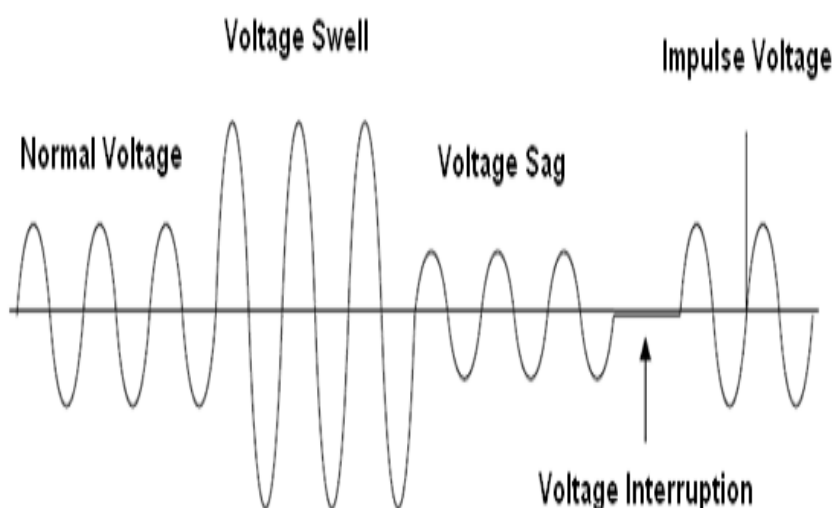
The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency. The main causes for harmonic distortion are rectifiers and all non-linear loads, such as power electronics equipment including VSDs.

### 2.4 Voltage Transients

They are temporary and undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20kV) that last for a very short time.

### 2.5 Flicker

Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz. The main causes are frequent start/stop of electric motors (for instance elevators), oscillating loads. The following Fig. 1 shows the sketch of a voltage waveform.



**Fig.1** voltage waveform.

## III. Solution Of Power Quality Problems

There are two approaches to tackle power quality problems. (a) Actions taken from the customer side or (b) Actions taken from the utility side. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The second approach consists of line conditioning systems that suppress or counteracts the power system disturbances. Currently, line conditioning systems are based on pulse width modulation (PWM) converters connected to low voltage and medium voltage distribution system in shunt mode or in series. However, with the restructuring of the power sector and with shifting trend towards distributed and dispersed generation, the line-conditioning systems or utility side solutions will play a major role in improving the inherent supply quality. Though there are many different methods to mitigate voltage sags and swells, the use of a custom Power device is considered to be the most efficient method.

The term custom power refers to the use of power electronics controllers in a distribution system, especially, to deal with various power quality problems. There are many types of Custom Power devices. Some of these devices include: Active Power Filters (APF), Battery Energy Storage Systems (BESS), Distribution STATIC Synchronous Compensators (DSTATCOM), Distribution Series Capacitors (DSC), Distribution static compensator(DSTATCOM), Surge Arresters (SA), Super-conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid -State Transfer Switches (SSTS), Solid State Fault Current Limiter (SSFCL), Static Var Compensator (SVC), Thyristor Switched Capacitors (TSC), and Uninterruptible Power Supplies (UPS). In this paper,an overview of the DSTATCOM, its functions, configurations, components, operating modes, voltage injection methods and closed loop control of the DSTATCOM limitations.

#### IV. Block Diagram of Proposed Method

A distribution system suffer from current as well as voltage related power quality problems, which include poor power factor, distorted source current and voltage disturbances .A STATCOM connected to the point of common coupling has been utilized to mitigate both types of PQ problems .When operating in CCM it injects reactive and harmonics components of load current to make source current balanced ,sinusoidal and in phase with the point of common coupling voltages. In VCM the STATCOM regulates PCC voltages at a references value to protect critical loads from voltage disturbances such as sag, swell and unbalances. However the advantages of CCM and VCM cannot be achieved simultaneously with one active filter device, since two modes are independent of each other.

A load works satisfactorily for a permissible voltage range. Hence, it is not necessary to regulate the PCC voltage at 1.0 p.u. While maintaining 1.0-p.u. voltage, DSTATCOM compensates for the voltage drop in feeder. For this, the compensator has to supply additional reactive currents which increase the source currents. This increases losses in the voltage-source inverter (VSI) and feeder. Another important aspect is the rating of the VSI. Due to increased current injection, the VSI is de-rated in steady-state condition. Consequently, its capability to mitigate deep voltage sag decreases. Also, UPF cannot be achieved when the PCC voltage. STATCOM can be replaced by DSTATCOM. The proposed block diagram is shown in the fig.2.It is applicable for both linear as well as non linear load.

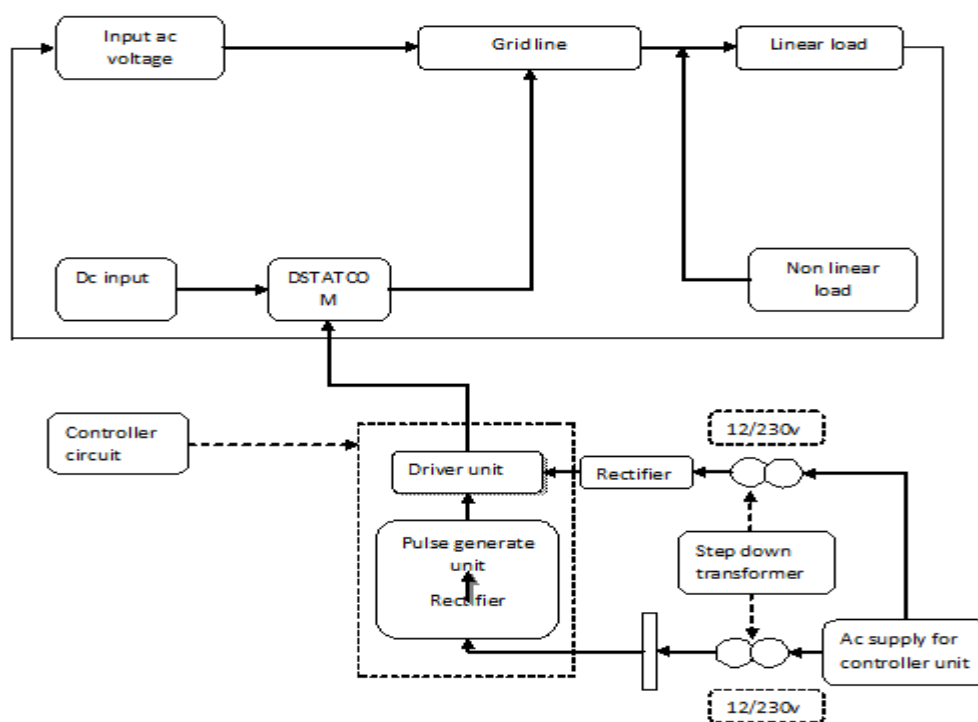


Fig.2 proposed block diagram

#### V. Distribution Static Compensator (D-Dstatcom)

##### 5.1 Introduction

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. 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; and
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. The basic configuration of the D-STATCOM is shown in the fig.3.

### 5.2 Configuration Of Dstatcom

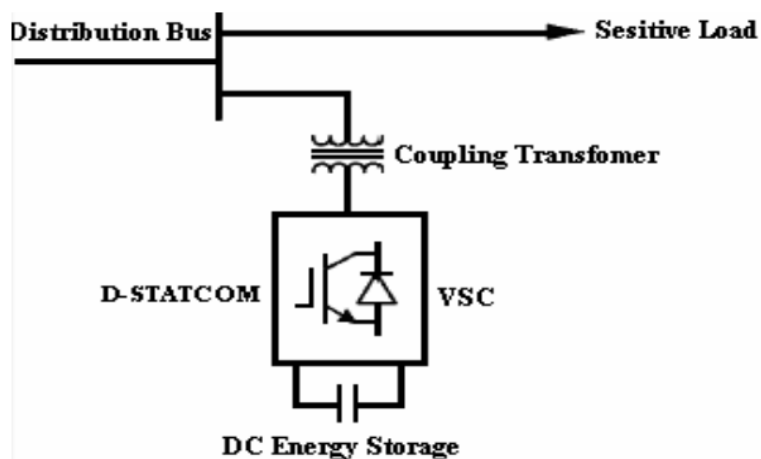


Fig.3 Configuration of a DSTATCOM.

### 5.3 Modelling Of Dstatcom

The singlephase equivalent circuit of STATCOM is shown in the fig.4.

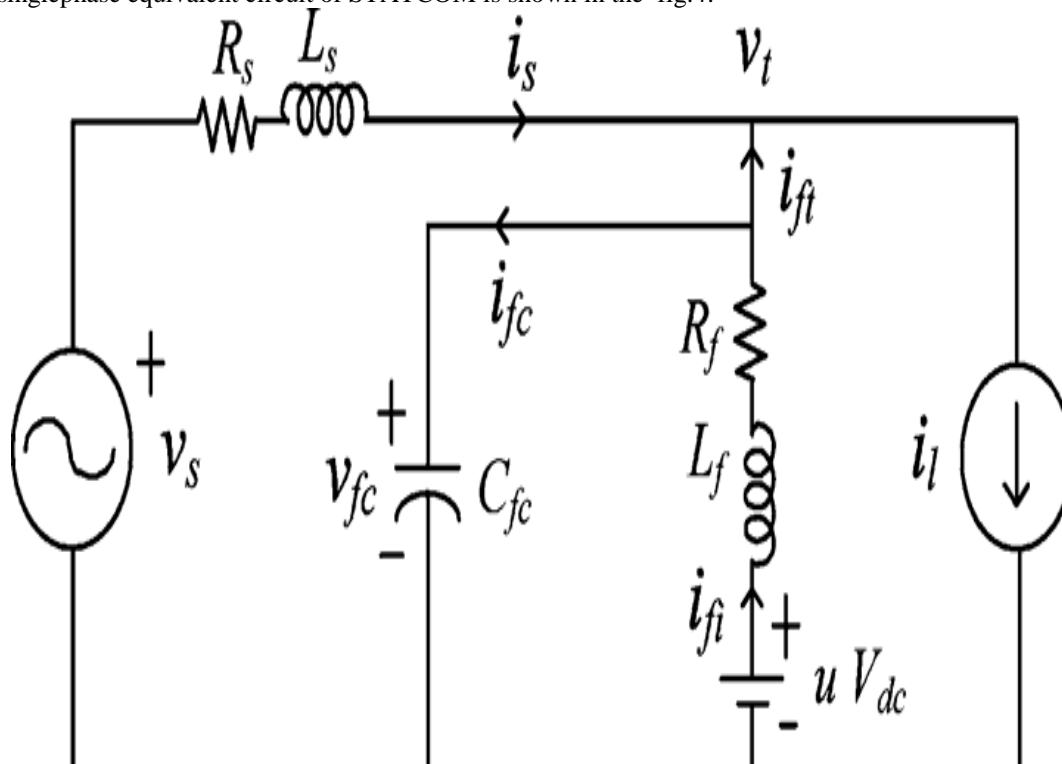


Fig.4 single phase equivalent circuit of STATCOM

The state-space equation for the circuit is given by

$$\dot{x} = Ax + Bz$$

where

$$A = \begin{bmatrix} 0 & \frac{1}{C_{fc}} & 0 \\ -\frac{1}{L_f} & -\frac{R_f}{L_f} & 0 \\ -\frac{1}{L_s} & 0 & -\frac{R_s}{L_s} \end{bmatrix},$$

$$B = \begin{bmatrix} 0 & -\frac{1}{C_{fc}} & 0 \\ \frac{V_{dc}}{L_f} & 0 & 0 \\ 0 & 0 & \frac{1}{L_s} \end{bmatrix},$$

$$x = [v_{fc} \quad i_{fi} \quad i_s]^t, \quad z = [u \quad i_{ft} \quad v_s]^t.$$

$$x(t) = e^{A(t-t_0)} x(t_0) + \int_{t_0}^t e^{A(t-\tau)} B z(\tau) d\tau. \quad (2)$$

The equivalent discrete solution of the continuous state is obtained by replacing  $t_0 = k T_d$  and  $t = (k + 1) T_d$  as follows:

$$x(k + 1) = e^{AT_d} x(k) + \int_{kT_d}^{T_d+kT_d} e^{A(T_d+kT_d-\tau)} B z(\tau) d\tau. \quad (3)$$

In (3),  $k$  and  $T_d$  represent the  $k$ th sample and sampling period, respectively. During the consecutive sampling period, the value of  $z(\tau)$  is held constant, and can be taken as  $z(k)$ . After simplification and changing the integration variable, (3) is written as [18]

$$x(k + 1) = e^{AT_d} x(k) + \int_0^{T_d} e^{A\lambda} B d\lambda z(k). \quad (4)$$

Equation (4) is rewritten as follows:

$$x(k + 1) = G x(k) + H z(k) \quad (5)$$

where  $G$  and  $H$  are sampled matrices, with a sampling time of  $T_d$ . For small sampling time, matrices  $G$  and  $H$  are calculated as follows:

$$G = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{bmatrix} = e^{AT_d} \approx I + AT_d + \frac{A^2 T_d^2}{2} \quad (6)$$

$$H = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} \end{bmatrix} = \int_0^{T_d} e^{A\lambda} B d\lambda$$

$$\approx \int_0^{T_d} (I + A\lambda) B d\lambda. \quad (7)$$

From (6) and (7),  $G_{11} = 1 - T_d^2/2L_f C_{fc}$ ,  $G_{12} = T_d/C_{fc} - T_d^2 R_f/2L_f C_{fc}$ ,  $G_{13} = 0$ ,  $H_{11} = T_d^2 V_{dc}/2L_f C_{fc}$ ,  $H_{12} = -T_d/C_{fc}$ , and  $H_{13} = 0$ . Hence, the capacitor voltage using (5) is given as

$$v_{fc}(k + 1) = G_{11}v_{fc}(k) + G_{12}i_{fi}(k) + H_{11}u(k) + H_{12}i_{ft}(k). \quad (8)$$

As seen from (8), the terminal voltage can be maintained at a reference value depending upon the VSI parameters  $V_{dc}$ ,  $C_{fc}$ ,  $L_f$ ,  $R_f$ , and sampling time  $T_d$ . Therefore, VSI parameters must be chosen carefully. Let  $v_t^*$  be the reference load terminal voltage. A cost function  $J$  is chosen as follows [8]:

$$J = [v_{fc}(k + 1) - v_t^*(k + 1)]^2. \quad (9)$$

The cost function is differentiated with respect to  $u(k)$  and its minimum is obtained at

$$v_{fc}(k + 1) = v_t^*(k + 1). \quad (10)$$

The deadbeat voltage-control law, from (8) and (10), is given as

$$u^*(k) = \frac{v_t^*(k + 1) - G_{11}v_{fc}(k) - G_{12}i_{fi}(k) - H_{12}i_{ft}(k)}{H_{11}}. \quad (11)$$

In (11),  $v_t^*(k + 1)$  is the future reference voltage which is unknown. One-step-ahead prediction of this voltage is done using a second-order Lagrange extrapolation formula as follows:

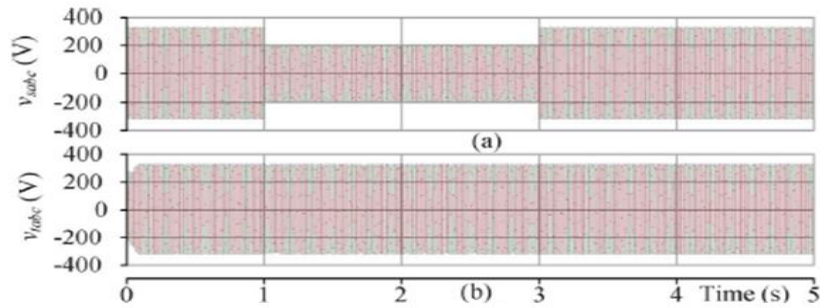
$$v_t^*(k + 1) = 3v_t^*(k) - 3v_t^*(k - 1) + v_t^*(k - 2). \quad (12)$$

### 5.3 Advantages of Dstatcom

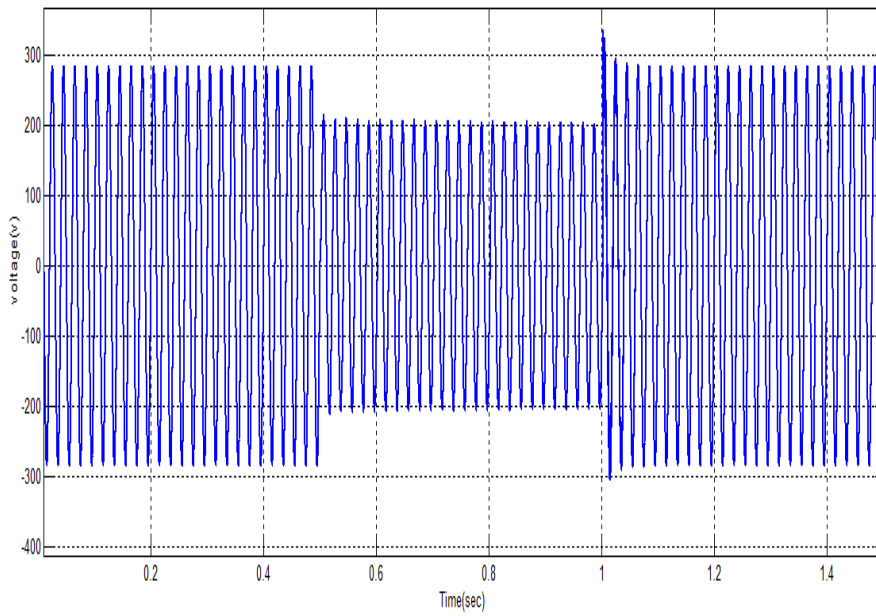
- Power factor correction
- Harmonic elimination
- Load balancing, and voltage regulation
- Based on the load requirement.

## VI. Simulation Results

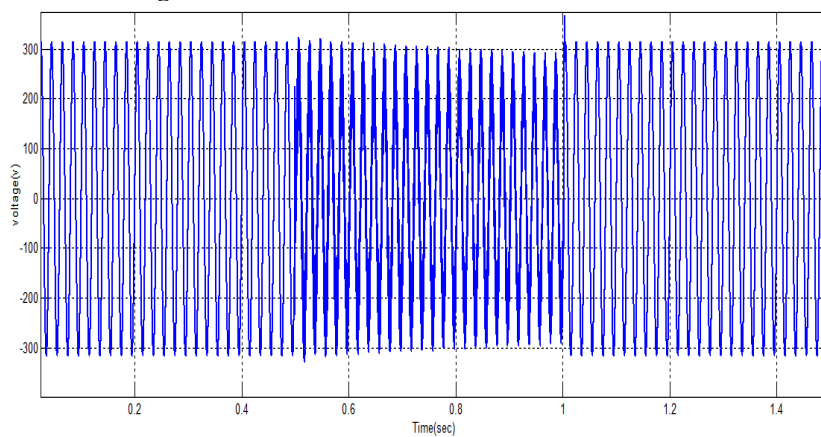
### 6.1 Conventional Sag Condition And Sag Compensated Voltages



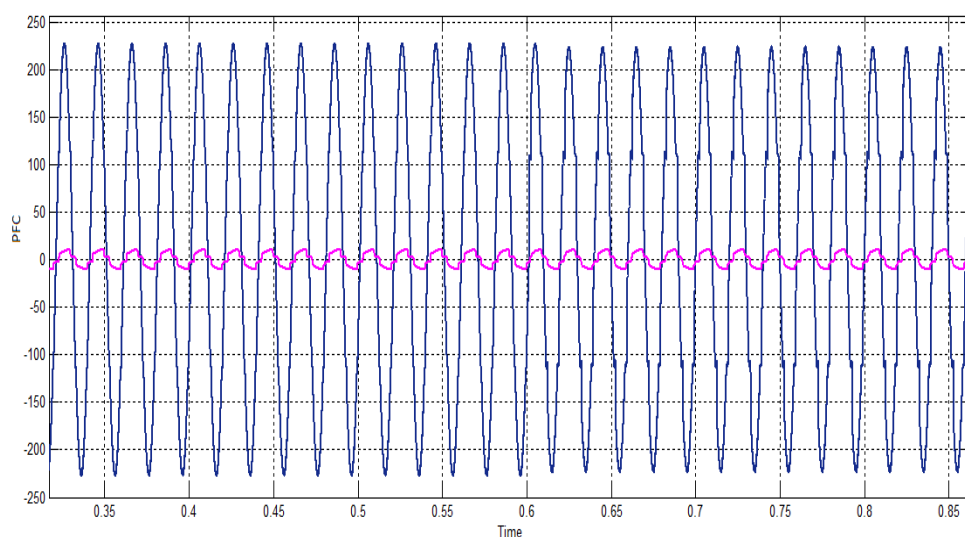
#### 6.1.1 Sag Condition



#### 6.1.2 Sag Compensated Voltage



### 6.1.2 Power Factor Correction



### VII. Conclusion

The performance of the proposed scheme is compared with the traditional voltage controlled DSTATCOM. The proposed method provides the following advantages- at nominal load, the compensator injects reactive and harmonic components of load currents, resulting in UPF; nearly UPF is maintained for a load change; fast voltage regulation has been achieved during voltage disturbances and losses in the VSI and feeder are reduced considerably, and have higher sag supporting capability with the same VSI rating compared to the traditional scheme. Different types of voltage sag conditions should be applied and compensated in a simulink environment. Additionally, power factor correction and voltage regulation, the harmonics are also checked, 20% voltage sag is eliminated under  $t=0.5$  to 1sec, thus the simulation results show that the proposed scheme provides DSTATCOM, a capability to improve several Power Quality problems (related to voltage and current).

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