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Intensification of a Distribution System using Sinusoidal Pulse Width Modulation by D-STATCOM for Voltage Sag and Swell

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Abstract-There has been increase in the demand for reliable and high quality power distribution systems. Power quality is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. The major problems dealt here is the voltage sag and swell. In order to achieve this Distributed Static Compensator (D-STATCOM) is used. D-STATCOM injects a current in to the system to correct the voltage sag and swell. The control of the Voltage Source Converter (VSC) is done with the help of SPWM. The proposed D-STATCOM is modelled and simulated using MATLAB/SIMULINK software.

Keywords - D-STATCOM, Sinusoidal Pulse Width Modulation, Voltage sag and swell, Voltage source converter, MATLAB/SIMULINK.

I. INTRODUCTION

In modern electrical power systems, electricity is produced at generating stations, transmitted through a high voltage network, and finally distributed to consumers. A modern power system should provide reliable and uninterrupted services to its customers at a rated voltage and frequency within constrained variation limits. The electrical system should not only be able to provide cheap, safe and secure energy to the consumer, but also to compensate for the continually changing load demand. During that process the quality of power could be distorted by faults on the system, or by the switching of heavy loads within the customers facilities. Highly interconnected transmission and distribution lines have highlighted the previously small issues in power quality due to the wide propagation of power quality disturbances in the system. The reliability of power systems has improved due to the growth of interconnections between utilities.

Now a days, modern industrial devices are mostly based on the electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems [1] such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments[3]. Voltage sag is defined as a short reduction in voltage magnitude for a duration of time, and is considered to be the most common power quality issue. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. D-STATCOM injects a current into the system to correct the voltage sag and swell. These power quality devices are power electronic converters connected in parallel or series with the lines and the operation is controlled by a digital controllers. They employ a shunt of voltage boost technology using solid state switches for compensating voltage sags and swells. The D-STATCOM applications are mainly for sensitive loads that may be drastically affected by fluctuations in the system voltage [4], [5].

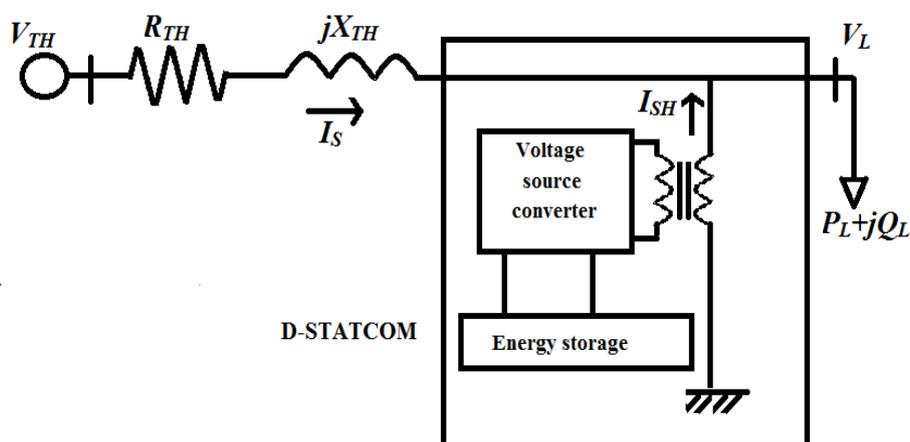


Fig.1: Schematic representation of the D-STATCOM for a typical custom power application

II. POWER QUALITY PROBLEMS

The power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices make them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc [6]. A power voltage spike can damage valuable components. Power quality problems encompass a wide range of disturbances such as voltage sags, swells, flickers, harmonic distortion, impulse transients, and interruptions.

A. Sources of Power Quality Problems

- Large motor starting
 - Different faults
 - Lightning
 - Capacitive loads
 - Open circuits
- } Leads to voltage sag
- } Leads to voltage swell

B. Causes of Voltage Sags and swells

- Rural location remote from power source
- Unbalanced load on a three phase system
- Switching of heavy loads
- Long distance from a distribution transformer with interposed loads
- Unreliable grid systems
- Equipments not suitable for local supply

C. Solutions to Power Quality Problems

- Increase in equipment side through capability
- Adding auxillary individual device
- Adding more mitigation measures
- Load conditioning from customer side
- Line conditioning from utility side

Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operate as a controllable voltage source. Both schemes are implemented in preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. However, with the restructuring of 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; some of the effective and economic measures can be identified as following [6]:

A) Lightning and Surge Arrester: Lightning arrester is designed to protect the insulation and conductors of the system from damaging effects of lightning. Arrester is designed for lightning protection of transformers, but is not limited to sufficient voltage limiting for protecting sensitive electronic control circuits from voltage surges. The purpose of surge arrester is to divert damaging over-voltage transients caused by external or internal events.

B) Thyristor Based Static Switch: The static switch is a solid state device that opens and closes circuit without use of moving mechanical parts for switching a new element in to the circuit when the voltage support is needed. It has a dynamic response time of about one cycle. To correct quickly for voltage spikes, sags, interruptions the static switch can be used to switch one or more devices such as capacitor, filter, alternate power line, energy storage systems etc. The static switch can be used in the alternate power line applications.

III. DISTRIBUTION STATCOM (D-STATCOM)

A D-STATCOM, which is schematically depicted in Fig. 2 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 [7]. Such configuration allows the device to absorb or generate controllable active and reactive power. The D-STATCOM has been utilized mainly for regulation of voltage, correction of power factor and elimination

of current harmonics. Such a device is employed to provide continuous voltage regulation using an indirectly controlled converter. The main purpose of D-STATCOM is to protect the consumer from supply voltage sag, voltage swell as well as provide unity power factor at the utility for different load power factor values. In this paper, the D-STATCOM is used to regulate the voltage at the point of connection. The control is based on sinusoidal PWM and only requires the measurement of the rms voltage at the load point.

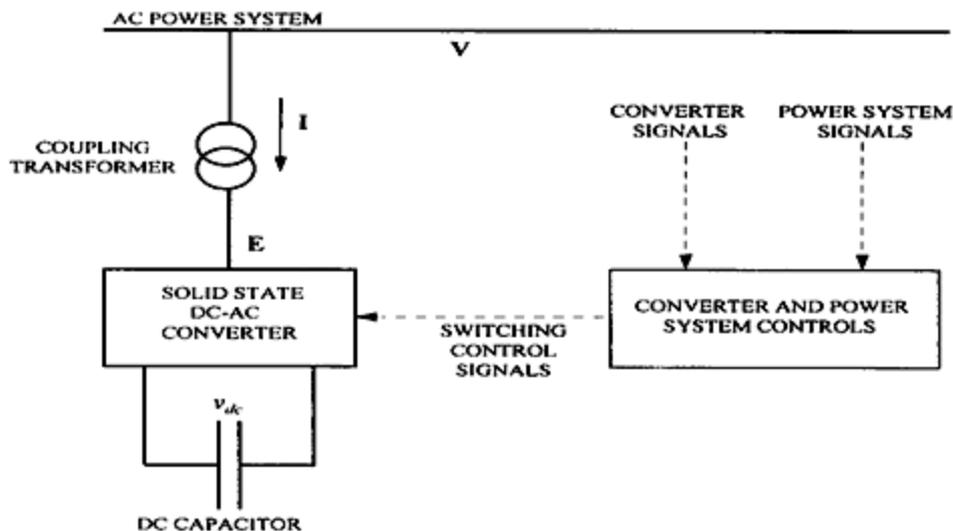


Fig. 2: Typical D-STATCOM overview

A. Equations related to D-STATCOM

From the Fig. 1, the shunt injected current I_{SH} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{TH} . The value of I_{SH} can be controlled by adjusting the output voltage of the converter.

The shunt injected current I_{SH} can be written as,

$$I_{SH} = I_L - I_S \quad (1)$$

$$\text{Where } I_S = (V_H - V_L) / Z_{TH} \quad (2)$$

Therefore

$$I_{SH} = I_L - I_S = I_L - (V_H - V_L) / Z_{TH} \quad (3)$$

or

$$I_{SH} \angle \eta = I_L \angle -\theta - V_{TH} / Z_{TH} \angle (\delta - \beta) + V_L / Z_{TH} \angle -\beta$$

The complex power injection of the D-STATCOM can be expressed as,

$$S_{SH} = V_L I_{SH}^* \quad (4)$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Z_{TH} or fault level of the load bus. When the shunt injected current I_{SH} is kept in quadrature with V_L , the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{SH} is minimised, the same voltage correction can be achieved with minimum apparent power injection into the system.

B. Voltage Source Converter (VSC)

A voltage source converter (VSC) is a power electronic device, which can generate a three-phase ac output voltage is controllable in phase and magnitude [1][4]. These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. VSCs are widely used in adjustable speed drives, but can also be used to mitigate the voltage sags and swells. 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 voltage. The converter is normally based on the some kind of energy storage, which will supply the converter with a dc voltage. In this the dc voltage always has one polarity, and the power reversal takes place through reversal of dc current polarity. For reasons of economics and performance these are often preferred [3].

IV. SINUSOIDAL PWM BASED CONTROL

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbance. The control system only measures the rms voltage at the load point i.e., no reactive power measurements are required [8]. Here the width of each pulse is varied in proportion to the amplitude of sine wave. The distortion factor is reduced. The VSC switching strategy is based on SPWM technique which offers simplicity and good response[2].

The PI controller process identifies the error signal and generates the required angle δ to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage. In the PWM generator, the sinusoidal signal $V_{control}$ is compared against a triangular signal in order to generate the switching signals for the VSC valves [1], [3]. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index M_a of signal $V_{control}$ and the frequency modulation index M_f of the triangular signal. The amplitude index M_a is kept fixed at 1 pu.

$$M_a = V_{control} / V_{tri} \quad (5)$$

Where $V_{control}$ is the peak amplitude of the signal

V_{tri} is the peak amplitude of the triangular signal

In order to obtain the highest fundamental voltage component at the controller output [9], the switching frequency is set at 450 Hz. The frequency of modulation index is given by,

$$M_f = F_s / F_f = 450 / 50 = 9 \quad (6)$$

Where M_f is the frequency of modulation index

F_s is the switching frequency

F_f is the fundamental frequency

In this paper, balanced network and operating conditions are assumed. The modulation angle δ is applied to the PWM generator in phase A. The angle for phases B and C are shifted by 240° and 120° , respectively [3].

V. MODELLING D-STATCOM USING THE SIMULINK POWER SYSTEM BLOCKSET

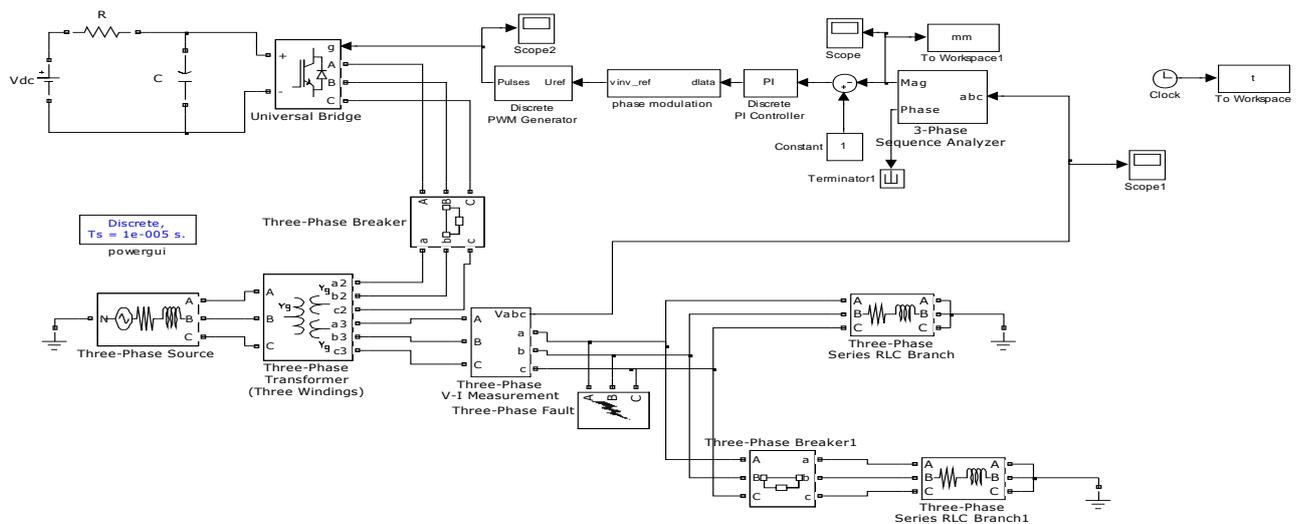


Fig. 3: Control scheme and test system implemented in MATLAB/SIMULINK to carry out the D-STATCOM simulations

A. D-STATCOM Simulations and Results for Voltage Sag

Fig. 3 shows the test system used to carry out the various DSTATCOM simulations presented in this section. The test system composes a 230 kV, 50 Hz generation system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point.

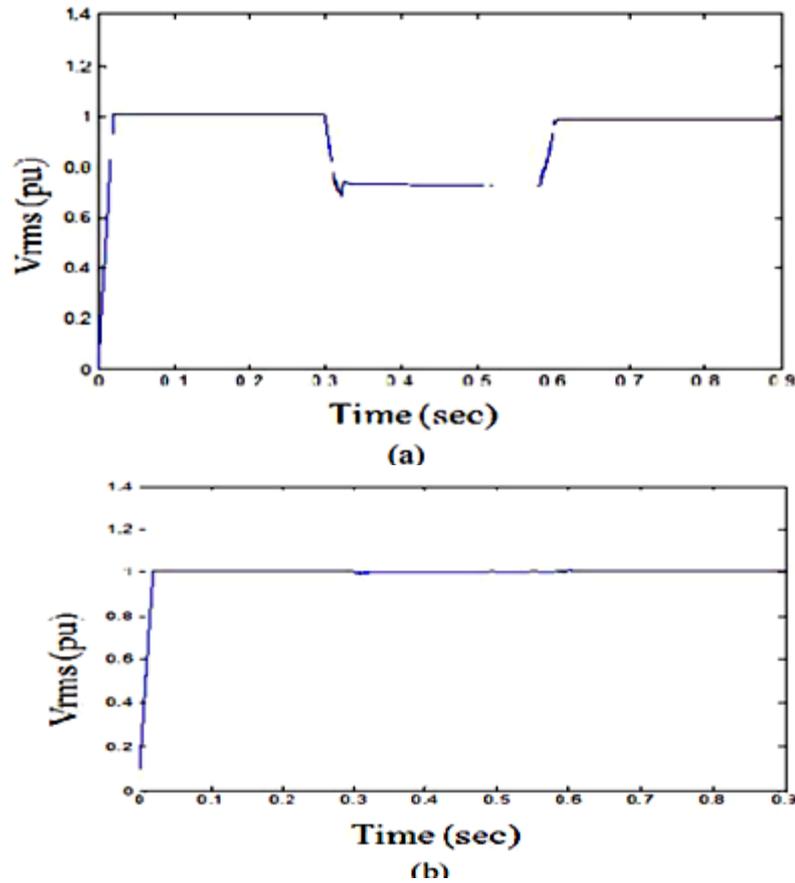
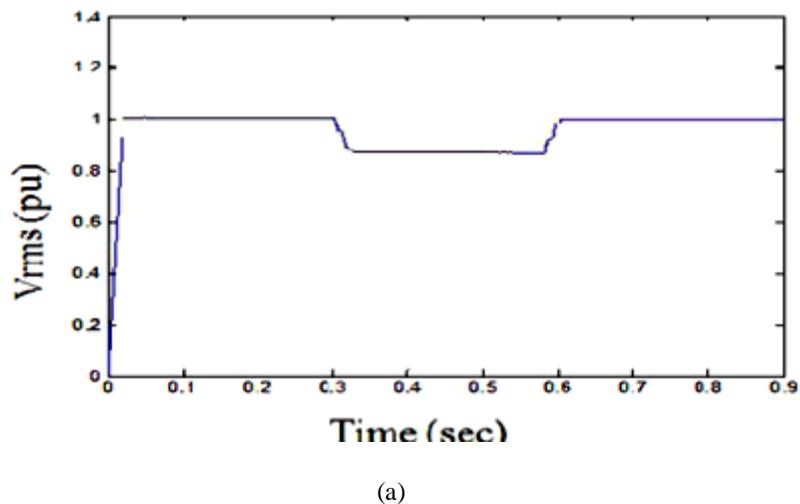


Fig. 4: Voltage V_{rms} at load point, with three-phase fault: (a) Without D-STATCOM and (b) With D-STATCOM.

- 1) The first simulation contains no D-STATCOM and a three-phase short-circuit fault is applied at point A, via a fault resistance of 0.2Ω , during the period 300-600 ms. The voltage sag at the load point is 36% with respect to the reference voltage.
- 2) The second simulation is carried out using the same scenario as above, but now D-STATCOM is connected to the system, then the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 99% as shown in Fig. 4(b).



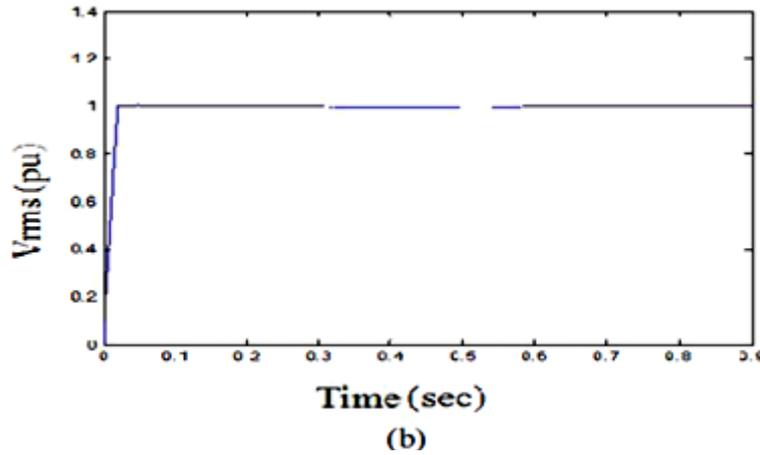


Fig.5: Voltage V_{rms} at load point, with line-ground fault: (a) Without D-STATCOM and (b) With D-STATCOM.

- 1) The first simulation contains no D-STATCOM and a line-ground fault is applied at point A, via a fault resistance of 0.4Ω , during the period 300-600 ms. The voltage sag at the load point is 20% with respect to the reference voltage.
- 2) The second simulation is carried out using the same scenario as above, but now D-STATCOM is connected to the system, then the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 99% as shown in Fig. 5(b).

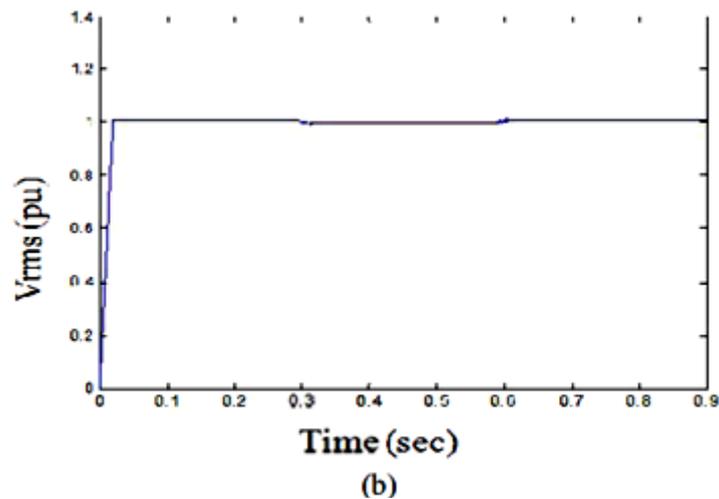
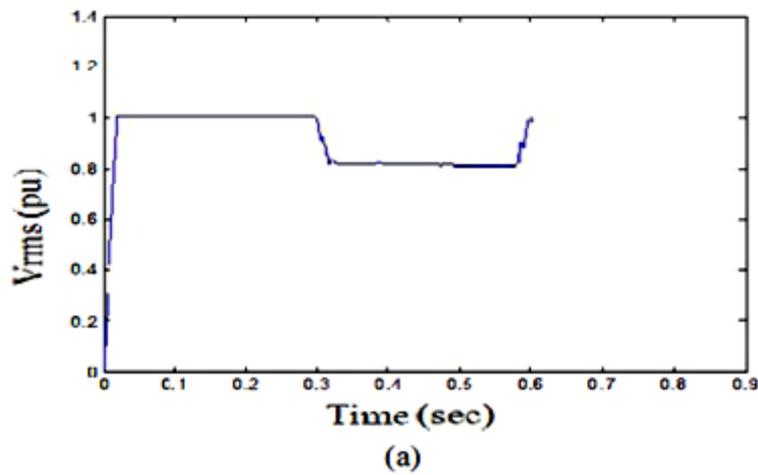


Fig. 6: Voltage V_{rms} at load point, with line-line fault: (a) Without D-STATCOM and (b) With D-STATCOM.

- 1) The first simulation contains no D-STATCOM and a line-line fault is applied at point A, via a fault resistance of 0.4Ω , during the period 300-600 ms. The voltage sag at the load point is 24% with respect to the reference voltage.
- 2) The second simulation is carried out using the same scenario as above, but now D-STATCOM is connected to the system, then the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 99% as shown in Fig. 6(b).

B. D-STATCOM Simulations and Results for Voltage S well

Fig. 3 shows the test system used to carry out the various D-STATCOM simulations presented in this section. The test system composes a 230 kV, 50 Hz generation system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer. A varying load is connected to the 11 kV, secondary side of the transformer, and $3\mu\text{F}$ capacitor bank is connected to the high voltage side of the network. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point.

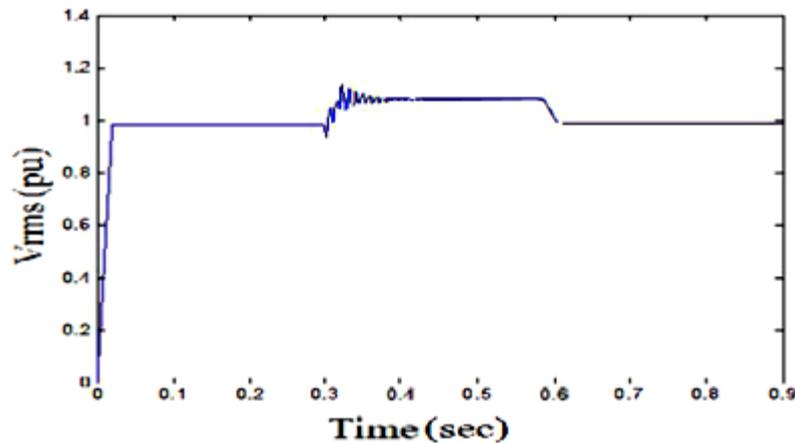


Fig.7: Voltage V_{rms} at load point, with three-phase fault, Without D-STATCOM.

- 1) The first simulation contains no D-STATCOM and a three-phase fault is applied at point A, during the period 300-600 ms. The voltage swell at the load point is 20% with respect to the reference voltage, as shown in Fig. 7.

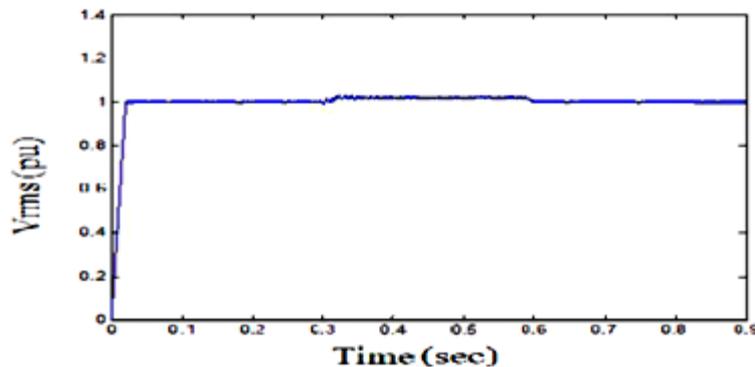


Fig. 8: Voltage V_{rms} at load point, with three-phase fault, With D-STATCOM.

- 2) The second simulation is carried out using the same scenario as above, but now D-STATCOM is connected to the system, then the voltage swell is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 98%.

VI CONCLUSION

This paper has presented the power quality problems like voltage sags and swells. To compensate these problems the custom power electronic device D-STATCOM was utilised. The design and applications of Distribution Static VAR Compensator (D-STATCOM) for voltage sags, swells and comprehensive results were obtained. The

Sinusoidal Pulse Width Modulation was used (SPWM) for the implementation of Voltage Source Converter (VSC). The control scheme was tested under wide range of operating conditions, and it was found robust in every case. The D-STATCOM was modelled and simulated and hence provides relatively better voltage regulation capabilities.

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