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D-STATCOM Modeling for Voltage Sag and Swell Type of Power Quality problems by SPWM Technique

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ABSTRACT

This paper presents the systematic modeling of the Distribution Static Compensator (DSTATCOM) for power quality issues like Sag and Swell in voltages based on pulse width modulation technique in sinusoidal. Quality of power is an occurrence manifested as un standard voltages, current and frequency that results in a malfunctioning of user equipments. The usual problems that occurred are sag and swell in voltages. To overcome these difficulties custom power models are used. Among them the most suitable device is the Distribution Static Compensator. The capability of such device is most effective and efficient in custom power elements considered at distribution level. It spreads a current in to the system to correct sag and swell in voltages. The Voltage Source Converter can be controlled by sinusoidal pulse width modulation technique. The modeling and simulation of D-STATCOM can be done by using MATLAB software.

Keywords: Voltage Sag, Voltage Swell, DSTATCOM, SPWM, VSC.

INTRODUCTION

In modern electric power systems, electricity is produced at generating stations, transmitted through a high voltage network and finally distributed to consumers. Due to the rapid increase in power demand, electric power systems have developed extensively during the 20th century, resulting in today's power industry probably being the largest and most complex industry in the world. Electricity is one of the key elements of any economy, industrialized society or country. The modern power system should provide reliable and uninterrupted services to its customers at a rated voltage and frequency within constrained variation limits. If the supply quality suffers a reduction and is outside those constrained limits, sensitive equipment might trip and any motors connected on the system might stall.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 such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments. 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 [1] are power electronic converters connected in parallel or series with the lines and the operation is controlled by a digital controllers. The modelling of these complex systems that contains both power circuits and control systems can be done different bases. One of those power electronic solutions to the voltage regulation is the use of a Distribution STATCOM (D-STATCOM). D-STATCOM is a class of custom power device for providing reliable distribution power quality. They employ a shunt 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 [3], [4].

2. POWER QUALITY ISSUES

2.1 Introduction

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 [5]. 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. In an electrical power system, there are various kinds of Power Quality disturbances. They are classified into categories and their descriptions are important in order to classify measurement results and to describe electromagnetic phenomena, which can cause Power Quality problems. Some disturbances come from the supply network, whereas others are produced by the load itself. The categories can be classified below.

(i). Short-duration voltage variations

(ii). Long-duration voltage variations
(iii). Transients
(iv). Voltage imbalance
(v). Waveform distortion
(vi). Voltage fluctuation
(vii). Power frequency variations
(viii). Voltage tolerance criteria

3. DISTRIBUTION STATCOM (D-STATCOM)

A D-STATCOM, which is schematically depicted in Fig. 3.1 consists of a two level voltage source converter, a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer [6], [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 [8]. 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.

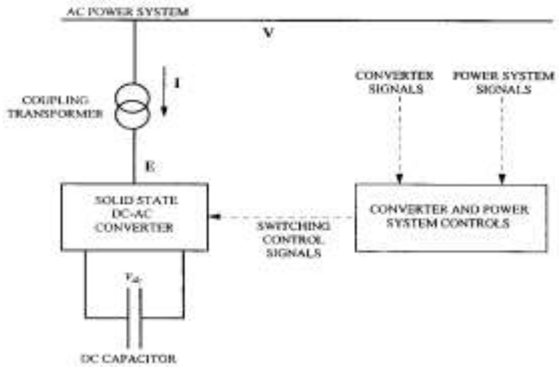

Fig 3.1. Typical DSTATCOM overview

3.1 Modelling of D-STATCOM

A simplified Controlled Current Source model, derived from the controlled current source model is shown in Fig.3.1.1, in which the control loop relating to the DSTATCOM droop characteristic is not represented. This is analogous to an IEEE basic type1 SVC model.

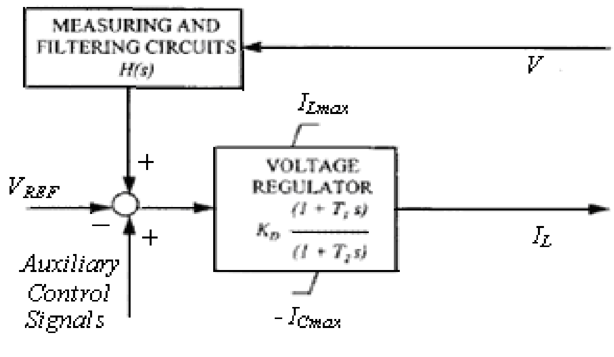

Fig 3.1.1. Simplified controlled current source model

3.1.1 Description of basic model

In this simplified DSTATCOM model, the current regulator transfer function has a steady state gain of K_0 (=1/slope) to represent the steady state droop, and a first order lead-lag term to represent the dynamics. Typically, T2 would be expected to be of the order of 15ms.

Choosing T_1 such that $K_D\left(\frac{T_1}{T_2}\right)=\frac{1}{X}$ (1)

This simplified model consists of the following elements

3.1.2 Measuring Module

The characteristics of the measuring circuit and filter circuit can be approximated by a second order transfer function giving a rise time of 15-20ms with acceptable overshoot, e.g.:

$$H(s) = \frac{1}{(1 + 2\zeta T_H s + T_H{}^2 s^2)} \qquad (2)$$

With $\zeta = 0.75$ and $T_H = 5$ms

3.1.3 Voltage Regulator Module

The voltage regulator M(s) incorporates integral action and can generally be represented by a transfer function of the form

$$M(s) = \frac{(1+T_1 s)}{(1+T_2 s)} \frac{(1+T_3 s)}{(1+T_4 s)} \frac{k(1+Ts)}{s} \qquad (3)$$

Where T_1, T_2, T_3, and T_4, are optional lead-lag time constants which may be applied depending up on the particular application.

3.2 Voltage Source Converter (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC 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. It also converts the DC voltage across storage devices into a set of three phase AC output voltages. In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages [9]. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage.

3.3 Sinusoidal PWM Based Control

Sinusoidal pulse width modulation is a method of pulse width modulation used in inverters. An inverter produces an AC output voltage from a DC input by using switching circuits to simulate a sine wave by producing one or more square pulses of voltage per half cycle. If the widths of the pulses are adjusted as a means of regulating the output voltage, the output is said to be pulse width modulated. With sinusoidal or sine weighted pulse width modulation, several pulses are produced per half cycle. The pulses near the edges of the half cycle are always narrower than the pulses near the center of the half cycle such that the pulse widths are proportional to the corresponding amplitude of a sine wave at that portion of the cycle. To change the effective output voltage, the widths of all pulses are increased or decreased while maintaining the sinusoidal proportionality. With pulse width modulation, only the widths (on-time) of the pulses are modulated. The amplitudes (voltage) during the "on-time" is constant unless a multi-step circuit is used. The line-to neutral voltage of a 3-phase inverter has two voltage levels. 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. The VSC switching strategy is based on sinusoidal PWM technique which offers simplicity and good response.

The PI controller process identifies the error signal and generates the required angle ϴ 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 (carrier) in order to generate the switching signals for the VSC valves. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index M_a of signal control and the frequency modulation index M_f of the triangular signal. The amplitude index M_a is kept fixed at 1 pu[10].

$$Ma = V_{control} / V_{trl}$$

Where $V_{control}$ is the peak amplitude of the signal,V_{trl} is the peak amplitude of the Triangular signal. In order to obtain the highest fundamental voltage component at the controller output, the switching frequency is set at 450Hz the frequency of modulation index is given by,

$$M_f = F_s / F_f = 450 / 50 = 9$$

Where

M_f = is the frequency of modulation index.

F_s = is the switching frequency.

F_f = is the fundamental frequency.

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

4. SIMULATIONS AND RESULTS

4.1 D-STATCOM Simulations and Results for Voltage Sag

Fig 4.1 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's 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.

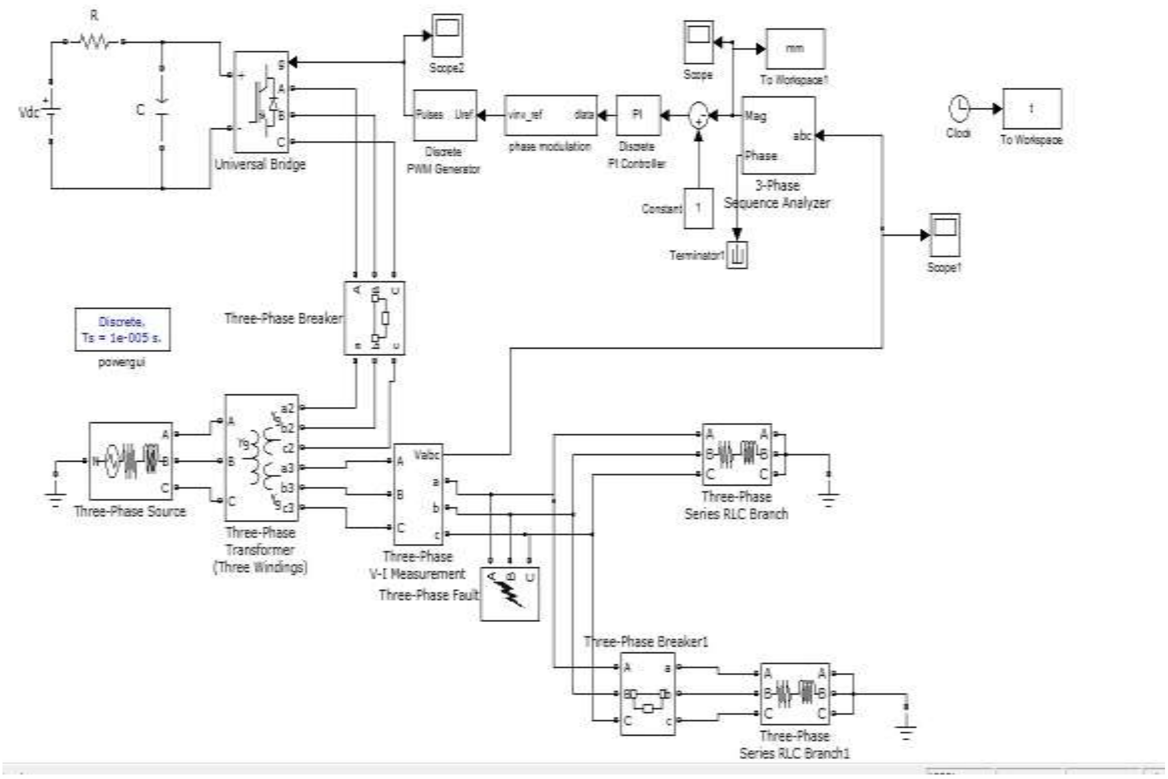

Fig 4.1.D-STATCOM control scheme and test system

The first simulation contains no D-STATCOM and a three-phase short-circuit fault is applied at point A, via a fault resistance of 0.2 Ω, during the period 300-600 ms. The voltage sag at the load point is 36% with respect to the reference voltage as shown in fig 4.2.

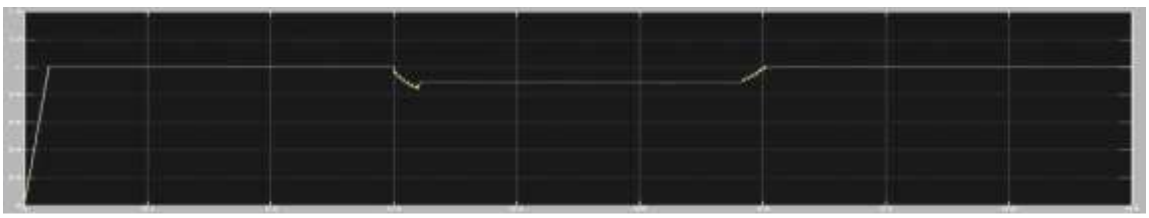

Fig 4.2.Voltage Vrms at load point, with three-phase fault without D-STATCOM

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 4.3.

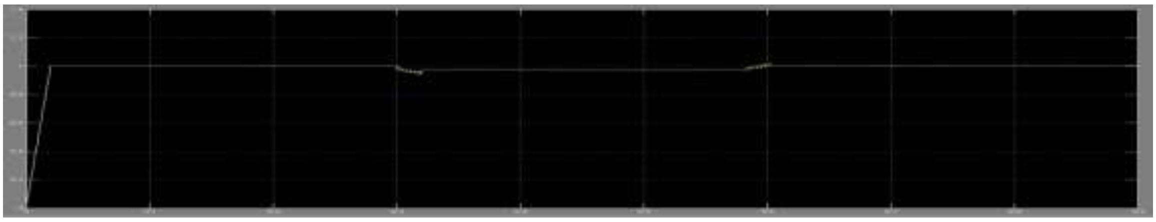

Fig. 4.3.Voltage Vrms at load point, with three-phase fault with D-STATCOM

Make the simulation without D-STATCOM and a three phase-ground fault is applied at point A, via a fault resistance of 0.4 Ω , during the period 300-600 ms. The voltage sag at the load point is 30% with respect to the reference voltage as shown in fig. 4.4.

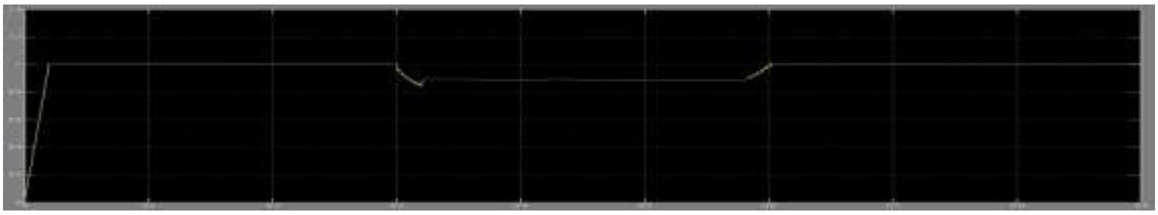

Fig 4.4.Voltage Vrms at load point, with three phase-Ground fault without D-STATCOM

Now 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.4.5

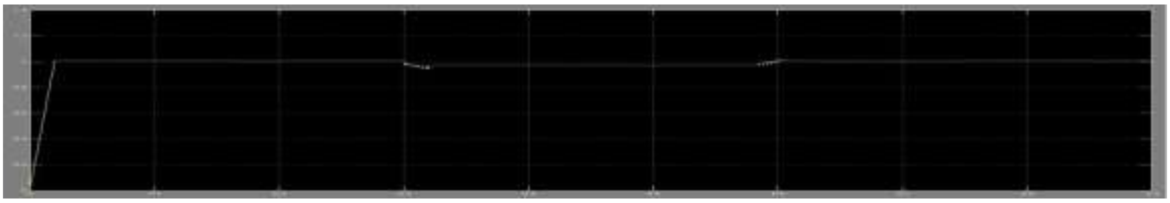

Fig 4.5.Voltage Vrms at load point, with three phase-Ground fault with D-STATCOM

Carryout the simulation without D-STATCOM and a line-ground fault is applied at point A, via a fault resistance of 0.4 Ω, during the period 300-600 ms. The voltage sag at the load point is 20% with respect to the reference voltage as shown in Fig 4.6.

Fig 4.6.Voltage Vrms at load point, with Line-Ground fault without D-STATCOM

Now 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 4.7.

Fig 4.7.Voltage Vrms at load point, with Line-Ground fault with D-STATCOM

Without D-STATCOM and a line-line fault is applied at point A, via a fault resistance of 0.4 Ω, during the period 300-600 ms. The voltage sag at the load point is 24% with respect to the reference voltage as shown in Fig 4.8.

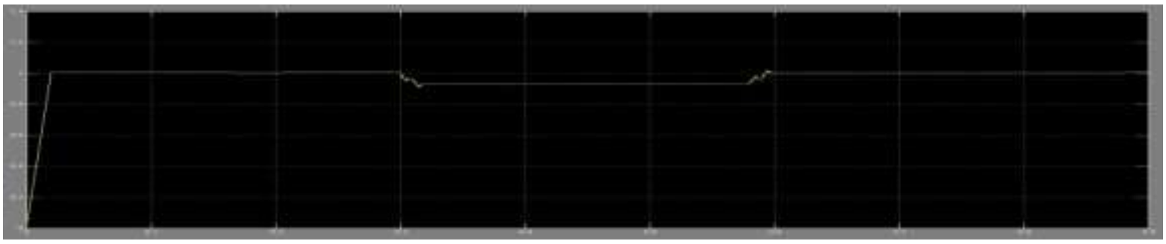

Fig 4.8. Voltage Vrms at load point, with Line-Line fault without D-STATCOM

Here 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 4.9.

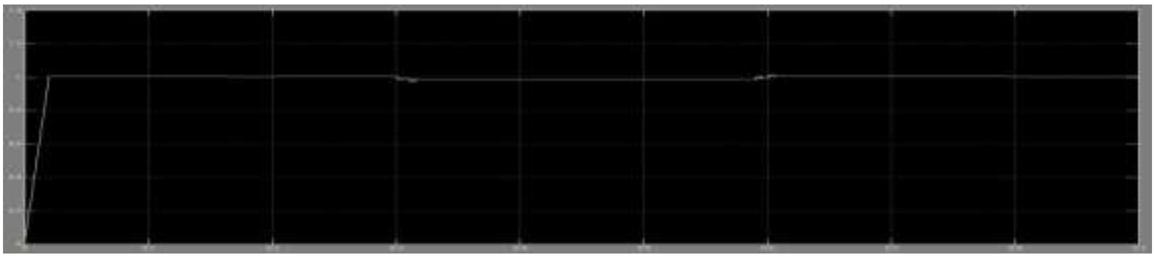

Fig 4.9. Voltage Vrms at load point, with Line-Line fault with D-STATCOM

Process the simulation without D-STATCOM and a line-line- ground fault is applied at point A, via a fault resistance of 0.4 Ω, during the period 300-600ms. The voltage sag at the load point is 28% with respect to the reference voltage as shown in Fig 4.10.

Fig 4.10.Voltage Vrms at load point, with Line-Line-Ground fault without D-STATCOM

Now 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 4.11.

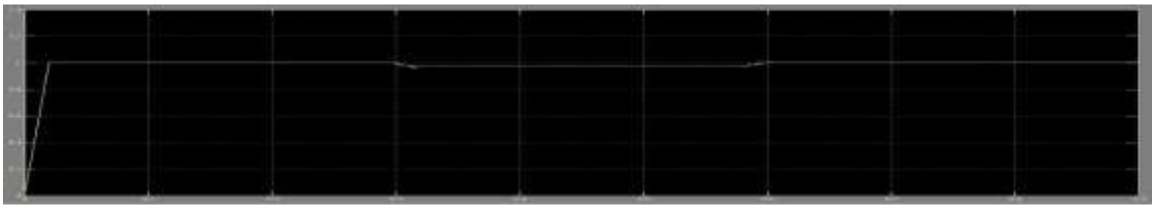

Fig 4.11.Voltage Vrms at load point, with Line-Line-Ground fault with D-STATCOM

4.2 D-STATCOM Simulations and Results for Voltage Swell

Fig 4.12 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 Thevenins 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 3μF 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.

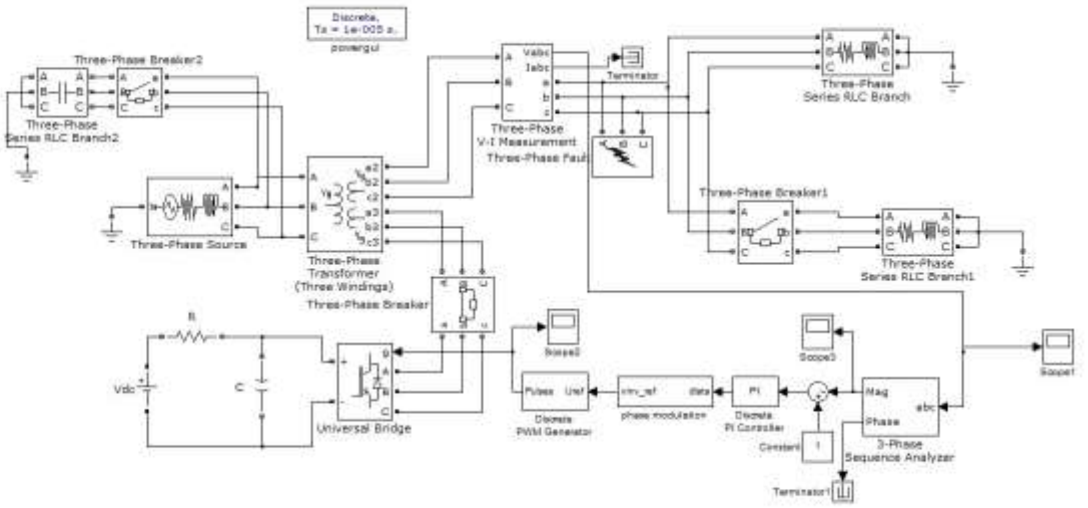

Fig 4.12.D-STATCOM control scheme and test system for Voltage swell simulations

Here 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 4.13.

Fig 4.13.Voltage Vrms at load point, with three-phase fault , Without D-STATCOM

Now 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% as shown in Fig 4.14.

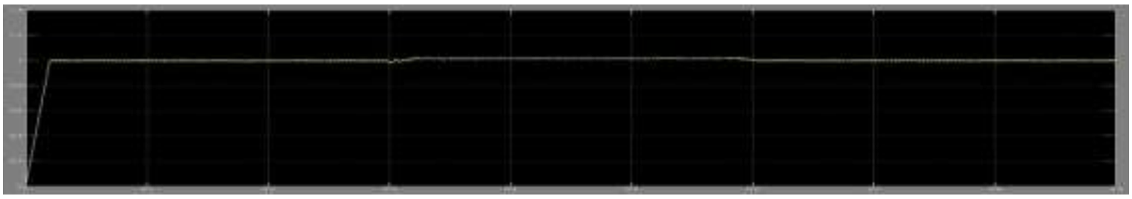

Fig 4.14.Voltage Vrms at load point, with three-phase fault with D-STATCOM

5. CONCLUSIONS

The systematic procedure of modelling and simulation of a Distribution STATCOM (D-STATCOM) has presented the solution for power quality problems like voltage sags and swells. To compensate these problems the custom power electronic device D-STATCOM was presented. The design and applications of Distribution Static VAR Compensator (D-STATCOM) for voltage sags, swells and comprehensive results were presented. The Sinusoidal Pulse Width Modulation was used (SPWM) was used to implement the Voltage Source Converter (VSC). The control scheme was tested under wide range of operating conditions, and it was found very robust in every case. The D-STATCOM was modelled and simulated by using the highly developed graphic facilities available in the MATLAB/SIMULINK. The simulations carried out here show that the D-STATCOM provides relatively better voltage regulation capabilities.

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