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A Phase Shift Control based DSTATCOM for Mitigation of Voltage Sag and Voltage Swell in Distribution Systems

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***Abstract*: Over recent years increasing demand for high quality, reliable electrical power and increasing number of distorting loads leads to an increased awareness of power quality. The Power Quality disturbances arises when the decided standard limit of voltage, current and frequency for safe operation is exceeded. This leads to suffering of utility distribution system from service interruption, outages and false operation or failure of end user equipment which results in financial loses. Hence it has become important to work in this area so that corrective measures are to be taken to improve the quality of power. Many compensating devices has been put forward by researchers and power engineers to curb this problem of power quality issues. Of recent developments, the involvement of D-STATCOM, a Voltage Source Converter has been instrumental. This paper puts forward the development of such a D-STATCOM in a power distribution network. The development of the controller, the advantages of installation of the compensating device with respect to voltage profile management, power quality has been discussed. The simulation of the proposed controller has been done in MATLAB Simulink and its performance based on various aspects has been done.**

Keywords: D-STATCOM, Harmonics, Mitigation.

I. INTRODUCTION

In recent years power quality has gained the attention of power engineers[7]. The quality of power supplied plays a very vital role in the economic growth and development of a country especially for developing countries like India, Argentina, Brazil, Pakistan etc. Restructuring of electric power utilities and demand for use of more energy efficient devices are some of the reasons which led to gaining of attention in the field of power engineering. Although many disturbances are caused due to poor quality of power but one of the most common disturbances faced nowadays is voltage sag, voltage swell and harmonics. To resolve the problem of disturbances caused due to unhealthy power supplied many compensating devices are developed which compensates the required missing voltage or current. With the development of FACTS (Flexible Transmission A.C transmission system) devices which is a power electronic based system the controllability of transmission line parameters is enhanced[3]. It enables a system to have complete control over its line parameters under both healthy and unhealthy conditions. Application of FACTS devices reduces cost and improves the quality of power transmission[3]. D-STATCOM is one of devices which belong to FACTS device family. D-STATCOM is applied for shunt compensation mainly in distribution systems[8]. It supplies the necessary missing voltage or current to the system under unhealthy conditions. In this paper DSTATCOM is applied mainly to solve some of the most frequently occurring power quality problems like voltage sag, voltage swell and total harmonic distortions with the help of MATLAB SIMULINK software.

II. POWER QUALITY ISSUES

A power quality problem is basically defined as deviation in voltage, current or frequency, which results in failure, loss of performance or life expectancy of end-use equipment[1]. Power Quality is a set of electrical boundaries to be maintained by the equipments for safe and efficient operation. The sources of problems that can disturb the power quality are: power electronic devices, arcing devices, load switching, large motor starting, embedded generation, sensitive equipment, storm and environment related damage, network equipment and design[2].Power quality is influenced by utility operations, customer load types and equipment designs. Electrical disturbances can develop from problems within the customer's facility, even though the supply voltage is constant [2]. Due to power quality problems a wide range of disturbances occur like voltage sag/swell, flicker, interruption, harmonics etc. Voltage swell is not as important as voltage sag because they are less common in distribution systems[1][2].In the present system with mostly distorting load voltage sags are one of the most concerned and frequently occurring power quality disturbance[1].

In order to overcome the above mentioned power quality problems many conventional mitigating devices are installed at the end user level such as Tap changers, constant voltage transformer ,buck-boost regulator, motor-generator set, UPS(uninterrupted power supply), shunt and series capacitor ,synchronous condenser ,SVC(static VAR compensator) etc[2]. But present day modern equipment is very sensitive to voltage sags so, the mitigating device has to be very fast in acting, which is not possible by above mentioned conventional devices[2]. So to overcome the

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above disadvantage a new category of devices called custom power devices are developed[2][8].Custom power devices are the new generation of power electronics-based equipment aimed at enhancing the reliability and quality power flows in low voltage distribution networks .There are three types of compensating custom power devices DSTATCOM(distribution static compensator) is a shunt compensating device, DVR(Dynamic voltage restorer) is a series compensating device, UPQC(Uninterrupted Power Quality Conditioner) is combination of DSTATCOM and DVR. These devices are used for voltage regulating (sag/swell),power factor improvement, load balancing, active filtering. Hence these compensating custom devices works very efficiently for mitigating the disturbances produced in power quality[6].

III. DSTATCOM (Distribution Static Compensator)

DSTATCOM is one of the custom power device used in the distribution networks for mitigating power quality disturbances which works as a shunt compensating device. A D-STATCOM basically is VSC based FACTS controller sharing many similar concept with that of STATCOM used at transmission level [9].DSTATCOM is widely applied nowadays in distribution networks compared to other compensating devices because of some of its additional features like it gives cost effective solutions and acts fast to the problems caused during unbalanced situation in the system [7][8]. During the unbalanced situation it provides the system with compensating voltage or current to mitigate the problems caused due to poor power quality[7]. The effectiveness of DSTATCOM is completely dependent on its control scheme [6].For compensating the power quality problems like voltage sag, voltage swell and harmonics etc it is connected to the load side of the system. Main components of DSTATCOM are:

i) VSC(voltage source converter)

VSC is the heart of DSTATCOM, it is basically a controllable voltage source.VSC is a power electronic based device which has the feature of generating sinusoidal voltage sinusoidal voltage at any required magnitude, frequency and phase angle[8]. VSC contains a solid electronic circuit which is switched using a control scheme to produce the compensating voltage or current during disturbances. Generating of the compensating voltage is based on energy storage device connected to it.

ii)Energy storage device:

Energy storage devices provides the energy required by the voltage source converter to generate the required sinusoidal voltage during the unbalanced situation. In this paper DC source is connected in parallel with the DC capacitor behaves as the reactive energy storage element.

iii) Harmonic Filter:

The main function of harmonic filter is to filter out the unwanted harmonics generated by the VSC and hence keep the harmonic level within permissible limit. In this proposed model LCL (inductor-capacitor–inductor) is used as harmonic filter.

iv) Coupling Transformer:

It serves two purposes, firstly it connects the DSTATCOM to distribution network via it and couples the injected compensating voltages generated by the VSC in shunt with the incoming supply voltage. Secondly it also serves the purpose of isolating the load from the system. The voltage source converters 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.

v) Controller:

The aim of the control scheme is to maintain the system voltage always equal to the reference voltage which is the voltage to be maintained constant under system disturbances by continuously comparing the system load voltage with the reference voltage to be maintained. The input of the controller is obtained from the measurement of RMS voltage at the load side. If the measured RMS voltage is equal to the reference voltage than the controller does not operate, but if the measured RMS voltage is deviates from the reference voltage these deviations generates an error which is given as input to the controller. The controller inputs the generated error and converts them into reference signals responsible for operating the voltage source converter. In this paper PI(Proportional Control) controller is used.

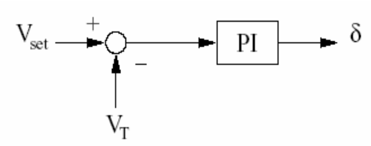

Fig.1- Basic Control Scheme

IV. WORKING PRINCIPLE OF DSTATCOM

DSTATCOM is VSC based shunt compensating device, 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 supplied by the energy storage device into three-phase ac output voltages. These voltages from the VSC are supplied to the system through the reactance of the coupling transformer to make the generated voltage in phase with the ac system. The operation of DSTATCOM starts with monitoring the load voltage of the system. If deviation from reference value occurs than an error is generated which is passed through a control scheme. The control scheme inputs the

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generated error and converts them into reference value which is responsible for operating the VSC. The VSC operates and shunt voltage injection takes place which is responsible for maintaining the voltage profile. The shunt injected current I_{sh}(shunt current) corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}.

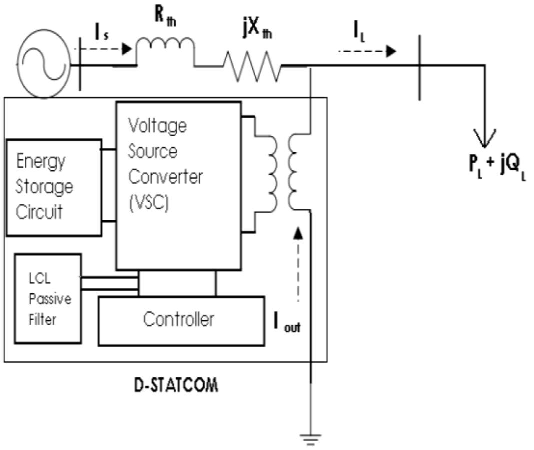

Fig.2- Schematic diagram of DSTATCOM

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[6],

$$I_{sh} = I_L - I_s = I_L - (V_{th} - V_L)/ Z_{th} \quad (1)$$

$$I_{sh}\angle\eta = I_L\angle-\theta - \frac{V_{th}}{Z_{th}}\angle(\delta-\beta) + \frac{V_L}{Z_{th}}\angle-\beta \quad (2)$$

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

$$S_{sh} = V_L I_{sh}^* \quad (3)$$

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 VL, 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 minimized, the same voltage correction can be achieved with minimum apparent power.

V. SINUSOIDAL PULSE WIDTH MODULATION BASED PHASE SHIFT CONTROL STRATEGY.

For regulation of voltage in DSTATCOM sinusoidal pulse width modulation based phase shift control scheme is used .

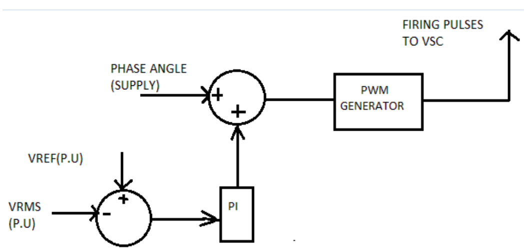

Fig.3- Phase shift control scheme

Firstly the RMS voltage is monitored and compared with the reference voltage to be maintained. If the monitored RMS voltage deviates from the reference voltage error signal is generated which is passed as input to the controller. This error signal is supplied as input to the PI(proportional integrator) which processes the error signal and produces the angle (δ) which is used to obtain the required phase shift between the output voltage of VSC and the AC terminal load voltage. The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle δ.

i.e.,

$$V_A = \sin(\omega t + \delta), \quad (4)$$

$$V_B = \sin(\omega t + \delta - 2\pi/3), \quad (5)$$

$$V_C = \sin(\omega t + \delta + 2\pi/3). \quad (6)$$

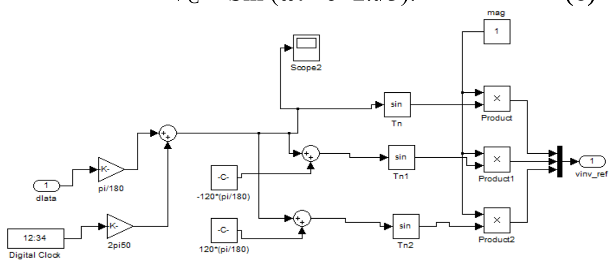

Fig. 4-Phase-Modulation of the control signal

The modulated signal $V_{control}$ is compared against a triangular signal in order to generate the triggering signals for switching the solid electronic circuit of VSC. The sinusoidal PWM(Pulse Width Modulation) scheme depends on two parameters they are the amplitude modulation index(M_a) of signal, and the frequency modulation index(F_f) of the triangular signal. The amplitude index is kept fixed at 1 pu, in order to obtain the highest fundamental voltage component at the controller output[6].

$$M_a = V_{Control}/ V_{tri} \quad (7)$$

Here,

$V_{control}$ = peak amplitude of sinusoidal signal.
V_{tri} = peak amplitude of triangular signal

The other is frequency modulation index (M_f) of the triangular signal,

$$M_f = F_s/F_f \quad (8)$$

Here, F_s= switching frequency
F_f= fundamental frequency

The modulating angle δ is summed with the phase angle of the balanced supply voltages ,assumed to be equally spaced by 120 degrees to produce the desired synchronizing signal required to operate the PWM generator .Hence, the modulating angle is applied to phase A and. the angles for phases B and C are shifted by 240 degrees and 120 degrees, respectively .During these scheme the DC voltage is maintained constant using separate battery source .The effectiveness of the control scheme is shown using Matlab Simulation.

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VI.PROPOSED TEST SYSTEM FOR SHOWING EFFECTIVENESS OF DESIGNED DSTATCOM.

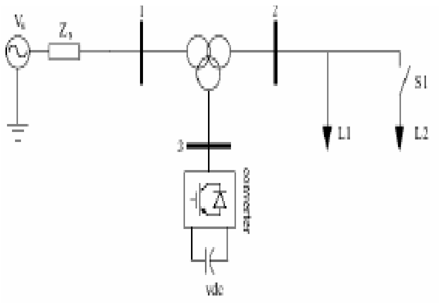

Fig 5.1: Single line diagram for DSTATCOM test system.

Where, Vs = 3-ph Voltage generator,
Z_S = Source Impedance,
V_{dc} = D.C voltage Source,

1 ,2 and 3 are known as feeders or buses to which we connect the various electric equipment's, L1, L2 are the loads connected to the system,S1 is used to attain various situations in the power system, i.e. sags, swells .In the actual practice we are using CB(Circuit breaker instead of switch), by varying the initial positions of the CB.

VII. MATLAB SIMULINK MODEL

The fig.6 shows the basic Simulink model of D-STATCOM test system which is used for performing different DSTATCOM simulations.

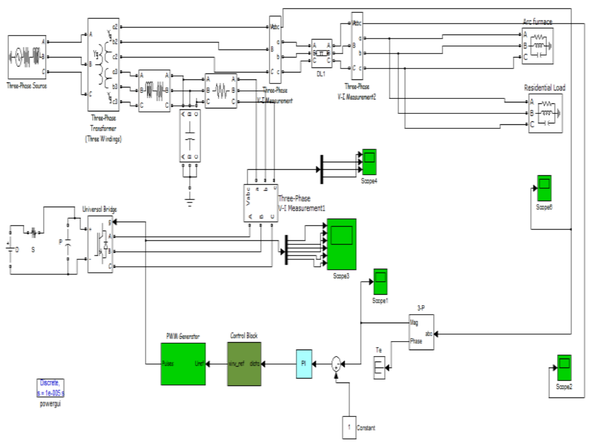

Fig.6- Simulink model of DSTATCOM test system.

It consists of 3-phase source required for supplying to loads which is having phase to phase 230 KV with phase angle of phase A is 0 degree and frequency 50 Hz and this generator internally connected as Y_n, with source resistance (R_S) 0.1 ohms and source inductance 0.758H. A 230kV 50 Hz 3 phase generating system supplying the primary side of the 3 winding step down transformer and the secondary and tertiary side of the transformer are feeding the 11kv double circuit line. Variable loads are connected to 11kv line. DSTATCOM is connected to the 11kv circuit to provide voltage support during power quality disturbances at load side. A fault box is also inserted at the 11kv circuit to create different types of faults in system for producing variable voltage sag. DSTATCOM consists of a DC voltage source of 19 KV magnitude, Universal bridge which is actually the IGBT based Voltage source converter used to convert the DC stored energy into 3-ph AC voltage and this is helpful to mitigate the faults occurred in the Power system. It also consists of Controller, Discrete PWM generator and filter circuit. The 3-ph RLC load is the general load that is connected to the supply mains through 3-ph transformer. Among the two loads connected to the supply one is connected through the 3-ph breaker which is may be closed/opened depends upon the fault requirement i.e. SWELL / SAG.

VIII. SIMULATION RESULTS AND DISCUSSION

Case1-Voltage sag simulation results with and without DSTATCOM

i. Voltage sag without DSTATCOM:

In the proposed test system fault is induced on the load side using the fault box from the Matlab library for voltage sag formation. A single line to ground fault is induced to load 2 that is the residential load, through a fault resistance of 0.6 Ω, during the period 400-600ms, with no DSTATCOM. The test system is simulated without DSTATCOM. Results obtained are shown below in the corresponding figures.

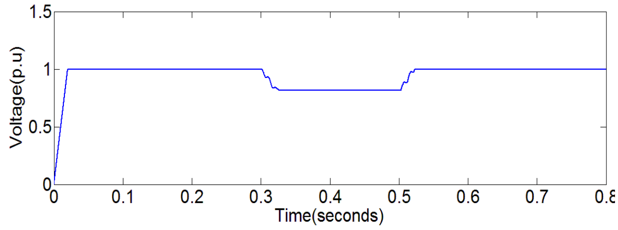

Fig.7- Voltage in p.u at the load end without DSTATCOM

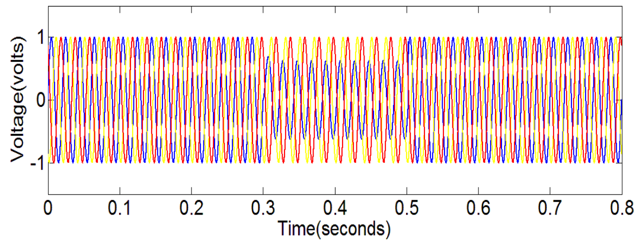

Fig.8- Three phase voltage waveform without DSTATCOM

From the simulation results it is observed that voltage sag of about 20% occurs in the proposed test system when simulated without DSTATCOM.

ii) *Voltage sag with DSTATCOM but without LCL filter*: In this case the modeled test system is simulated with DSTATCOM but without LCL filter. The results obtained from the simulation are shown below.

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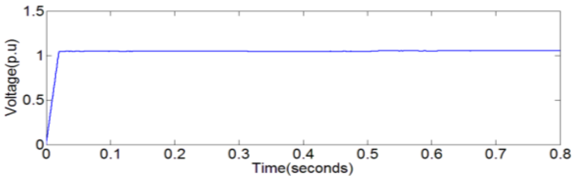

Fig.9-Voltage in p.u with Dststcom but without filter.

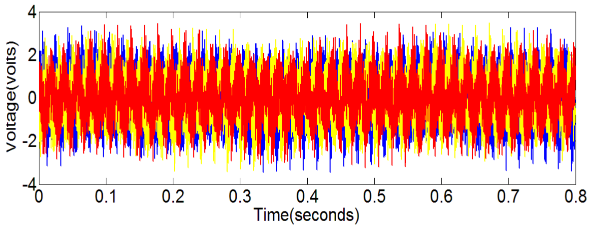

Fig.10-Three phase voltage waveform with DSTATCOM without filter.

From the above figures it is been observed that after connecting the DSTATCOM to the test circuit voltage sag due to fault on the load side is almost mitigated but it is observed that the three phase waveform is highly distorted. Distortion and transients are observed in the three phase waveform due to the absence of filter in the circuit.

iii) Voltage sag with DSTATCOM including LCL filter:

The modeled test system is simulated with DSTATCOM having LCL filter in the circuit. The results obtained are shown below.

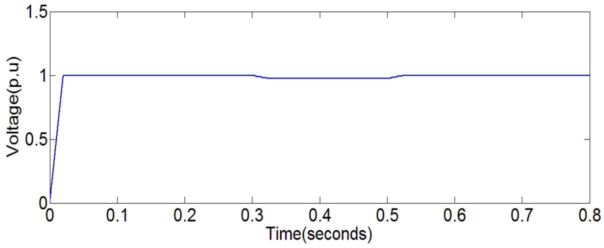

Fig.10- Voltage in p.u with DSTATCOM with filter.

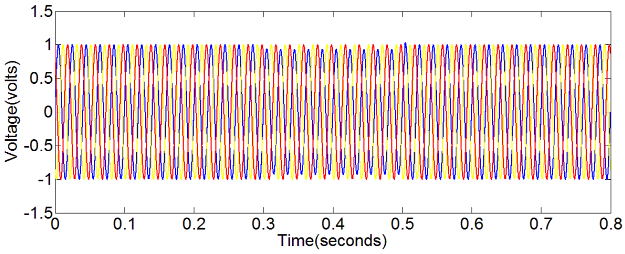

Fig.11-Three phase voltage waveform with filter.

From the above figures it is observed that the distortion and transient seen in the three phase voltage waveform is cleared after connecting a LCL filter in the model. It is also observed that the voltage sag is almost mitigated from 20% to 3% after connecting DSTATCOM with LCL filter.

CASE 2: Voltage swell with and without DSTATCOM

i) *Voltage swell without DSTATCOM:* In this case capacitive load is used as one of the two load in the proposed test system and is connected to the system through a circuit breaker. The simulation results obtained are shown below.

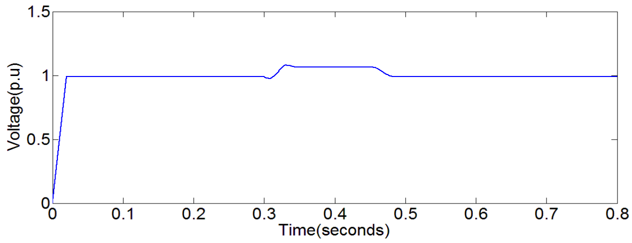

Fig.11- Voltage in p.u without DSTATCOM

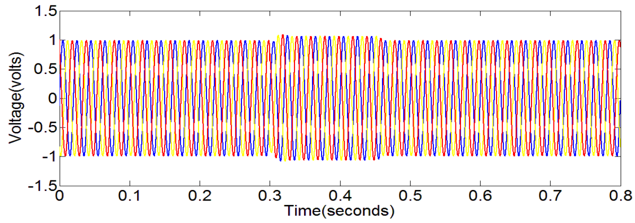

Fig.12- Three phase voltage waveform without DSTATCOM

From the simulation results obtained it is observed that voltage swell of about 110% occurs in the proposed test system when simulated without DSTATCOM.

ii) *Voltage swell with DSTATCOM including LCL filter*: The proposed test system is simulated with DSTATCOM having LCL filter circuit. The simulation results are shown below.

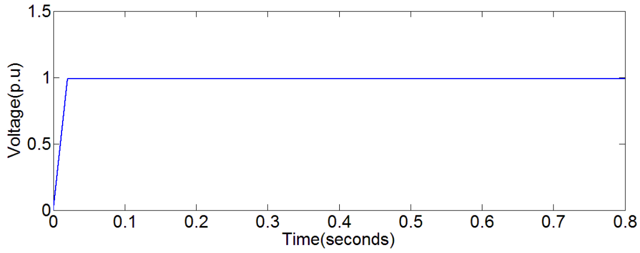

Fig.13-Voltage in p.u with DSTATCOM

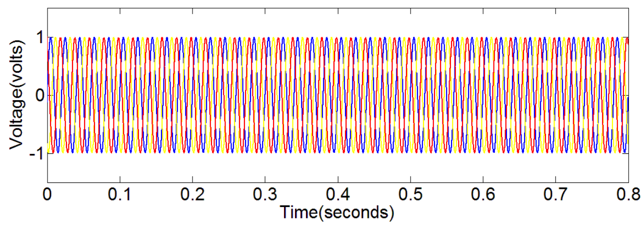

Fig.14-Three phase voltage waveform with DSTATCOM

From the simulation results it is observed that the voltage swell is completely mitigated.

CASE 3. FFT analysis of voltage sag and voltage swell with and without DSTATCOM.

A. FFT analysis of voltage sag with and without DSTATCOM i)*FFT analysis of voltage sag without DSTATCOM*

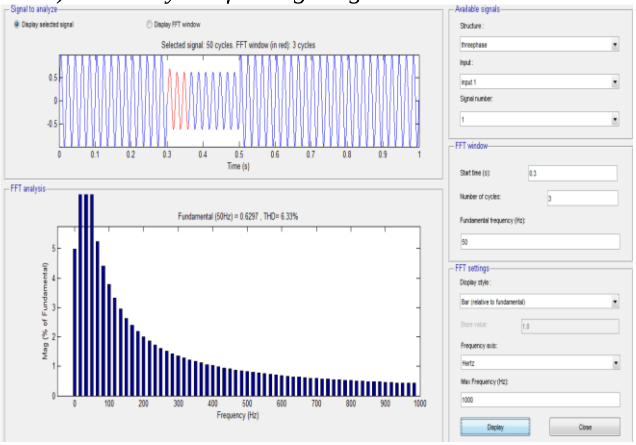

Fig.14- Analysis for voltage sag mitigation without DSTATCOM

ii) FFT analysis for voltage sag with DSTATCOM

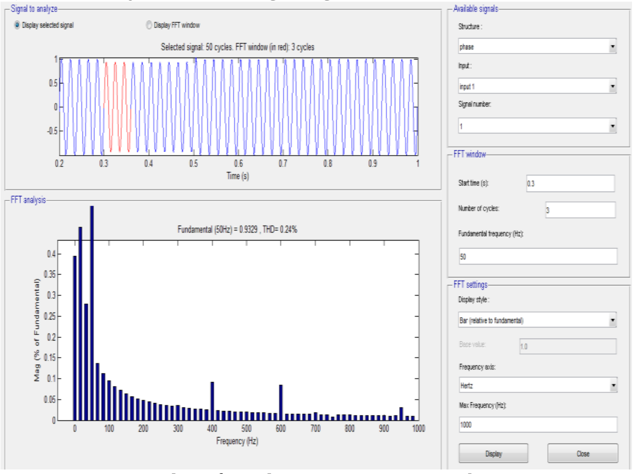

Fig.15- FFT analysis for voltage sag mitigation with DSTATCOM.

B. FFT analysis for voltage swell with and without DSTATCOM

i) FFT analysis for voltage swell without DSTATCOM

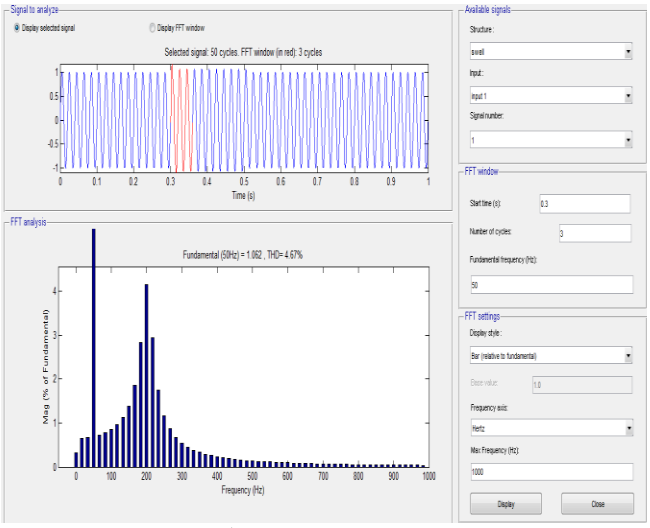

Fig.16-FFT analysis for voltage swell mitigation model without DSTATCOM.

ii) FFT analysis for voltage swell with DSTATCOM.

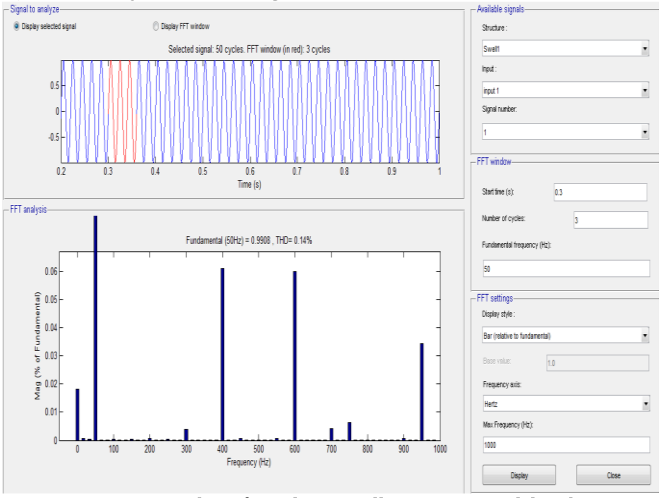

Fig.17-FFT analysis for voltage swell mitigation model with DSTATCOM.

Table.1- Voltage sag and Voltage swell simulation results with and without DSTATCOM

Power Quality Disturbances	Without DSTATCOM	With DSTATCOM
Voltage Sag (%)	20%	3%
Voltage Swell (%)	110%	0%

Table.2- FFT analysis results for both voltage sag and voltage swell

Fast Fourier Transform Analysis	Voltage Sag		Voltage swell	
	Without DSTATCOM	With DSTATCOM	Without DSTATCOM	With DSTATCOM
Total Harmonic Distortion (THD)	6.33%	0.24%	4.67%	0.14%

IX. CONCLUSIONS

This paper has presented the design and applications of D-STATCOM for voltage sags, swells and THD mitigation. A new sinusoidal PWM-based phase shift control scheme has been implemented to control the electronic valves in the two-level VSC used in the D-STATCOM. The developed DSTATCOM is implemented on a small test system for both the cases and simulations are done using SimPower system toolbox of MATLAB/SIMULINK software .In this paper firstly the modeled DSTATCOM simulation for voltage sag mitigation is done with and without LCL filter to show the effectiveness of LCL filter. From the simulation results it is observed that the modeled DSTATCOM almost mitigates the disturbances caused due to voltage sag and voltage swell. In this paper FFT analysis is also done for both the cases and it is observed that the modeled DSTATCOM is also efficient in mitigating THD (Total Harmonic Distortion).

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IX. REFERENCES

[1] SHILPA.R, P.S.PUTTASWAMY "*A review on power quality issues in power systems*" International Journal of Industrial Electronics and Electrical Engineering Volume-2, ISSN: 2347-6982 ,Issue-10, Oct.-2014.

[2] G.Srinivas and T. S Chaitanya "*Power quality improvement using facts device (STATCOM)*" ISSN VOLUME-2, ISSUE-5, 2015.

[3] Mohanty, A. K., & Barik, A. K. (2011). "*Power system stability improvement using facts devices.* "International Journal of Modern Engineering Research (IJMER), 1(2), 666-672.

[4] Jaswani, Manisha, Satyadharma Bharti, and S. P. Dubey. "*A Study of Reactive Power Compensation in Transmission System*." Int. J. Adv. Engg. Res. Studies/IV/II/Jan.-March 351 (2015): 353.

[5] Singh, B., Jayaprakash, P., & Kothari, D. P. (2008). "*A T-connected transformer and three-leg VSC based DSTATCOM for power quality improvement*" IEEE transactions on power electronics, 23(6), 2710-2718.

[6] Bapaiah, P. Power Quality Improvement by using DSTATCOMInternational Journal of Emerging Trends in Electrical and Electronics (IJETEE) Vol. 2, Issue. 4, April-2013.

[7] David Vorganti, Cholleti Sriram "*Implementation of SPWM Technique in D-STATCOM for Voltage Sag and Swell*" International Electrical Engineering Journal (IEEJ) Vol. 5 (2014).

[8] Mithilesh Kumar Kanaujia, Dr. S.K. Srivastava, "*Power Quality Enhancement With D-Statcom Under Different Fault Conditions*" International Journal of Engineering Research and Applications (IJERA), Vol. 3, Issue 2, March -April 2013.

[9] Singh, Raghvendra Singh Dharmendra "*Study of Load Compensation with DSTATCOM*" International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-3, Issue-4, April 2015.