ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 6, June 2014

Power Quality Improvement Using D-STATCOM In Distribution System At Various Faults

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Abstract: DSTATCOM (Distribution Static Compensator) is Used for Mitigation of Power Quality Problems under unbalance caused by various loads and faults in distribution system. This paper addresses the modelling and analysis of custom power controllers, power electronic-based equipment aimed at enhancing the reliability and quality of power flows in low voltage distribution networks using DSTATCOM. A new PWM- based control scheme has been proposed that only requires voltage measurements the operation of the proposed control method is presented for D-STATCOM. Simulations and analysis are carried out in MATLAB/SIMULINK with this control method for two proposed systems.

Keywords: D-STATCOM, VSC, FACTS Controller, PCC, VSC.

I. INTRODUCTION

In recent years, the custom power technology, the low voltage counterpart of the more widely known flexible ac transmission system (FACTS) technology, aimed at high voltage power transmission applications, has emerged as a credible solution to solve many of the problems relating to continuity of supply at the end-user level. Both the FACTS and custom power concepts are directly credited to EPRI. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator (DSTATCOM) based on the VSC principle has been used to perform the Modelling and analysis of such controllers for a wide range of operating conditions based PWM control reported in this seminar for the DSTATCOM. It relies only on voltage measurements for its operation, i.e., it does not require reactive power measurements. A sensitivity analysis is carried out to determine the impact of the dc capacitor size on DSTATCOM performance. When used in low-voltage distribution systems the STATCOM is normally identified as Distribution STATCOM (D-STATCOM). It operates in a similar manner as the STATCOM (FACTS controller), with the active power flow controlled by the angle between the AC system and VSC voltages and the reactive power flow controlled by the difference between the magnitudes of these voltages. As with the STATCOM, the capacitor acts as the energy storage device and its size is chosen based on power ratings, control and harmonics considerations. The D-STATCOM controller continuously monitors the load voltages and currents and determines the amount of compensation required by the AC system for a variety of disturbances.

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1consists 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 DSTATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM 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
3. Elimination of current harmonics

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

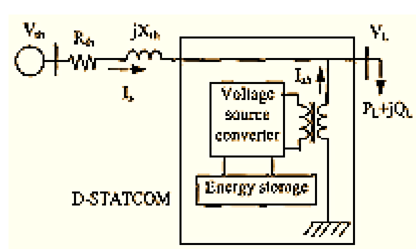


Fig. 1. Single line diagram of D-STATCOM connected distribution system

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

II. SYSTEM REPRESENTATION DISTRIBUTION STATIC COMPENSATOR(D-STATCOM)

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 DSTATCOM 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. Figure.1- the shunt injected current Ish corrects the voltage sag by adjusting the voltage drop across the system impedance Zth. The value of Ish can be controlled by adjusting the output voltage of the converter.

The shunt injected current Ish can be written as,

$$I_{sh=}\ I_{L-}\ I_{S=}\ I_{L-}\ (Vth - VL)/Zth \quad ....(1)$$

$$Ish^\wedge\eta_{=}\ I_L^\wedge\ \text{-}\theta\ \text{-}\ (Vth/Zth)\ ^\wedge(\delta\text{-}\beta) + (Vth/Zth)\ ^\wedge\text{-}\ \beta\ ....(2)$$

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

$$S_{sh}=V_L\ I_{sh}^{*}$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Zth or fault level of the load bus. When the shunt injected current Ish 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 Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. The control scheme for the DSTATCOM follows the same principle as for DVR. The switching frequency is set at 475 Hz.

TEST SYSTEM

Figure shows the test system used to carry out the various DSTATCOM simulations.

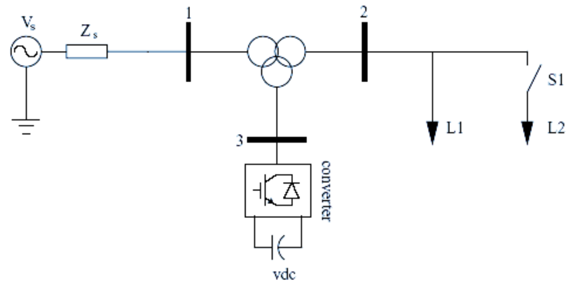
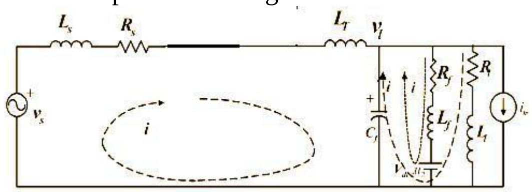


Fig.2 Single line diagram of the test system for D-STATCOM.

State Space Modelling Of D-STATCOM



III. CONTROL STRATEGY

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. 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 a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favoured in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

In fig .3 shows that the controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller and the output is the angle d, which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller process the error signal and generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

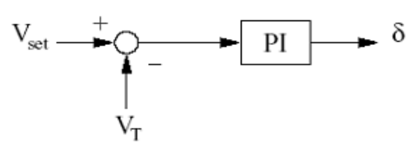


Fig. 3 Indirect Controller

The sinusoidal signal $V_{CONTROL}$ is phase-modulated by means of

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 6, June 2014

the angle δ. i.e.

$$VA=\sin(wt+\delta)$$
$$VB=\sin(wt+\delta-120^o)$$
$$VC=\sin(wt+\delta+120^o)$$

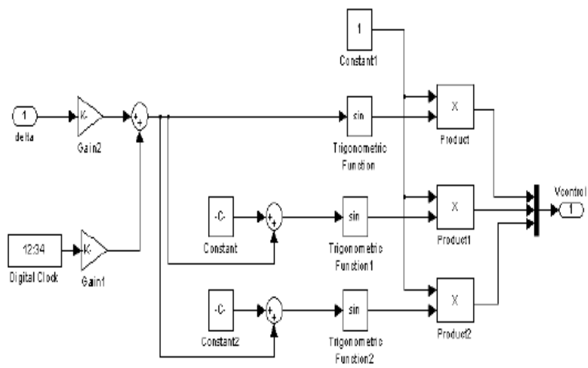


Fig. 4 The sinusoidal signal VCONTROL

The modulated 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 of signal, and the frequency modulation index of the triangular signal. The amplitude index is kept fixed at 1 p.u, in order to obtain the highest fundamental voltage component at the controller output.

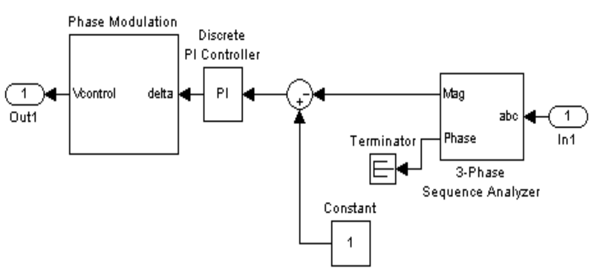


Fig.5 Simulink Model of D-STATCOM Controller

Where $V_{CONTROL}$ is the peak amplitude of the control signal V_{Tri} is the peak amplitude of the triangular signal the switching frequency is set at 450 Hz. The frequency modulation index is given by,

$$Ma=\frac{Vcontrol}{VTRI}=1\,p.u.$$

$$Mf=\frac{fx}{f1}=9$$

Where f_1 is fundamental frequency

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 240° and 120° respectively. It can be seen in that the control implementation is kept very simple by using only voltage measurements as the feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the simulation results. The Simulink block diagram of SPWM generator is as shown in fig.6

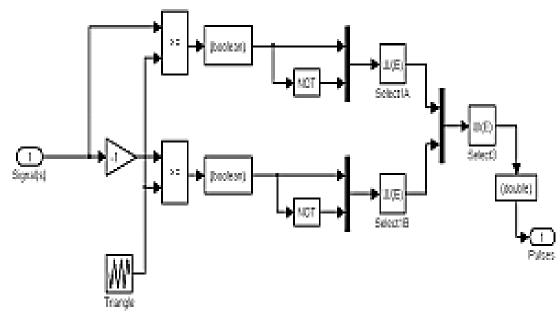


Fig.6 The Simulink block diagram of SPWM generator

IV. SYSTEM MODELLING & RESULTS

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. In the absence of DSTATCOM we can see the voltage sag due to the three phase fault introduced during different conditions.

Here Simulation results are presented for four cases. In case one voltage sag without DSTATCOM at three phase fault, case two voltage sag with DSTATCOM at three phase fault, case three voltage swell without DSTATCOM by removing three phase load and in case four voltage swell with DSTATCOM by removing three phase load is considered.

A. *Case one*

The first simulation contains no D-ST ATCOM and a three phase fault is applied at point A, via a fault resistance of 0.4 fl, during the period 400-600 ms. The voltage sag at the load point is seen with respect to the reference voltage.

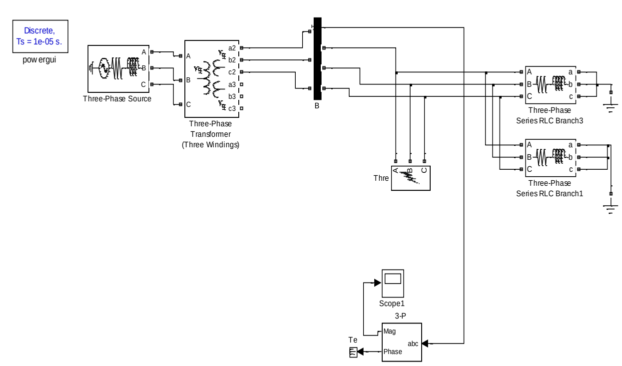


Fig.7 Test system for voltage Sag Without DSTATCOM.

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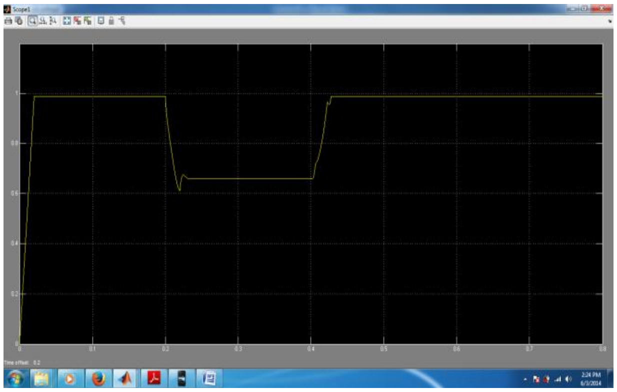

Fig.8 Simulation results for three phase fault for voltage sag without DSTATCOM.

B. ***Case Two***

The second simulation contains D-ST ATCOM and a three phase fault is applied at point A, via a fault resistance of 0.4 fl, during the period 400-600 ms. The improved voltage sag at the load point is seen with respect to the reference voltage.

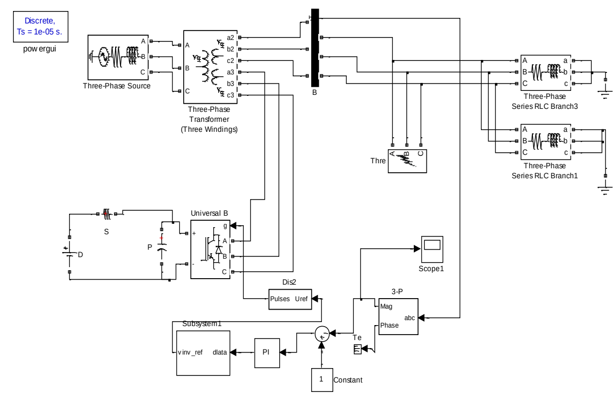

Fig.8 Test system for voltage Sag With DSTATCOM.

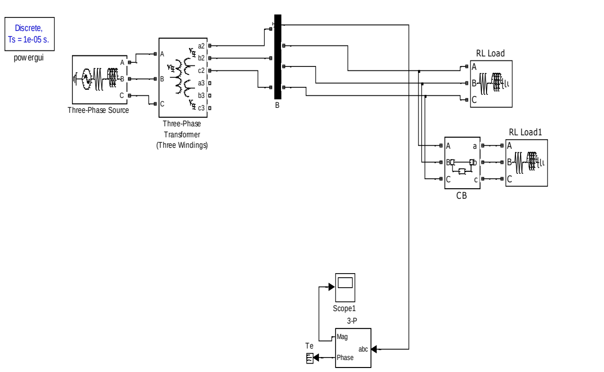

Fig.10 Test system for voltage Swell Without DSTATCOM

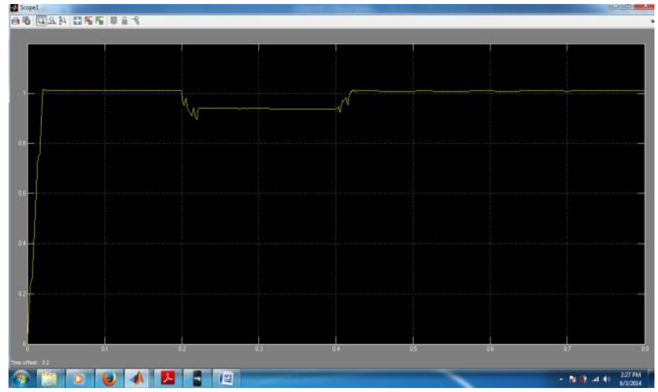

Fig.9 Simulation results for three phase fault for voltage sag with DSTATCOM.

C. ***Case Three***

The third simulation contains no D-ST ATCOM and a three phase load is removed at point A, via a circuit breaker, during the period 400-600 ms. The voltage swell at the load point is seen with respect to the reference voltage.

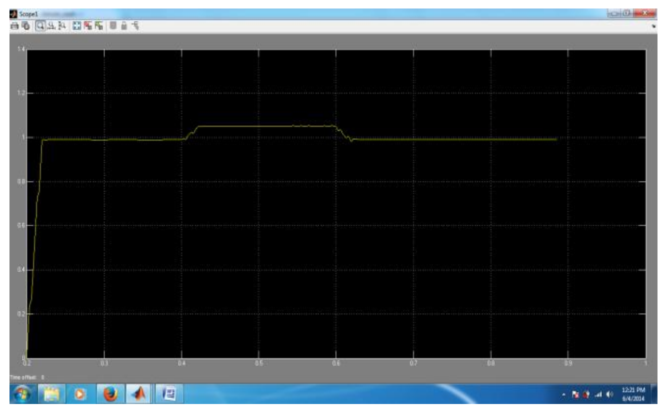

Fig.13 Simulation results for three phase load for voltage swell with DSTATCOM.

E. ***TABLE SHOWING THE VARIATION OF VOLTAGE IN SAG FOR DIFFERENT FAULT RESISTANCE***

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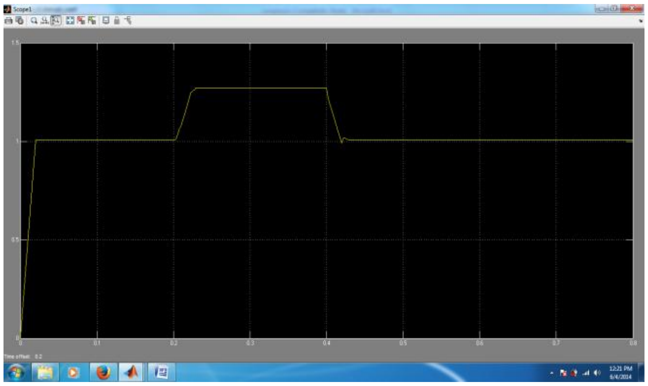

Fig.11 Simulation results for three phase load for voltage swell without DSTATCOM.

F. ***Case Four***

The fourth simulation contains D-ST ATCOM and a three phase load is removed at point A, via a circuit breaker during the period 400-600 ms. The improved Voltage swell at the load point is seen with respect to the reference voltage.

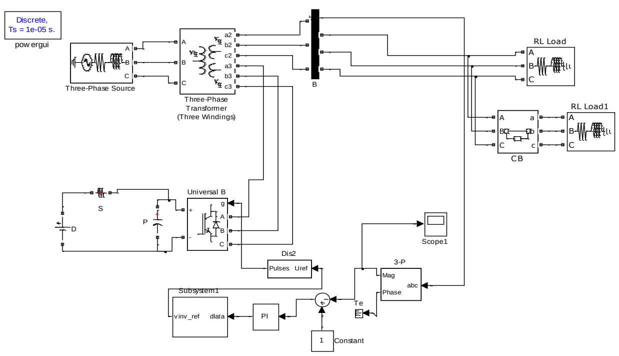

Fig.12 Test system for voltage Swell With DSTATCOM

TABLE I

Fault resistance	3P fault		L-G fault		L-L fault		2L-G fault		3P-G fault	
	With D STATCOM	Without DSTATCOM	With DSTATCOM	Without DSTATCOM	With DSTATCOM	Without DSTATCOM	With DSTATCOM	Without DSTATCOM	With DSTATCOM	Without DSTATCOM
0.4	0.88	0.48	0.95	0.75	1.02	0.64	0.95	0.55	0.88	0.48
0.6	0.92	0.62	0.98	0.81	1.01	0.73	0.98	0.68	0.92	0.62
0.8	0.95	0.72	0.99	0.85	1.01	0.8	0.99	0.76	0.93	0.73
1	0.98	0.8	0.99	0.88	1.01	0.85	0.99	0.82	0.98	0.8

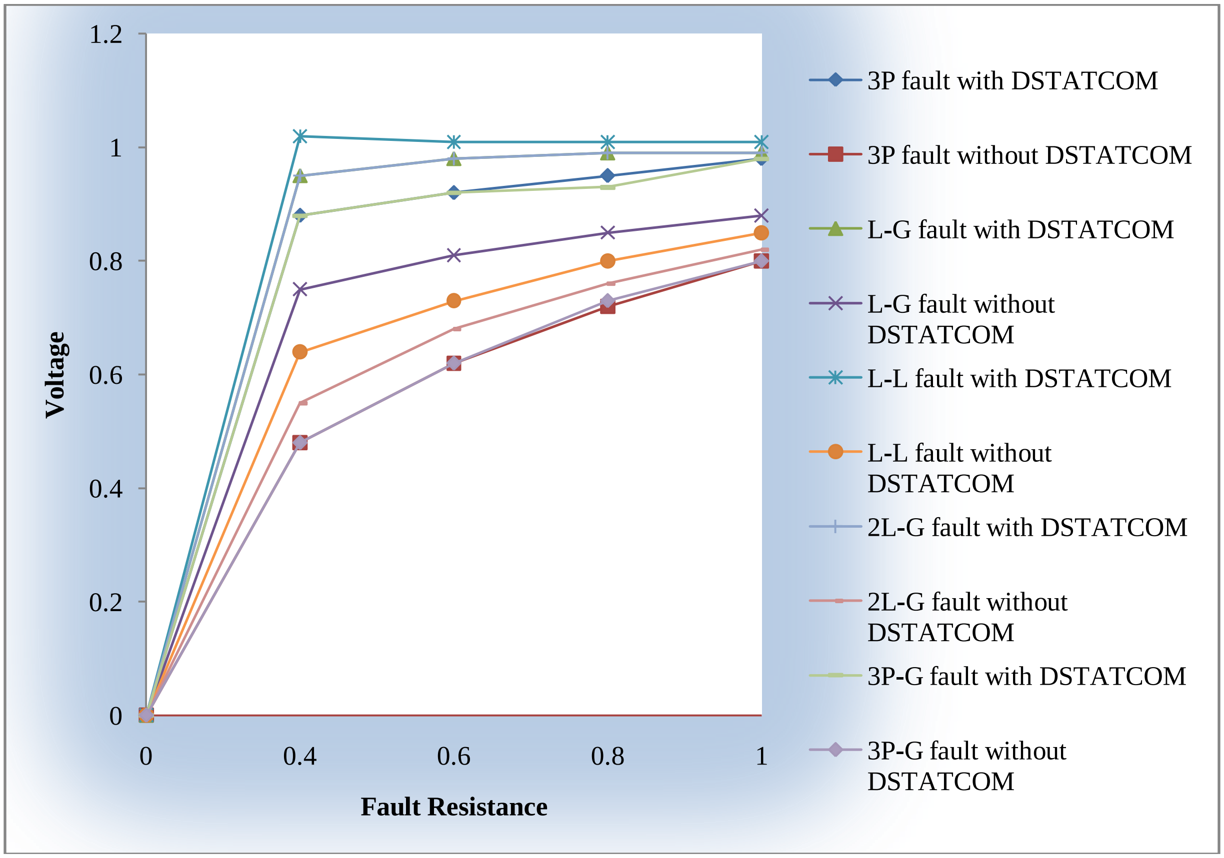

Fig.14 Graphical Representation for data in the table .

As shown in above graph, a very effective voltage regulation which is provided by the D-STATCOM can be clearly appreciated. The D-STATCOM eliminates the voltage sag & swell. In spite of sudden fault and load variations, the regulated RMS voltage shows a reasonably smooth profile, where power quality of the system is improved upto 95-98% of the poor voltage.

V. CONCLUSION

This paper has presented the power quality problems such as voltage sags and swell. Compensation techniques of custom power electronic device D-ST ATCOM was presented. The design and applications of D-STATCOM for voltage sags, swells and comprehensive results were presented. The simulation results show that the voltage sags can be mitigate by inserting DSTATCOM caused due to faults & swell due to sudden switching of loads in the distribution system. The Voltage Source Convert (VSC) was implemented with the help of Sinusoidal Pulse Width Modulation (SPWM). The control scheme was tested under a wide range of operating conditions, and it was observed to be very robust in every case. For modeling and simulation of a D-STATCOM by using the highly developed graphic facilities available in MATLAB/SIMULINK were used. The simulations carried out here showed that the D-STATCOM provides relatively better voltage regulation capabilities.

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BIOGRAPHIES

Chanchal S. Katariya received her BE degree in Electrical Engineering (E & P) from RTM Nagpur University / India. She is working towards his Master in Power Electronics & Power System from RTM Nagpur University. She has also attended various national and international Conferences. Her paper has been included in the Conference proceeding bearing the ISBN 978-81-923297-1-0,978-93-65823-42-6h and ISSN 2321-8134. Her research is focused on Advancement in Power Quality, Electrical Power System. She is currently working as a Assistant Professor in Electrical Engineering at Jagadambha College of Engineering & Technology, Yavatmal (M.S.), INDIA, since 2010 to till date.

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