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

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

# Improvement of Voltage Profile using D-STATCOM – Simulation under sag and swell condition

**Brijesh Parmar[1], Prof. Shivani Johri[2], Chetan Chodavadiya[3]**

M. Tech. Student, Electrical Engineering Department, SBTC, Jaipur, India[1]

Assistant Professor, Electrical Engineering Department, SBTC, Jaipur, India[2]

Assistant Professor, Electrical Engineering Department, MGITER, Navsari, India[3]

**Abstract**: The study of shunt connected FACTS devices is a connected field with the problem of reactive power compensation and better mitigation of transmission related problems in today's world. In this paper we study the shunt operation of FACTS controller, the STATCOM, and how it helps in the better utilization of a network operating under abnormal conditions. Voltage sags and a swell in the medium and low voltage distribution grid impact on sensitive loads is severe. In this paper, the performance of voltage-source converter-based shunt compensators used for load voltage control in electrical power distribution network has been analyzed and compared, when a nonlinear load is connected across the load bus. . Possible control schemes and their effects on the oscillation attenuation are also studied. This research paper described DSTATCOM principles and voltage restoration methods for balanced and/or unbalanced voltage sags and swells in a distribution system. Simulation results were presented to illustrate and understand the performances of DSTATCOM under voltage sags/swells conditions. The MATLAB simulation verification of the results derived has been obtained using a model of the three-phase DSTATCOM.

**Keywords**: Voltage Source Converter(VSC), Distributed Static Compensator (DSTATCOM), Flexible Alternating Current Transmission System, (FACTS), load voltage control, Transient, nonlinear load, swell condition.

## I. INTRODUCTION

Power Generation and Transmission is a complex process and it is required to maintain the voltage to deliver the active power through the lines. To improve the performance of ac power systems, we need to manage this reactive power in an efficient way and this is known as reactive power compensation.

It 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 main objective of this paper is to show that using Distributed Static Compensators (DSTATCOMs) are now becoming more established in industry to reduce the impact of voltage dips on sensitive loads. A voltage dip is commonly defined as any low voltage drop event between 10% and 90% of the nominal RMS voltage[1].

Dynamic Voltage Restorer (DSTATCOM) it is possible to reduce the voltage fluctuations like sag and swell conditions in distribution systems. DSTATCOM which is used for improving power quality is modelled and simulated using proposed control strategy and the performance is compared by applying it to a Single-machine infinite bus system with and without DSTATCOM. MATLAB R2009a version 7.8.0.347(64-bit) is used for Simulation of DSTATCOM model.

## II. NEED FOR REACTIVE POWER COMPENSATION

The main reason for reactive power compensation in a system is:

(1) To improve the voltage regulation;
(2) To increased system stability;
(3) For better utilization of machines connected to the system;
(4) For reducing losses associated with the system; and
(5) To prevent voltage collapse as well as voltage sag.

The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines.

## III. IMPACTS OF POWER QUALITY PROBLEMS

Some of the common power quality issues and their prominent impact are summarized below [11]:

- Voltage sags:- Devices /Process down time, effect on product quality, failure/malfunction of customer equipments and associated scrap cost, clean up costs, maintenance and repair costs etc.
- Transients:- Tripping, components failures, flashover of instrument insulation hardware re booting, software glitches, poor product quality etc.
- Harmonics:- Excessive losses and heating in motors, capacitors and transformers connected to the system

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Vol. 2, Issue 7, July 2014

- Flicker:- Visual irritation, introduction of many harmonic components in the supply power and their associated equipment.

## IV. DISTRIBUTED STATIC COMPENSATOR (DSTATCOM)

A shunt compensator – it protects a sensitive load from the distortion in the supply side voltage. By inserting a voltage of required magnitude and frequency, the shunt compensator can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. Usually, a shunt compensator is used to protect sensitive loads during faults in the supply system. The shunt voltage controller is connected in shunt with the protected load as shown in Fig.1. Usually the connection is made via a transformer, but configurations with direct connection via power electronics also exist. The resulting voltage at the load bus bar equals the sum of the grid voltage and the injected voltage from the DSTATCOM. The converter generates the reactive power needed while the active power is taken from the energy storage.

A power electronic converter based shunt compensator which will save critical loads from all supply side disturbances other than outages is called a dynamic voltage restorer (DSTATCOM).

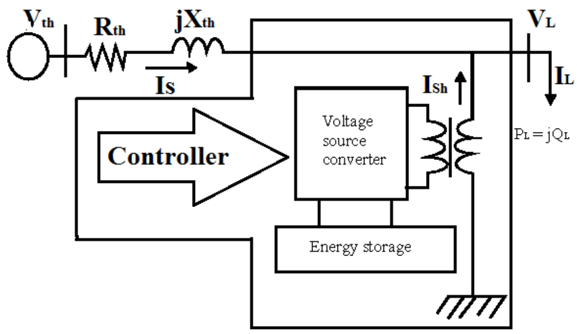


Fig. 1 Schematic diagram of DSTATCOM[10]

Figure-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[10],

$$I_{sh} = I_L - I_s = I_L - \left(\frac{V_{th} - V_L}{Z_{th}}\right)$$

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

$I_{Sh}$= Output of Compensator
$I_L$= Load Current
$I_S$= Source Current
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.

The energy storage can be different depending on the need of compensation. 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 minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. 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 de-vices 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. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers.

The DSTATCOM often has limitations on the depth and duration of the voltage dip that it can compensate. In figure 1, the circuit on the left hand side of the DSTATCOM represents the Thevenin equivalent circuit of the system. The system impedance $Z_{th}$ depends on the fault level of the load bus. When the system voltage ($V_{th}$) drops, the DSTATCOM injects a shunt current $I_{Sh}$ through the injection transformer so that the desired load voltage magnitude $V_L$ can be maintained.

## V. CONTROLLER SCHEME

To maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances we must introduce controller. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM. This methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favoured in FACTS applications. 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 the output is the angle δ, which is provided to the PWM signal generator. The PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

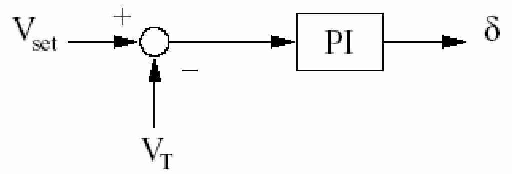


Fig. 2 Schematic diagram of PI controller[4]

The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle □[4]. i.e.,

$$V_a = \sin(\omega t + \delta)$$
$$V_b = \sin\left(\omega t + \delta - {}^{2\pi}/_{3}\right)$$
$$V_c = \sin\left(\omega t + \delta + {}^{2\pi}/_{3}\right)$$

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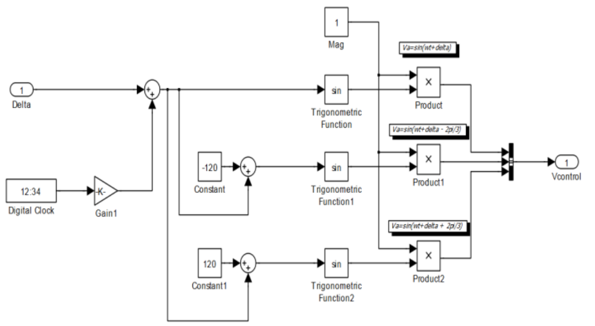


Fig. 3 Mathematical model of PWM generator[4]

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 main parameters of the sinusoidal PWM scheme are the amplitude modulation indeed 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. The switching frequency is set at 1080 Hz. The frequency modulation index is given by,

$M_F = Fs/F_1 = 1080/50 = 21.6$

Where, $F_1$ is the fundamental frequency.

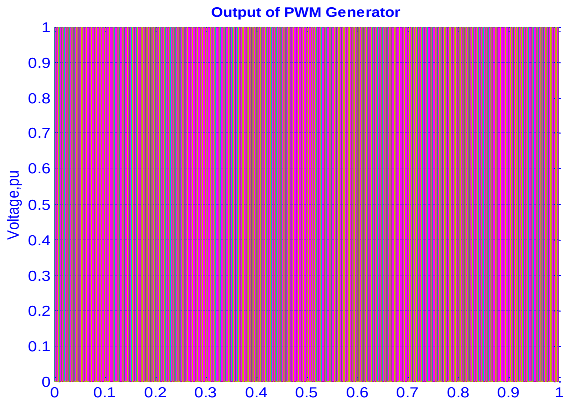


Fig. 4 Output of PWM generator

## VI. RESULTS AND DISCUSSION DSTATCOM: A SHUNT VOLTAGE CONTROLLER

Using the facilities available in MATLAB SIMULINK, the DSTATCOM is simulated to be in operation only for the duration of the fault, as it is expected to be the case in a practical situation. Power System Block set for use with Matlab/Simulink is based on state-variable analysis and employs either variable or fixed integration-step algorithms.

### A. *Single line to ground fault Without DSTATCOM*

The first simulation contains no DSTATCOM and a single line to ground fault is applied as shown in below Fig.5, via a fault resistance of 0.2 Ω during the period 300-600 ms.

The voltage sag at the load point is 25-30% with respect to the reference voltage.

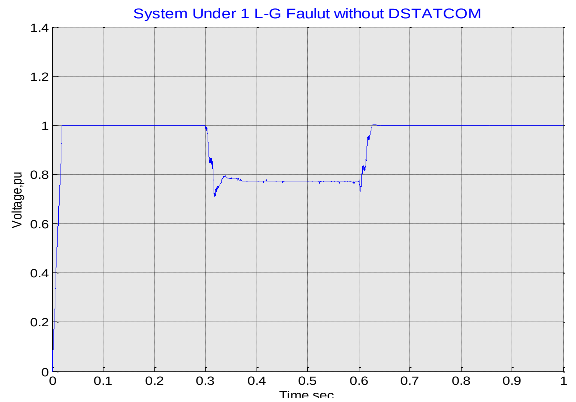


Fig. 5 L-G fault Without DSTATCOM

### B. *Single line to ground fault With DSTATCOM*

Now with the DSTATCOM in operation. The total simulation period is 1000 ms. When the DSTATCOM is in operation the voltage sag is mitigated almost completely and the r.m.s voltage at the sensitive load point is maintained at 99.99%, as shown in figure 6.

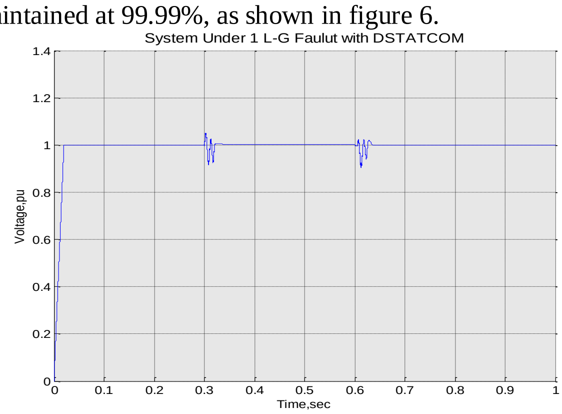


Fig. 6 L-G fault With DSTATCOM

### C. *Double Line to Ground Fault Without DSTATCOM*

The first simulation contains no DSTATCOM and a double line to ground fault is applied as shown in below Fig.7, via a fault resistance of 0.2 Ω during the period 300-600 ms. The voltage sag at the load point is 40% with respect to the reference voltage.

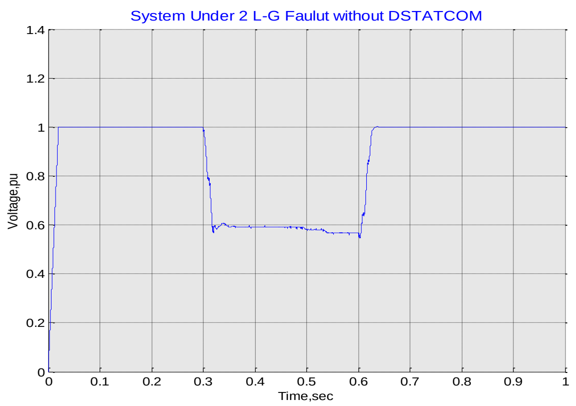


Fig. 7 2L-G Fault Without DSTATCOM

### D. *Double Line to Ground Fault With DSTATCOM*

Now with the DSTATCOM in operation and simulation period is 1000 ms. When the DSTATCOM is in operation

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INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
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the voltage sag is mitigated almost completely and the r.m.s voltage at the sensitive load point is maintained at 99.99%, as shown in figure 8.

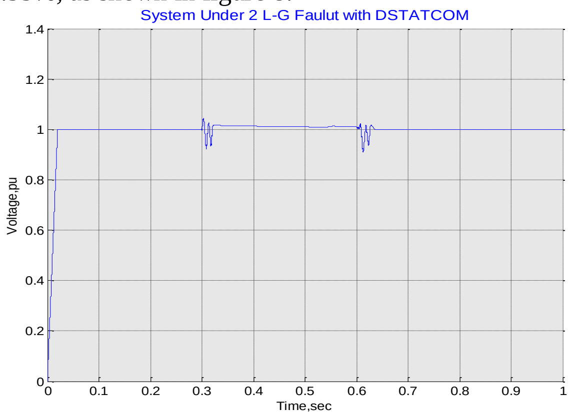


Fig. 8 2L-G Fault With DSTATCOM

*E. Triple Line to Ground Fault Without DSTATCOM*

The first simulation contains no D-STATCOM and three phase fault is applied at point A, via a fault resistance of 0.02 Ω, during the period 300-600 ms. The voltage at the load point is just only 30% with respect to the reference voltage is shown in Figure-9.

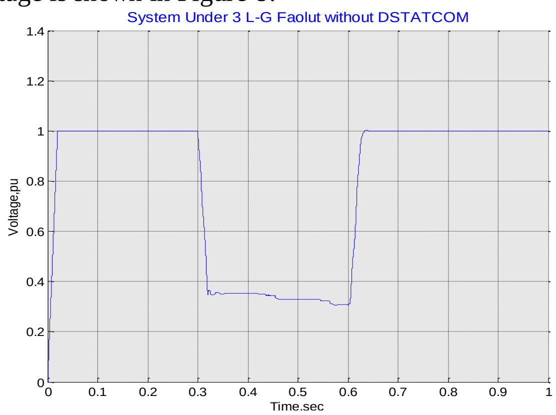


Fig. 9 3 L-G Fault Without DSTATCOM

*F. Triple Line to Ground Fault With DSTATCOM*

Now, a new set of simulations was carried out with the D-STATCOM connected to the system, the load voltage shown in Figure-9 is compensated almost 100%.

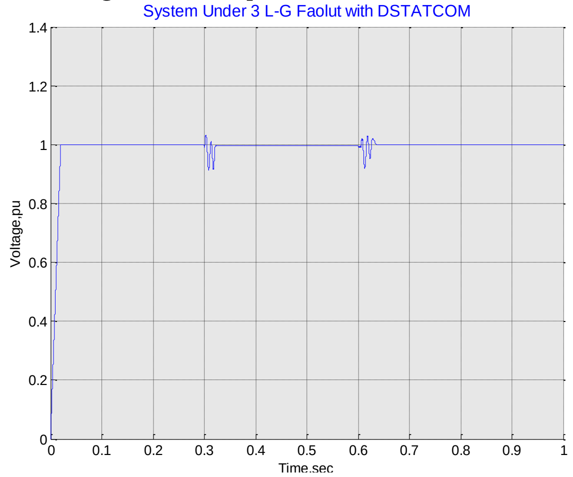


Fig. 10 3 L-G Fault With DSTATCOM

*G. System under Swell condition Without DSTATCOM*

The first simulation for system under swell condition and without D-STATCOM for during the period 300–600 ms. The voltage swell at the load point is 35- 40% with respect to the reference voltage is shown in Figure-11.

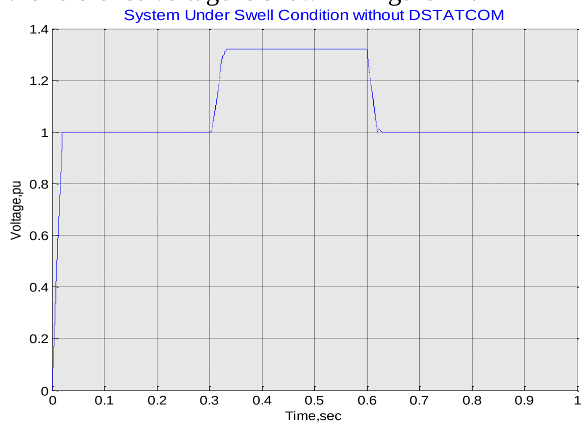


Fig. 11 Swell condition Without DSTATCOM

*H. System under Swell condition With DSTATCOM*

The test system for the simulation of same system with D-STATCOM for voltage swell is compensated shown in Figure-12.

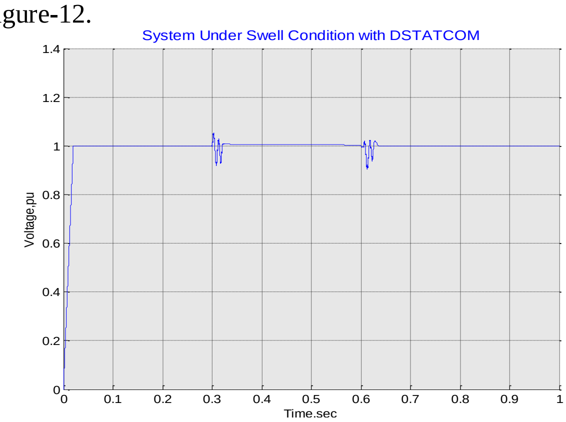


Fig. 12 Swell condition With DSTATCOM

## VII. CONCLUSIONS

With these results, we can conclude that the STATCOM is an effective solution for reducing voltage fluctuations caused by disturbing loads and may be applied for voltage profile improvement.Since, from above comparison the basic difference of DSTATCOM to have overall superior functional characteristics, better performance with greater flexibility make more adoptable for low voltage distribution power network. This paper has presented the power quality problems such as voltage dips, voltage swell and interruption, consequences and mitigation techniques of custom power electronic devices DSTATCOM. The design and applications of DSTATCOM for voltage sags caused by different faults and swells and comprehensive results are presented. This characteristic makes it ideally suitable for medium-voltage power distribution system.

## ACKNOWLEDGMENT

I express my sincere thanks to **Prof. Shivani Johri, SBTC-Jaipur** for her invaluable guidance to complete this work.

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

*INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING*
*Vol. 2, Issue 7, July 2014*

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