International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

A New Design of D-STATCOM forMitigation of Power Quality Problems

V.Indrasen [1], K.Bharath Bhushan [2], P.Vasudevanaidu [3]

1st and 2nd author's students of Electrical & Electronics Engg, GITAM UNIVERSITY-Hyderabad
3rdauthor Asst.Professor, Electrical & Electronics Engg,GITAM UNIVERSITY-Hyderabad

Abstract

This paper deals with A New design of D-STATCOM (Distribution Static Compensator) isUsed for Mitigation of Power Quality Problems under unbalance caused by various loads in distribution system. This paper addresses the modeling 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.

Keyword: D-STATCOM, VSC, FACTS Devices, PQ, PCC.

I. INRODUCTION

From the past few decades, the increase in electrical energy demand for industries and domestic use resulted in the higher production of electrical energy which has consequently resulted in higher tariff rates, for industrial and domestically usage A.C Power is essential, In A.C the power factor is described as the ratio of real power to the apparent power (real power+ reactive power).

Reactive power is produced when the current and voltage waveforms are out of phase with each other, in a capacitive load current leads voltage whereas in inductive load current lags voltage, reactive power is denoted as var. Reactive power compensation is essential to increase the power factor quality, which obviously results in the decrease of power consumption and tariffs; finally the aim is to decrease the reactive power.Reactive power can be decreased by placing a shunt capacitor in line but it does not fulfill the problem because it gets in resonance when it gets tuned with reactance of the system. In order to overcome the disadvantages caused by placing a shunt capacitor in line, facts devices have been developed to solve the problem effectively examples of FACTS devices are SC, TSC...etc. Though the power electronic devices known asFactsdevices are developed for transmission part of the system its model have been changed from past few years to serve better power quality at low and medium voltages.
DSTATCOM is a distribution static compensator network which is placed at the distribution part of the system which works with the FACTS devices which react faster than the shunt capacitors actually.

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 [1], [2]. 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 (D-STATCOM) based on the VSC principle [3]-[5] 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 D-STATCOM. It relies only on voltage measurements for its operation, i.e., it does not require reactive power measurements [6]. A sensitivity analysis is carried out to determine the impact of the dc capacitor size on D-STATCOM 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 theSTATCOM (FACTS controller), with the active power flowcontrolled 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 allowsthe 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 threequite distinct purposes [7]:

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 continuousvoltage regulation using an indirectly controlled converter.

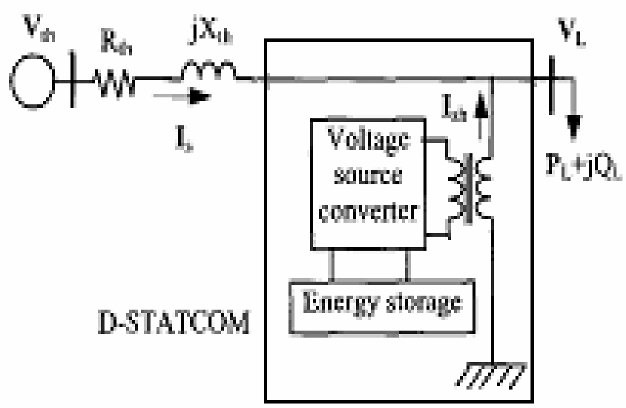


Fig. 1. Single line diagram of D-STATCOM connected distribution system.

II. System Representation

DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

A D-STATCOM (Distribution Static Compensator), which is pictorially depicted in Figure, is accumulated with 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 dc voltage across the storage device into a set of three-phase ac output voltages with the use of VSC. 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 D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. The configuration allows the device to absorb or generate controllable active and reactive power.

The ac system in combination with a shunt VSC provides a multifunctional topology results in the following advancements:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor; and
3. Elimination of current harmonics.

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,

$$I_{sh} = I_L - I_s = I_L - \frac{V_{TH} - V_L}{Z_{Th}} \quad (1)$$

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

$$S_{sh} = V_L I_{sh}^* \quad (2)$$

It may be mentioned that the reliability 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 Ish is kept in quadrature with V_L, the desired voltage correction can be achieved without injecting any active power into the system. When the value of Ish is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system on the other hand. The control scheme for the D-STATCOM. The switching carrier frequency is set at 1075 Hz.

TEST SYSTEM

Figure shows the test system used to carry out the various D-STATCOM simulations.

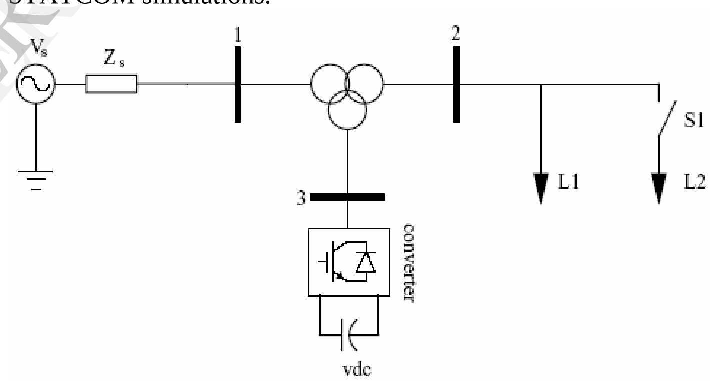


Fig.2.Single line diagram of the test system for D-STATCOM.

III. State Space Model of MC UPQC and Switching Control

A. State Space Modelling Of D-STATCOM:

This section presents D-STATCOM the mathematical modelling used in the development of state space model. The considered electrical circuit is a two feeder, three-phase three-wire system.

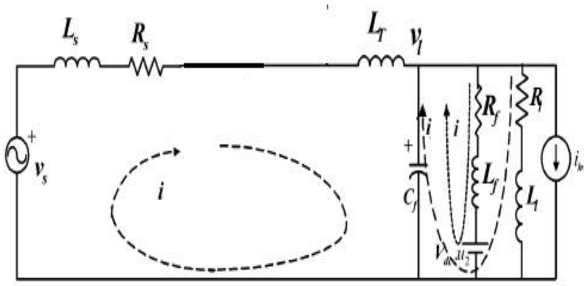


Fig.3.Single line equivalent circuit diagram of the test system for D-STATCOM

$$L_s \frac{di_1}{dt} = -R_s i_1 - V_s + V_l \quad (2)$$

$$L_{sh} \frac{di_2}{dt} = -R_{sh} i_2 - V_l + u_1 V_{dc} \quad (3)$$

$$L_l \frac{di_3}{dt} = -R_l i_3 + V_l \quad (4)$$

$$C_{sh} \frac{dV_l}{dt} = i_1 - i_2 - i_3 - i_h \quad (5)$$

Where μ_1 represent theduty ratio of the control variables of shunt VSC.

The single phase equivalent circuit of D-STATCOM compensated distribution system to find the state-space model of the system in fig. State variables are three loop currents and one capacitor voltages. They consist of five forcing functions.

State vector is defined as following.

$X^T=[i_1 \quad i_2 \quad i_3 \quad v_l]$ (6)

Controlling vector

$u^T= [u_1]$ (7)

The above circuit is modeled in state-space analysis as

$\dot{X}$=AX+$B_1 V_{s1}$+B_2u+$B_3 i_h$ (8)

Where the matrices A, B1, B2, and B_3 are shown appendix

B. SWITCHING 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 favored 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 .2 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 PIcontroller process the error signal and generates the required angle to drive the error to zero, i.e., the load rmsvoltage is brought back to the reference voltage.

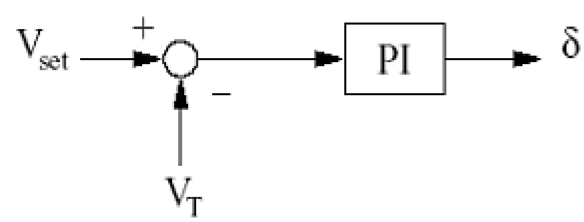


Fig. 2. Indirect Controller

The sinusoidal signal $V_{CONTROL}$ is phase-modulated by means of the angle δ.

i.e.

$V_A = \sin(\omega t + \delta)$

$V_B = \sin(\omega t + \delta - 120°)$

$V_C = \sin(\omega t + \delta + 120°)$(9)

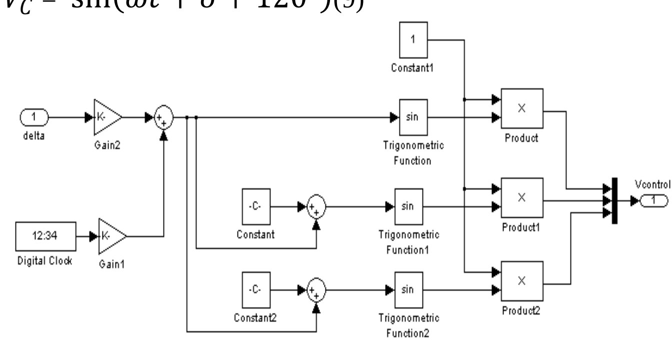
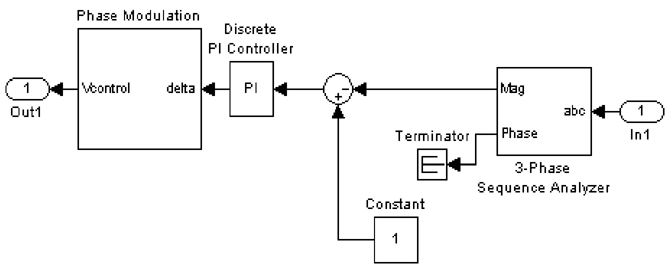


Fig. 3. The sinusoidal signal $V_{CONTROL}$

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.



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 1075Hz. The frequency modulation index is given by;

$$M_a = \frac{V_{CONTROL}}{V_{TRI}} = 1\text{p.u}$$

$$M_f = \frac{f_x}{f_1} = 25(9)$$

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.4

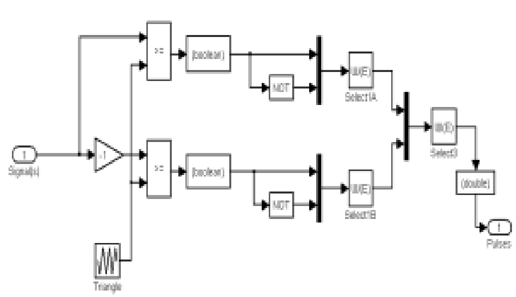


Fig.4.The Simulink block diagram of SPWM generator

IV. SYSTEM MODELLING

To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB/SIMULINK version R2007b. Figure.5 below shows the flowchart for the methodology. The test system shown in figure 6 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. 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. A 750 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system.

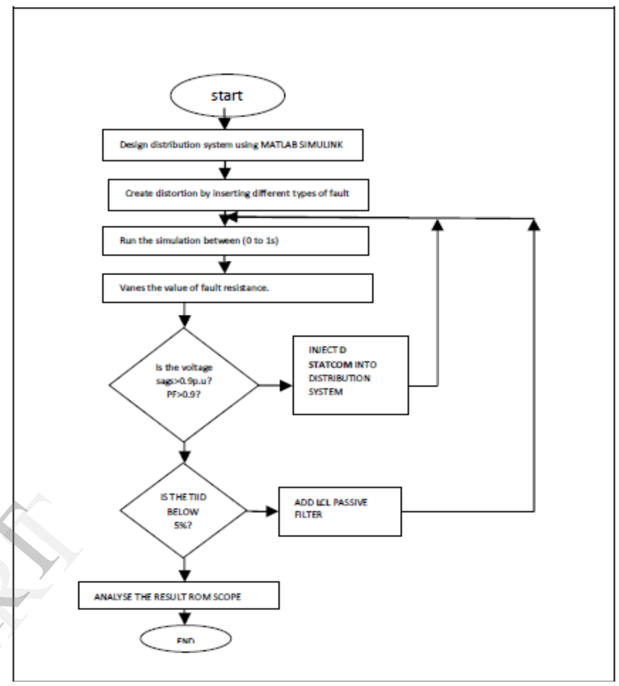


Fig.5.Flow Chart diagram of D-STATCOM test system

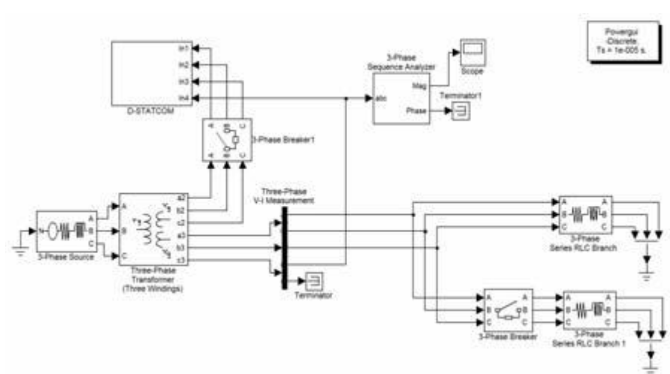


Fig.6.Simulink model of D-STATCOM test system.

TABLE I

System Parameters	Values
System frequency (*f*)	50HZ
Rated voltage	230KV
Voltage source v_{S1}	230KV,Phase angle 0^0
Voltage source v_{S2}	230KV,Phase angle 0^0
Feeder-1	1+j0.8Ω

Load-1	A three-phase diode bridge rectifier with an resistor (500) Ω

D-STATCOM PARAMETERS

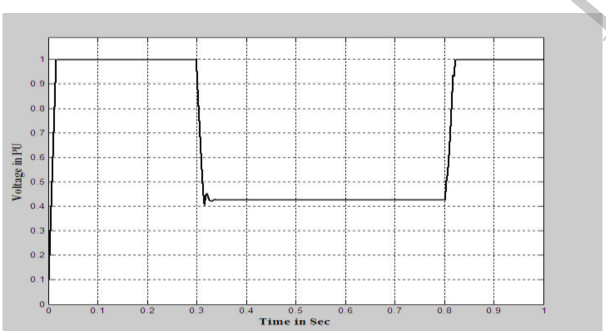
System Parameters	Values
System frequency (f)	50HZ
VSC-1 single-phase transformers ($T1$)	100MVA,230KV/11KV, 2% resistance and 8% leakage Reactance
VSC-2 single-phase transformers ($T2$)	100MVA,230KV/11KV, 2% resistance and 8% leakage Reactance

The test system shown in figure 6 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. 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. A 750 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system.

Case-1

Simulated Results of Sag modeled system with and without D-STATCOM:

The circuit shown is Fig. 6, is nothing but a sag generating circuit without the D-STATCOM connected to it is simulated and the magnitude ofvoltage is as shown in the Fig 7.1.



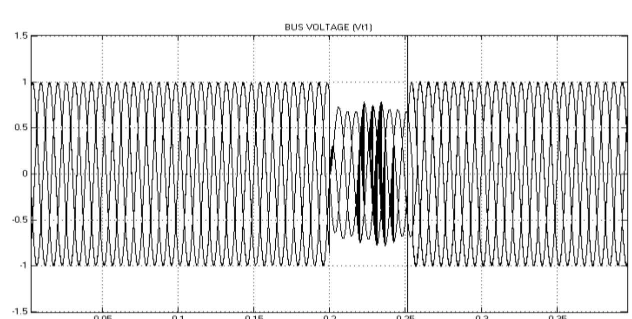
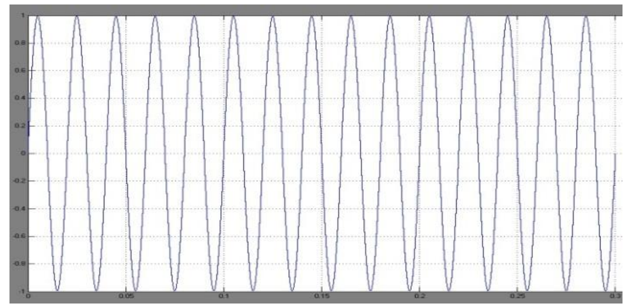


Fig.6.VRMS Voltage at the Load Point of the Sag System without D-STATCOM.

The circuit shown is Fig. 5, is nothing but a sag eliminating circuitwith the D-STATCOM connected to it is simulated and the magnitude ofvoltage is as shown in the Fig 6.2.



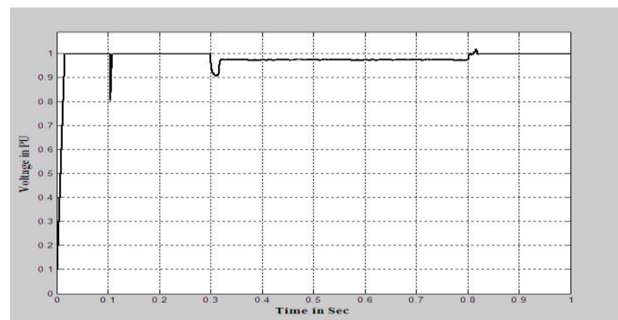


Fig.7.2 .V_{RMS} Voltage at the Load Point of the System with D-STATCOM.

As shown in fig.7.2, a very effective voltage regulation which isprovided by the D-STATCOM can be clearly appreciated. The D-STATCOMsupplies reactive power to the system to eliminate the voltage sag. In spite ofsudden load variations, the regulated RMS voltage shows a reasonably smoothprofile, where the transient overshoots is almost non-existent.

Case-2

Simulated Results of Swell modeled system with and without D-STATCOM:

The circuit shown is Fig. 8, is nothing but a swell generating circuitwithout the D-STATCOM connected to it is simulated and the magnitude ofvoltage is as shown in the Fig8.1.

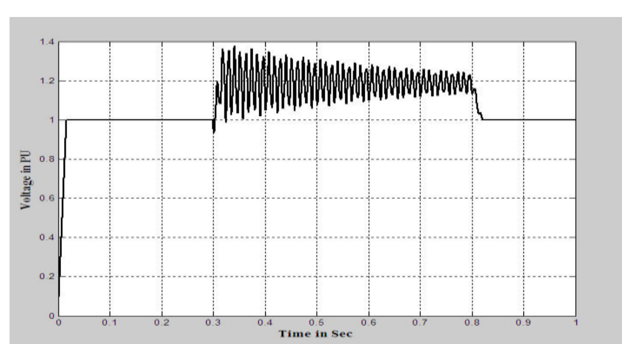
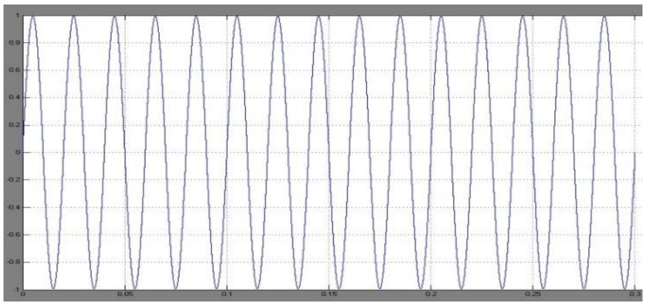


Fig 8.1 VRMS Voltage at the Load Point of the Swell System without D-STATCOM.

ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

The circuit shown is Fig. 8, is nothing but a swell eliminating circuit with the D-STATCOM connected to it is simulated and the magnitude ofvoltage is as shown in the Fig 8.2



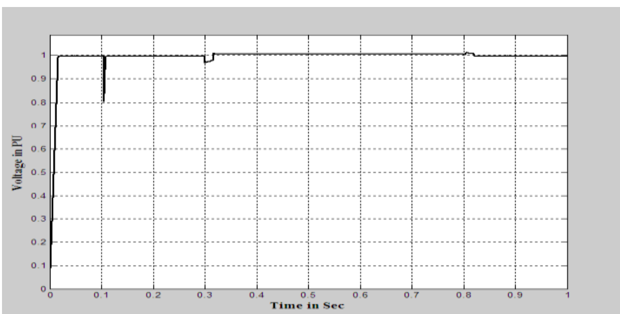


Fig 8,2 V_{RMS} Voltage at the Load Point of the Swell System with D-STATCOM.

As shown in fig.8.2, a very effective voltage regulation which isprovided by the D-STATCOM can be clearly appreciated. The D-STATCOMeliminates the voltage swell. In spite of sudden load variations, the regulatedRMS voltage shows a reasonably smooth profile, where the transientovershoots is almost non-existent.

VI. Conclusion

The power quality problems mitigated by using DSTATCOM is presented in this paper and design the state space model of a D-STATCOM was analysed and developed for use in Simulink environment with power system block sets. Here a control system is designed in MATLAB Simulink. A D-STATCOM can control reactive power and also regulate bus voltage. It can improve power quality in power system. Here waveform shows the performance of D-STATCOM in a distribution system.

Appendix-A

$$A_1 = \begin{bmatrix} \frac{-R_{s1}}{L_{s1}} & 0 & 0 & \frac{-1}{L_{s1}} \\ 0 & \frac{-R_{sh}}{L_{sh}} & 0 & \frac{1}{L_{sh}} \\ 0 & 0 & \frac{-R_{L1}}{L_{L1}} & \frac{1}{L_{L1}} \\ \frac{1}{C_{SH}} & \frac{-1}{C_{SH}} & \frac{-1}{C_{SH}} & 0 \end{bmatrix} \quad B2 = \begin{bmatrix} 0 \\ \frac{-v_{dc}}{L_{sh}} \\ 0 \\ 0 \end{bmatrix}$$

$$B2 = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L_{sh}} \\ 0 \end{bmatrix} \quad B3 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{C_{SH}} \end{bmatrix}$$

References

[1] N.G. Hingorani "Introducing custom power," *IEEE spectrum*, vol.32, June 1995, pp. 41-48.

[2] Ray Arnold "Solutions to Power Quality Problems" power engineering Journal, Volume 15; Issue: 2 April 2001, pp: 65-73.

[3] John Stones and Alan Collision "Introduction to Power Quality" power engineering journal, Volume 15; Issue 2, April 2001, pp: 58-64.

[4] Anaya-Lara, O.; Acha, E." Modeling and analysis of custom power systems by PSCAD/EMTDC", *IEEE Transactions on Power Delivery*,Volume: 17, Issue: 1, Jan. 2002 pp: 266 – 272.

[5] Po-Tai Cheng; Chian-Chung Huang; Chun-Chiang Pan; Bhattacharya, S.;" Design and implementation of a series voltage sag compensator Under practical utility conditions" *IEEE Transactions on Industry Applications*, Volume: 39 , Issue: 3 , May-June 2003

[6] Soo-Young Jung; Tae-Hyun Kim; Seung-Il Moon; Byung-Moon Han;" Analysis and control of DSTATCOM for a line voltage regulation"Power Engineering Society Winter Meeting, 2002. IEEE, Volume: 2, 27-31 Jan. 2002, pp: 729 - 734

[7] Bollen, M.H.J.," Voltage sags in three-phase systems" *PowerEngineering Review, IEEE*, Volume: 21, Issue: 9, Sept. 2001, pp: 8 -11, 15.

[8] Hague, M.H." Compensation of distribution system voltage sag by DVR and D-STATCOM", *IEEE Porto Power Tech Conference*,Volume: 1, 10th-13th Sept. 2001.

[9] L. Gyugyi, K. K. Sen and C. D. Schauder, "The interline power flow controller concept: a new approach to power flow management in transmission system," *IEEE Trans. Power Deliv.*, Vol. 14, No. 3, pp.1115- 1123, 1999.

[10] A. Ghosh and G. Ledwich, *Power Quality Enhancement Using Custom Power Devices*, Norwell, MA: Kluwer, 2002.