Improve Voltage Profile of Power System Network using D-STATCOM and DVR with Matlab Simulation

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Abstract

A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. The issue of power quality is going to take newer dimensions. In developing countries like India, where the variation of power frequency and many such other determinants of power quality are themselves a serious question, it is very vital to take positive steps in this direction.

This present work describes the techniques of correcting the supply voltage sag, swell and interruption in a distributed system. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Power electronic-based equipment aimed at enhancing the reliability and quality of power flows in low voltage distribution networks. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle. A DVR injects a voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption. The reliability and robustness of the control scheme in the system response to the voltage disturbances due to system faults or load variations is obviously proved in the simulation results.

Keywords: D-Statcom, DVR, voltage dips, swells, power quality.

1. Introduction

In the power system, the major power quality problems are poor load power factor, harmonic contents in loads, notching in load voltages, DC offset on load voltages, unbalanced loads, supply voltage distortion, voltage sag, & voltage swell. One of the most common power quality problems today is voltage sag. Voltage sag is a short time event during which a reduction in R.M.S. voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude is ranged from 10-90% of nominal voltage (which corresponds to 90-10% remaining voltage) and with a duration from half a cycle to 1 minute. In a three-phase system, the voltage sag is by nature a three-phase phenomenon which affects both the phase-to-ground and phase-to-phase voltages. The faults are single-phase or multiple-phase short-circuit, which leads to high currents. The high current results in a voltage drop over the network impedance. Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems[1].

The introduction of FACTS has given the new direction to the power system to solve the power quality problems. At present, a wide range of very flexible controllers are emerging for custom power applications. The FACTS controllers like Static VAR Compensator(SVC), Thyristor controlled switch capacitor(TCSC), Thyristor controlled phase shifting transformer(TCPST), STATCOM, Static

Synchronous Series Compensator(SSSC), unified power flow controller(UPFC), etc. are mainly used controllers. Among these, the STATCOM is the most effective device. The STATCOM is a shunt device & based on VSC principle. The inverter circuit along with interface transformers/inductors is called a STATCOM[1][2][3].

2. Voltage Source Converters (VSC) Based Controllers

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC is used to either completely replace the voltage or to inject the 'Dip voltage'. The 'Dip voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage i.e. capacitor, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

A. Shunt voltage controller [Distribution Static Compensator (DSTATCOM)]

The D-STATCOM (Distribution Static Compensator) configuration consists of a VSC, a DC energy storage device; a coupling transformer connected in shunt with the ac system, and associated control circuits. Fig. 1, shows the basic configuration of D-STATCOM. Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. 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 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[1].

Figure 1 shows 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,

$$I_{sh} = I_L - I_s$$

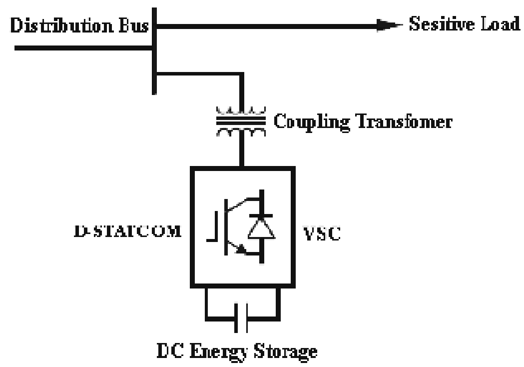

Figure 1. Basic configuration of D-STATCOM

It is mentioned that the effectiveness of the 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 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.

Simulation of D-STATCOM and Result

Fig. 2 shows the test system implemented in PSCAD to carry out simulations for the D-STATCOM.

A two-level D-STATCOM is connected to the tertiary winding to provide instantaneous voltage support at the load point. The capacitor on the dc side provides the D-STATCOM energy storage capabilities. The set of switches shown in Fig. 3 were used to assist different loading scenarios being simulated. To show the effectiveness of this controller in providing continuous voltage regulation, simulations were carried out with and without D-

STATCOM connected to the system. A set of simulations was carried out for the test system shown in Fig. 3[4].

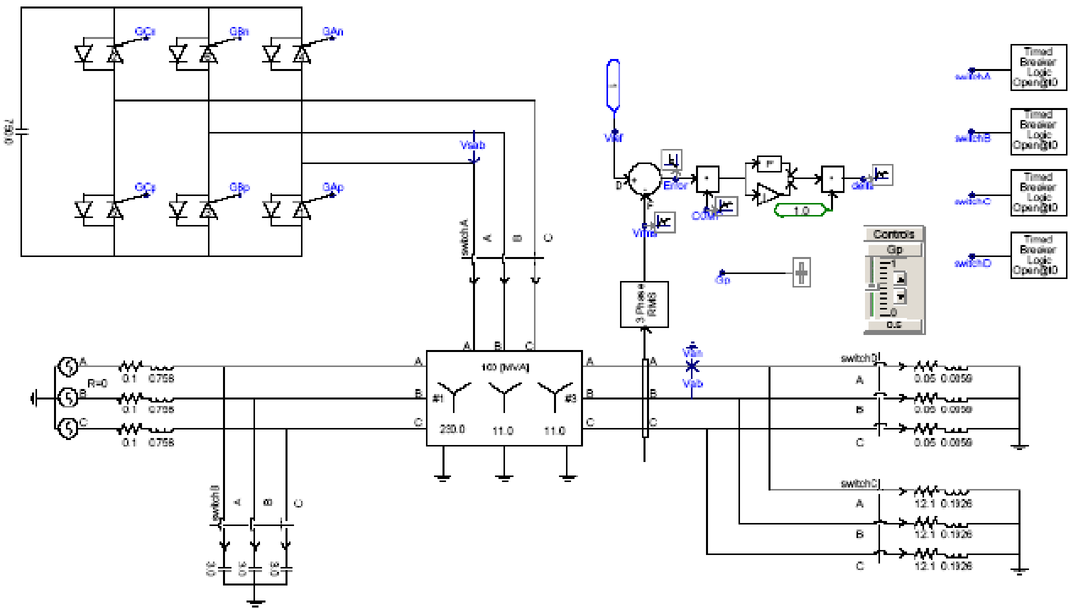

Figure 2. Schematic model of D-STATCOM

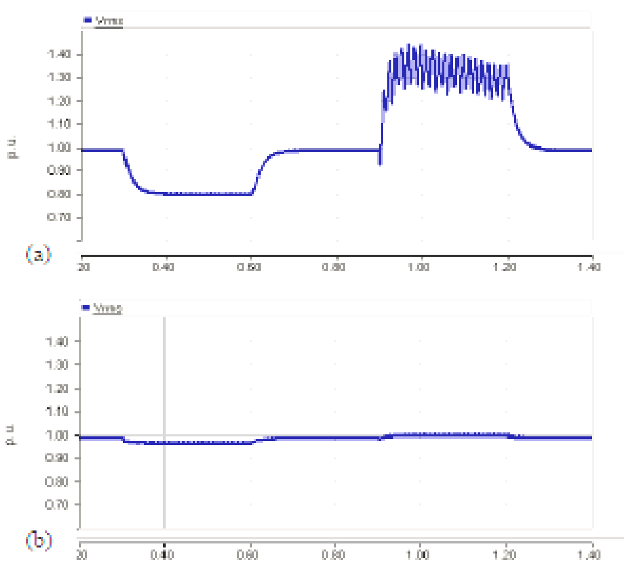

Figure 3. Variation of sensitive load rms voltage: (a) without D-STATCOM, (b) with D-STATCOM

B. Series voltage controller [Dynamic Voltage Restorer, (DVR)]

The DVR is a powerful controller that is commonly used for voltage sags mitigation at the point of connection. DVR is connected in series with the protected load as shown in Fig.3. Usually the connection is made via a transformer, but configurations with direct connection via power electronics also exist.

The VSC generates a three-phase ac output voltage which is controllable in phase and magnitude. These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference. The converter generates the reactive power needed while the active power is taken from the energy storage.

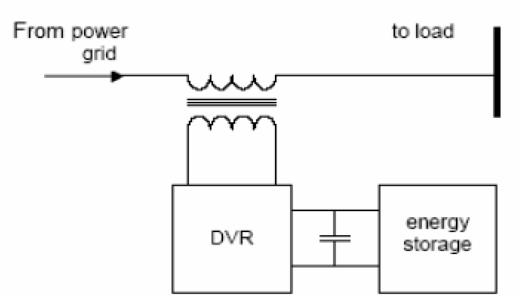

Figure-4. Basic configuration for a DVR.

The apparent power of DVR is:

$$S_{1DVR} = I_L V_{1DVR}$$
$$= I_L \sqrt{V_L^2 + V_S^2 - 2 V_L V_S \cos(\theta_L - \theta_S)}$$

And the active power of DVR is:

$$P_{1DVR} = I_L \left(V_L \cos\theta_L - V_S \cos\theta_S \right)$$

Simulation of DVR and Results

The modulated signal $V_{control}$ is compared against a triangular signal 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.

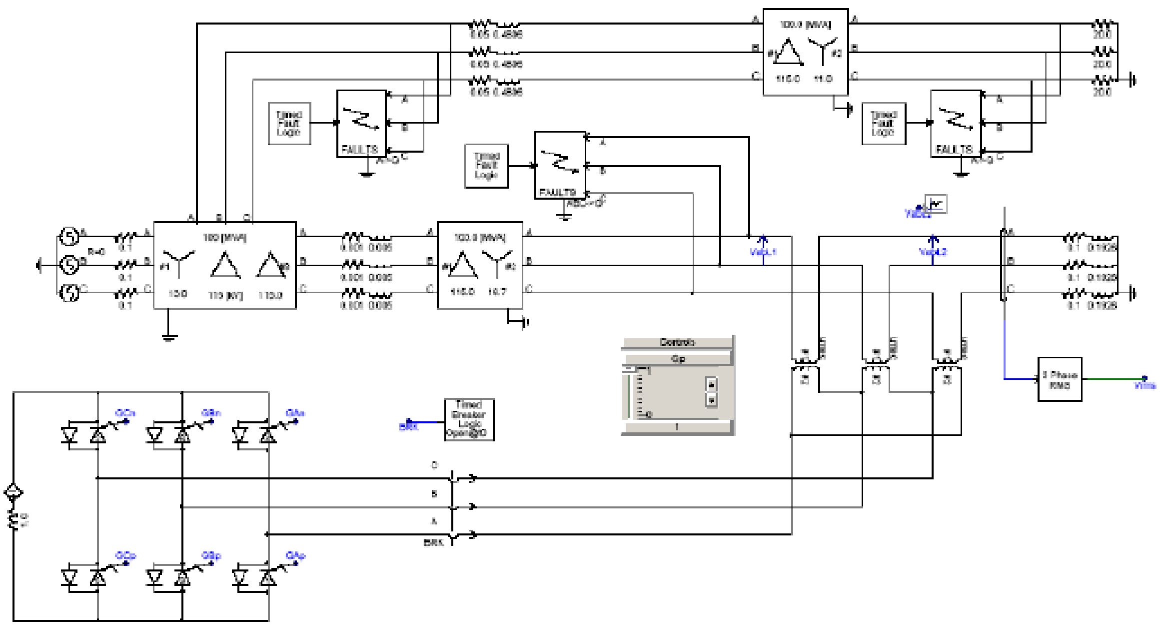

Figure 5. Schematic diagram of DVR

Fig. 5 shows the test system used to carry out the various DVR simulations presented in this section. The DVR coupling transformer is connected in delta in the DVR side, with a leakage reactance of 10%. A unity transformer turns ratio was used i.e. no booster capabilities exist. The capacity of the dc storage device is 5 kV. Two simulations are carried out as follows:

1) The first simulation contains no DVR and various faults is applied at point **A**, via a fault resistance of 0.35 Ω, during the period 300–600 ms. The voltage sag at the load point and the variation of load rms voltages for various faults are presented in Figures .

2) The second simulation is carried out using the same scenario as above but now with the DVR in operation[2][8].

a.) Voltage sags

A case of Three-phase voltage sag was simulated and the results are shown in Fig. 6. Figure 6a shows a 50% voltage sag initiated at 100 ms and it is kept until 300 ms, with total voltage sag duration of 200 r.m.s. Figure 4b and c show the voltage injected by the DVR and the compensated load voltage, respectively. As a result of DVR, the load voltage is kept at 1 p.u. throughout the simulation, including the voltage sag period. Observe that during normal operation, the DVR is doing nothing. It quickly injects necessary voltage components to smooth the load voltage upon detecting voltage sag [2][8].

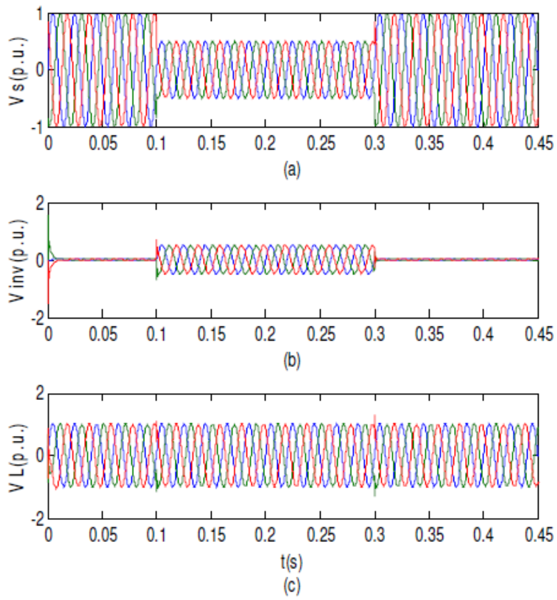

Figure 6. Three-phase voltage sag; (a): Source voltages, (b): Injected voltages; (c): Load voltages

b.) Voltage swells

The performance of DVR for a voltage swell condition was investigated. Here, the supply voltage swell was generated as shown in Fig. 6a. The supply three-phase voltage amplitudes were increased about 125% of nominal voltage. The injected three phase voltage that was produced by DVR in order to correct the load voltage and the load voltage are shown in Fig. 6b and c, respectively. As can be seen from the results, the load voltage was kept at the nominal value with the help of the DVR. Similar to the case of voltage sag, the DVR reacted quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage[2][8].

CONCLUSIONS

This paper has presented the power quality problems such as voltage dips, swells and interruptions, consequences, and mitigation techniques of custom power electronic devices DVR, D-STATCOM, and SSTS. The design and applications of DVR, D-STATCOM for voltage sags, interruptions and swells, and comprehensive results are presented. Also it is presented electromagnetic transient models of power electronic based equipment D-STATCOM and DVR and their power quality characteristics were studied. This characteristic makes it ideally suitable for low-voltage custom power applications. The simulations carried out showed that the DVR and DSTATCOM provide excellent voltage regulation capabilities. It was observed that theirs capacity for power compensation and voltage regulation depends mainly on two factors: the rating of the dc storage device and the characteristics of the coupling transformer. These two factors determine the maximum value of sag mitigation that the DVR and DSTATCOM can provide.

REFERENCES

[1] Ravi Kumar, S.V. and S. Siva Nagaraju, 2007. Power quality improvement using d-statcom and DVR. Int. J. Elect. Power Eng., 1: 368-376.

[2] Nielsen, J.G., 2002. Design and control of a dynamic voltage restorer. Ph. D. Thesis, Aalborg University, Institute of Energy Technology. ISBN: 87-89179-42-0.

[3] John Newman, M., D. Grahame Holmes, J. Godsk Nielsen and F. Blaabjerg, 2003. A Dynamic Voltage Restorer (DVR) with selective harmonic compensation at medium voltage level. IEEE.

[4] Moreno-Mun_oz, A., D. Oterino, M. González and F.A. Olivencia, 2006. Study of Sag Compensation with DVR: Benalmádena (Málaga), Spain. IEEE MELECON May, pp: 16-19.

[5] Stump, M.D., G.J. Kaene and F.K.S. Leong, 1998. Role of custom power products in enhancing power quality at industrial facilities. In: Conf. Rec. IEEE/EMPD, pp: 507-517.

[6] Li, B.H., S.S. Choi and D.M. Vilathgamuwa, 2001. Design considerations on the line-side filter used in the dynamic voltage restorer: IEE Proc. Generat. Transmission Distribut., 148: 1-7.

[7] Chan, K., 1998. Technical and performance aspects of a dynamic voltage restorer. In IEE Half Day Colloquium on Dynamic Voltage Restorers- Replacing Those Missing Cycles, pp: 5/1-525.

[8] Buxton, R., 1998. Protection from voltage dips with the dynamic voltage restorer. In IEE Half Day Colloquium on Dynamic Voltage Restorers- Replacing Those Missing Cycles, pp: 3/1-3/6.

[9] Sng, E.K.K., S.S. Choi and D.M. Vilathga-Muwa, 2004. Analysis of series compensation and DC-link voltage controls of a transformerless self-charging dynamic voltage restorer. IEEE Trans. Power Delivery, 19: 1511-1518.

[10] E-Otadui, U. Viscarret, S. Bacha, M. Caballero and R. Reyero, 2002. Evaluation of different strategies for series voltage sag cornpensation. Proc. IEEE PESC, 4: 1797-1802.