Power Quality Enhancement of Nigerian Power Distribution Systems by Use of Distribution Static Compensator (D-STATCOM)

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Abstract: This study addresses the issue of regulating the voltage of a low-voltage distribution system in Nigeria in order to enhance the reliability, stability and quality of power flows in the system. A well-developed graphic facility available in PSCAD/EMTDC is used to carry out extensive simulation studies. Graphics-based model suitable for electromagnetic transient studies is presented for the distribution static compensator (D-STATCOM). Comprehensive results are also presented to assess the performance of the D-STATCOM. Finally, the impact of the dc capacitor size on D-STATCOM performance is highlighted.

Key words: Custom power devices, distribution system, D-STATCOM, PMW, PSCAD/EMTDC, VSC

INTRODUCTION

For more than a decade, frequent outages in electrical power supply in Nigeria at distribution level have been a common phenomenon that has given consumers a lot of concern. This situation has led to the proliferation of standby electric power supply in domestic dwellings and large consumer premises. Even when power is available from the mains, problems of over-voltages and under-voltages have ruined a lot of industrial plants and domestic appliances.

However, the situation can be ameliorated by the use of custom power devices. In recent years, custom power devices have been investigated that may be used to increase power system operation and controllability and to enhance the system stability at the end-user level. Distribution Static Compensator (D-STATCOM) is one of the custom power devices harnessed with power electronics components that is based on the principle of voltage sourced converters. Its development is carried out under sponsorship of the Electric Power Research Institute (EPRI) in USA (Hingorani, 1991).

Indeed, 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 constant supply of electricity at the end-user level (Olimpo and Acha, 2002). PSCAD/EMTDC (Manitoba HVDC Research Center, 1994) has been used in this study to conduct simulations on voltage regulation at the point of connection of D-STATCOM to the system. PSCAD/EMTDC is a highly developed graphical interface which has proved instrumental in implementing the graphics-based Pulse-width Modulation (PWM) control

reported in this study for the D-STATCOM. It relies only on voltage measurements for its operation, i.e., it does not require reactive power measurements (Hernandez et al., 1998).

A sensitivity analysis is performed to determine the impact of the dc capacitor size on D-STATCOM feat. However in this study, the objective is to regulate voltage at the point of connection using D-STATCOM thus, enhancing the voltage stability of the system.

MATERIALS AND METHODS

D-STATCOM configuration and its controls: In its most basic form, the D-STATCOM configuration consists of a two-level Voltage Sourced Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt with the ac system and associated control circuits (Venkataramanan and Johnson, 1997; Fernando et al., 2004; Xu et al., 2000) as shown in Fig. 1. The VSC
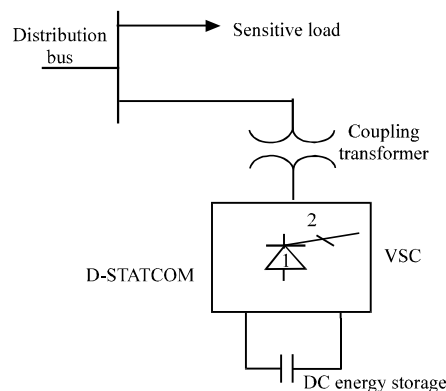

Fig. 1: Schematic representation of the D-STATCOM as a custom power controller
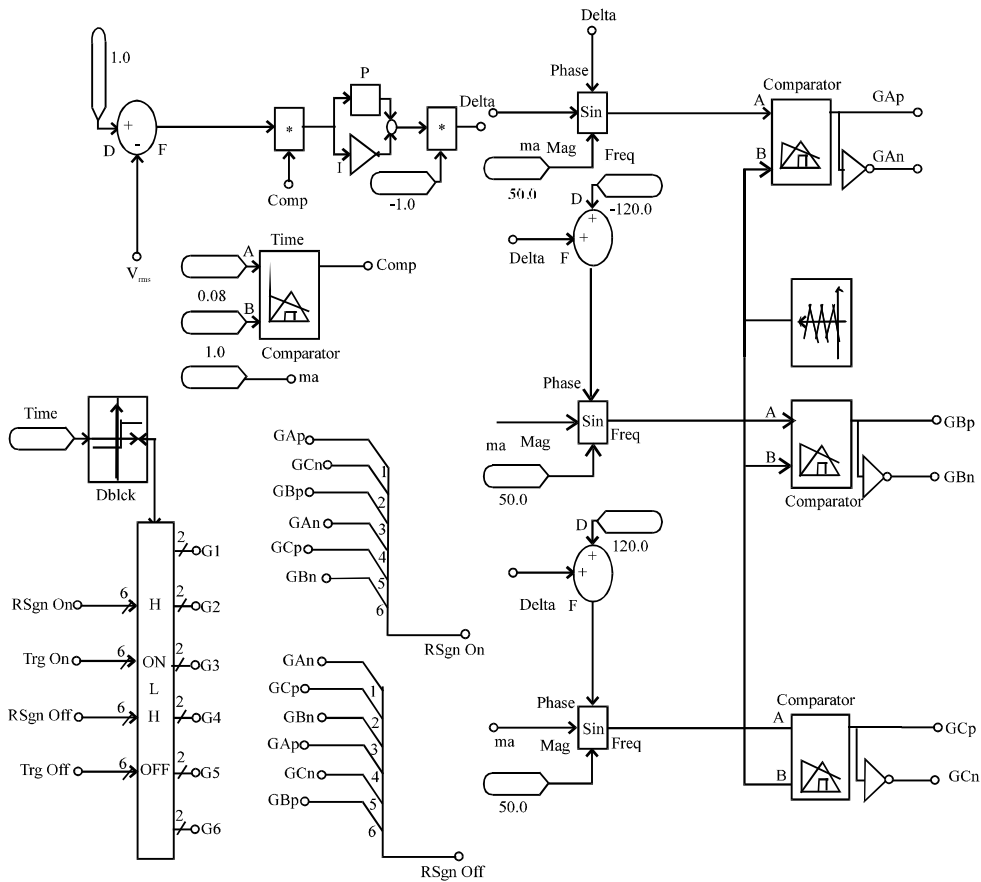
Fig. 2: The PWM generators and control system of D-STATCOM

3 converts the dc voltage across the storage device into a set of 3-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 D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Furthermore, the VSC connected in shunt with the ac system can be used for various purposes as stated below (Singh *et al.*, 1999):

- Voltage regulation and compensation of reactive power
- Correction of power factor
- Elimination of current harmonics

Controls for D-STATCOM: Figure 2 shows the PWM-based control scheme with reference to the D-STATCOM. 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 techniques offer a more flexible option than the fundamental frequency switching techniques favoured in FACTS applications (Acha *et al.*, 2001).

The D-STATCOM control system puts forth voltage angle control as an error signal obtained by comparing the reference voltage with the rms voltage measured at the load point. Then PI controller processes the error signal and generates the required angle delta to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage. In the PWM generators, the sinusoidal signal $V_{control}$ is phase-modulated by means of the angle delta. 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 $V_{control}$ and the frequency modulation index of the triangular signal. The
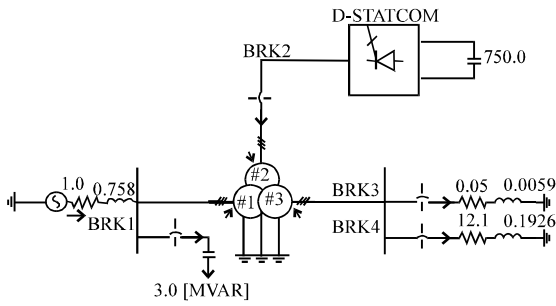
Fig. 3: The studied system

amplitude modulation index is kept fixed at 1.0 p.u. in order to obtain the highest fundamental voltage component at the controller output. The modulating angle delta is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 240 and 120°, respectively. The speed of response and robustness of the control scheme are clearly shown in the simulation results.

Studied system: The studied system comprises a 132 kV transmission system feeding into the primary side of a 3-winding transformer as shown in Fig. 3. A varying load is connected to the 11 kV, secondary side of the transformer. A 2-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. The studied system is implemented in PSCAD/EMTDC to carry out simulations for the D-STATCOM.

RESULTS AND DISCUSSION

The system in Fig. 3 shows the studied system implemented in PSCAD/EMTDC to carry out simulations for the D-STATCOM. A set of switches shown in the figure was used to assist different loading scenarios being simulated with ease. The effectiveness of this controller in providing continuous voltage regulation was determined by simulations carried out with and without D-STATCOM connected to the system. The simulations were conducted under four operating conditions without D-STATCOM connected to the system:

• At the load when BRK3 is opened and remains so throughout the rest of the simulation. The load voltage is observed to be 0.9915 p.u., very close to the reference value (i.e., 1.0 p.u.) as shown in Fig. 4
• When the load is increased (i.e., BRK3 is closed), the voltage drops by 23% (i.e., load voltage becomes 0.7641 p.u.) with respect to the reference value (Fig. 5)
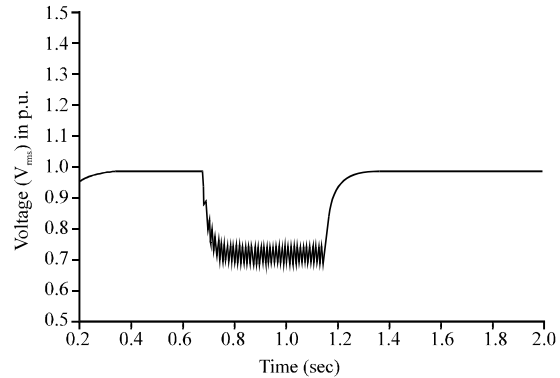

Fig. 4: Voltage at load point without D-STATCOM having BRK3 and capacitor bank opened
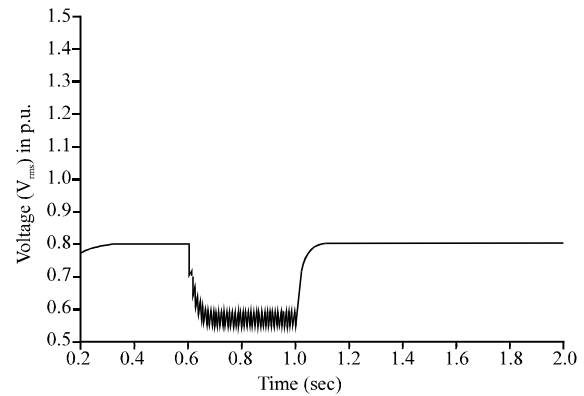

Fig. 5: Voltage at load point without D-STATCOM having BRK3 closed and capacitor bank opened

• When BRK3 is opened at 800 ms and remains so throughout the rest of the simulation. The load voltage (i.e., 0.9915 p.u.) is very close to the reference value as depicted in Fig. 6
• When the capacitor bank is connected to the high voltage side of the system network at 1200 ms. The load voltage increases (1.2787 p.u.) approximately by 28% with respect to the reference voltage (Fig. 7)

Figure 4-7 show the rms voltage at the load point for the case when the system operates with no D-STATCOM connected. Similarly, a new set of simulations was carried out but now with the D-STATCOM connected to the system and the results are as shown in Fig. 8. In spite of sudden load variations, the regulated rms voltage shows a reasonably smooth profile without transient overshoots as D-STATCOM is connected.

It should be noted that capacitor size has great effect on the performance of D-STATCOM. However, adequate precaution should be taken in order to identify
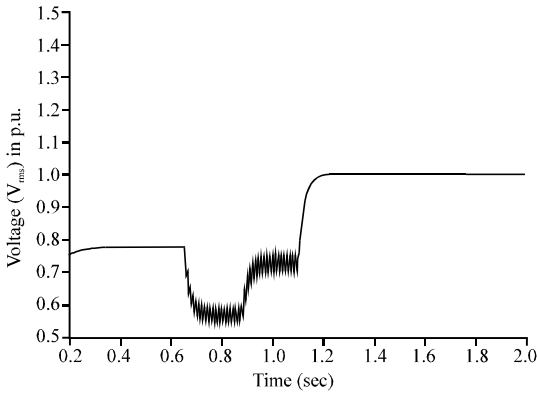
Fig. 6: Voltage at the load point without D-STATCOM having BRK3 opened at 800 ms and capacitor bank opened
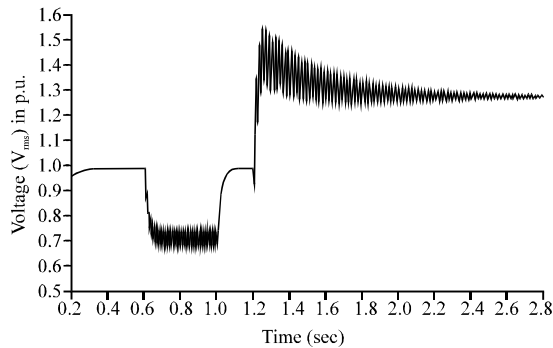

Fig. 7: Voltage at load point without D-STATCOM having BRK3 opened and capacitor bank closed at 1200 ms
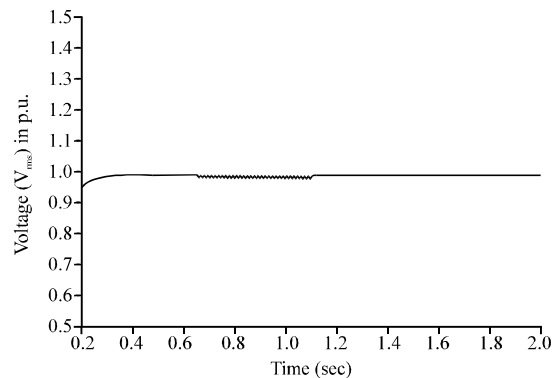

Fig. 8: Voltage at load point with D-STATCOM having 75 μF capacitor size

the most suitable capacitor size, aiming at minimizing waveform distortion and keeping transient overshooting at minimum values. Now with the use of 750 μF capacitor, a rapid regulation response is obtained and transient

overshoots are almost nonexistent. This however, contrasts with cases where the capacitor is undersized (e.g., 75 μF) that is a sluggish response and large transient overshoots are observed or oversized (e.g., 7500 μF) where the D-STATCOM exhibits a very different harmonic generation behaviour.

CONCLUSION

This study has presented electromagnetic transient model of the Distribution Static Compensator (D-STATCOM) and applied it to the study of power quality. A new PWM-based control scheme has been implemented to control the electronic valves in the 2-level VSC used in the D-STATCOM. As opposed to fundamental frequency switching schemes already available in the PSCAD/EMTDC, this PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications.

Finally, extensive simulations were conducted to gain insight into the speed of response of the PWM control and transient overshooting and results obtained showed that the D-STATCOM provides good voltage regulation capabilities.

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