Investigation on D-STATCOM and DVR Operation for Voltage Control in Distribution Networks with a New Control Strategy

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Abstract—This paper addresses the issue of 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. A new PWM-based control scheme has been proposed that only requires voltage measurements and no reactive power measurements are required. The operation of the proposed control method is presented for D-STATCOM and DVR. Simulations and analysis are carried out in PSCAD/EMTDC with this control method for two proposed systems. 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.

Index Terms—D-STATCOM, DVR, VSC, PSCAD/EMTDC.

I. INTRODUCTION

The last decade has seen an increase on the extension of equipment that is highly sensitive to poor quality electricity supply. Several large industrial users are reported to have experienced large financial losses as a result of even minor lapses in the quality of electricity supply. Many efforts have been made to remedy the situation with solutions based on the use of the latest power electronic technology [1,2]. At present, a wide range of very flexible controllers are emerging for power system applications. Among these, the distribution Static Compensator (D-STATCOM) and the Dynamic Voltage Restorer (DVR), both of them based on the VSC principle has been used in this paper to perform the modeling and analysis of such controllers for a wide range of operating conditions [3].

PSCAD/EMTDC's highly developed graphical interface has proved instrumental in implementing the PWM controller reported in this paper for the D-STATCOM and DVR. It relies only on voltage measurements for its operation, i.e., it does not require reactive power measurements. Effects of load variation and system faults on the sensitive loads are investigated and the control of voltage disturbances are analyzed and simulated.

II. VSC-BASED CONTROLLERS

This section presents an overview of the VSC-based custom power controllers addressed in the paper.

A. D-STATCOM

In its most basic form, the D-STATCOM configuration consists of a VSC, a dc energy storage device, a coupling transformer connected in shunt with the ac system, and associated control circuits. The design approach of the control system determines the priorities and functions developed in each case. In this paper, the D-STATCOM is used to regulate voltage at the point of connection. The control is based on sinusoidal PWM and only requires the measurement of the rms voltage at the load point as explained in Section III.

B. DVR

The DVR is a powerful controller that is commonly used for voltage sags mitigation at the point of connection. The DVR employs the same blocks as the D-STATCOM, but in this application, the coupling transformer is connected in series with the ac system. The control is based on sinusoidal PWM and only requires the measurement of the rms voltage at the load point as explained in Section III.

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.

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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 main features of the DVR control scheme implemented in this paper are explained in Section III.

III. SINUSOIDAL PWM-BASED CONTROL

This section describes the PWM-based control scheme with reference to the D-STATCOM and DVR. 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.

Because distribution network is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching 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.

Figures 3 and 4 show the test system and D-STATCOM controller respectively implemented in PSCAD/EMTDC.

The D-STATCOM control system exerts voltage angle control as follows: 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 \( \delta \) 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 \( v_{\text{control}} \) signal is phase-modulated by means of the angle \( \delta \). The modulated signal \( v_{\text{control}} \) 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 \( m_a \) of signal \( v_{\text{control}} \), and the frequency modulation index \( m_f \) of the triangular signal.

The amplitude index \( m_a \) is kept fixed at 1 pu, in order to obtain the highest fundamental voltage component at the controller output. The switching frequency is set at 450 Hz, then \( m_f = 9 \). It should be noted that, in this paper, balanced network and operating conditions are assumed. 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.

It can be seen in Figures 4 and 6 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.

IV. STUDY CASE AND SIMULATION RESULTS

This section is divided into two parts. Simulations relating to the D-STATCOM are presented first. This is followed by simulations carried out for the DVR.

A. D-STATCOM Simulations and Results

Fig. 3 shows the test system implemented in PSCAD/EMTDC to carry out simulations for the D-STATCOM. The test system comprises a 230 kV transmission system, represented by a Thevenin equivalent feeding into the primary side of a 3-winding transformer. A varying load is connected to the secondary side of the transformer. 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. The simulations relate to three main operating conditions:
Fig. 3. Test system implemented in PSCAD/EMTDC to carry out the D-STATCOM simulations.

1) In the simulation period 300–600 ms, the load is increased by closing Switch D. In this case, the voltage drops by almost 20% with respect to the reference value.

2) At 600 ms, the switch D is opened and remains so throughout the rest of the simulation. The load voltage is very close to the reference value, i.e., 1 pu.

3) In the simulation period 900–1200 ms, Switch B is closed, connecting a capacitor bank to the high voltage side of the network. The rms voltage increases 20% with respect to the reference voltage.

Fig. 4. Control scheme for the D-STATCOM applications.

Fig. 7(a) shows the rms voltage at the load point for the case when the system operates without D-STATCOM. Similarly, a new set of simulations was carried out but now with the D-STATCOM connected to the system. The results are shown in Fig. 7(b), where the very effective voltage regulation provided by the D-STATCOM can be clearly appreciated. When the Switch D closes, the D-STATCOM supplies reactive power to the system, and when Switch D opens and Switch B closes, the D-STATCOM absorbs reactive power in order to get the voltage back to reference. In spite of sudden load variations, the regulated rms voltage shows a reasonably smooth profile, where the transient overshoots are almost nonexistent. The magnitude of these transients is kept very small with respect to the reference voltage. In fact, they do not last for more than two cycles.

B. DVR Simulations and Results

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 8-11.

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

Fig. 6. Control scheme for the DVR applications.
The total simulation period is 900 ms. Using the facilities available in PSCAD/EMTDC, the DVR 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. When the DVR is in operation the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 97%, as shown in Figures 8-11.

The PWM control scheme controls the magnitude and the phase of the injected voltages, restoring the rms voltage very effectively.

The sag mitigation is performed with a smooth, stable, and rapid DVR response; no transient overshoots are observed when the DVR comes in and out of operation. It should be noted that in the DVR, the dc voltage is supplied by a dc source as opposed to the dc capacitor used in the D-STATCOM. Several simulations were carried out to assess the performance of the DVR. As expected, the DVR required a higher rating of dc storage device to provide appropriate levels of sag mitigation when the fault was applied in point A. This is due to the short electrical distance between the point in fault and the DVR coupling transformer. Clearly, the controller must be designed to satisfy the most severe case, where the voltage sag is due to a fault quite close to the sensitive load.
Fig. 8. Variation of sensitive load rms voltage during single phase to ground fault: (a) without DVR, (b) with DVR.

Fig. 9. Variation of sensitive load rms voltage during phase-to-phase ground fault: (a) without DVR, (b) with DVR.

Fig. 10. Variation of sensitive load rms voltage during phase-to-phase fault: (a) without DVR, (b) with DVR.

Fig. 11. Variation of sensitive load rms voltage during three phase fault: (a) without DVR, (b) with DVR.

V. CONCLUSIONS

This paper has presented electromagnetic transient models of power electronic based equipment D-STATCOM and DVR and their power quality characteristics were studied. A new PWM-based control scheme has been implemented to control the electronic valves in the VSC used in the D-STATCOM and DVR. 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. The control scheme was tested under a wide range of operating conditions, and it was observed to be very robust in every case.

The simulations carried out showed that the DVR and D-STATCOM 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 D-STATCOM can provide.

VI. REFERENCES

Hojat Hatami was born in Orumie, Iran, in 1981. He received his BSc. Degree in Electrical Engineering in 2005 from University of Tabriz, Tabriz, Iran, where he is currently studying towards his M.Sc. degree. His special fields of interest included Power Electronics, Power Quality and Electric Machines and Drives.

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