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Comparative Analysis of Shunt and Series Controllers Based Voltage Source Converter in DG Systems

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ABSTRACT:

In this paper, the performance of voltage-source converter-based shunt and series compensators used for load voltage control in electrical power distribution systems has been analyzed and compared, when a nonlinear load is connected across the load bus. The comparison has been made based on the closed-loop frequency response characteristics of the compensated distribution system. A distribution static compensator (DSTATCOM) as a shunt device and a dynamic voltage restorer (DVR) as a series device are considered in the voltage-control mode for the comparison. The power-quality problems which these compensator address include voltage sags/swells, load voltage harmonic distortions, and unbalancing. The effect of various system parameters on the control performance of the compensator can be studied using the proposed analysis. In particular, the performance of the two compensators is compared with the strong ac supply (stiff source) and weak ac supply (non-stiff source) distribution system. The experimental verification of the analytical results derived has been obtained using a laboratory model of the single-phase DSTATCOM and DVR.A generalized converter topology using a cascaded multilevel inverter has been proposed for the medium-voltage distribution system. Simulation studies have been performed in the PSCAD/EMTDC software to verify the results in the three-phase system.

I. INTRODUCTION:

The voltage related power-quality (PQ) problems, such as sags and swells, voltage dips, harmonic distortions due to nonlinear loads and voltage unbalancing in electrical power distribution systems, have been a major concern for the voltage-sensitive loads.

Load voltage regulation using VSC for different grid-connected applications has been recently attempted. With the increased use of power-electronics devices in the consumer products, the loads are becoming voltage sensitive and nonlinear in nature. Depending upon the applications, these loads are connected to the distribution system having varying voltage and power levels. Also the radial feeders of the distribution system to which these loads are connected have varying length and short circuit current (SCC)levels. This depends upon the location of the load, distribution system size, and its voltage and volt-ampere (VA) ratings. This leads to the wide variations in the The venin's equivalent feeder impedance looking from the load side. If the load is connected at the end of the long feeder and has small short circuit current value, it is called a weak ac supply system (or non-stiff source). These feeders have significant line impedance depending upon their length and short-circuit current value. Similarly, if the load is connected close to the feeder, it is referred to as strongac supply system (or stiff source). The line impedance of these feeders is very small or negligible. In this project, the performance of the DSTATCOM and the DVR used for the load bus voltage control have been analyzed and compared when a nonlinear load is connected across the load bus. Both of these compensators are used under closed-loop voltage-control mode.

II. DSTATCOM & DVR:

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure 1, consists 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.

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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; and
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

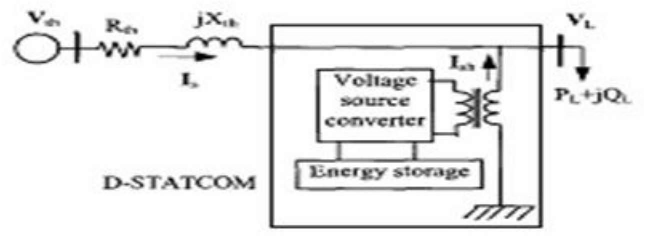

Fig 1: Model of D-STATCOM

DSTATCOM Model:

The single-phase equivalent circuit of a DSTATCOM-compensated distribution system is shown in Fig 2. The VSC is used for the injection of the controllable ac voltage V_{dc} in order to control the load bus V_l voltage under the closed loop. The dc link voltage may be self-supported by a dc-link capacitor for the case of DSTATCOM. The current injected in the shunt path is denoted byi_{sh}. A voltage-source-type nonlinear load as considered in Fig.6 is connected with the The venin equivalent voltage Vd and impedance (L_{lac}, R_{lac}).

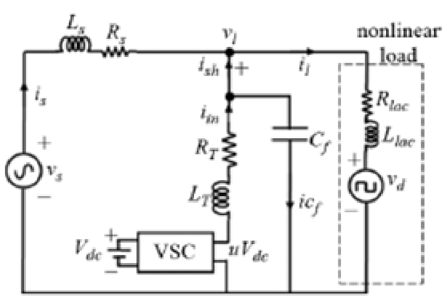

Fig 2: Equivalent circuit of a DSTATCOM-compensated distribution system

Choosing the state vector $x^T = [i_{sh} \quad i_{cf} \quad v_l \quad i_l]$ and considering the load voltage Vl as output, the following state spacer presentation can be derived:

$$\dot{x} = Ax + b_1 v_s + b_2 u + b_3 v_d$$
$$v_l = cx \quad (1)$$

DYNAMIC VOLTAGE RESTORER (DVR):

The major objectives are to increase the capacity utilization of distribution feeders (by minimizing the rms values of the line currents for a specified power demand), reduce the losses and improve power quality at the load bus. The major assumption was to neglect the variations in the source voltages. This essentially implies that the dynamics of the source voltage is much slower than the load dynamics.

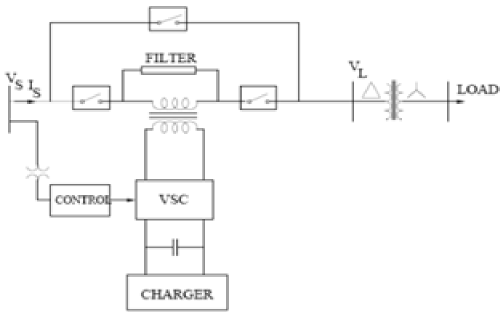

Fig 3: Dynamic voltage restorer

When the fast variations in the source voltage cannot be ignored, these can affect the performance of critical loads such as (a) semiconductor fabrication plants (b) paper mills (c) food processing plants and (d) automotive assembly plants. The most common disturbances in the source voltages are the voltage sags or swells that can be due to (i) disturbances arising in the transmission system, (ii) adjacent feeder faults and (iii) fuse or breaker operation. Voltage sags of even 10% lasting for 5-10 cycles can result in costly damage in critical loads. The voltage sags can arise due to symmetrical or unsymmetrical faults. In the latter case, negative and zero sequence components are also present. Uncompensated nonlinear loads in the distribution system can cause harmonic components in the supply voltages.

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To mitigate the problems caused by poor quality of power supply, series connected compensators are used.

- Standby (also termed as short circuit operation (SCO) mode) where the voltage injected has zero magnitude.
- Boost (when the DVR injects a required voltage of appropriate magnitude and phase to restore the Pre fault load bus voltage).

DVR Model:

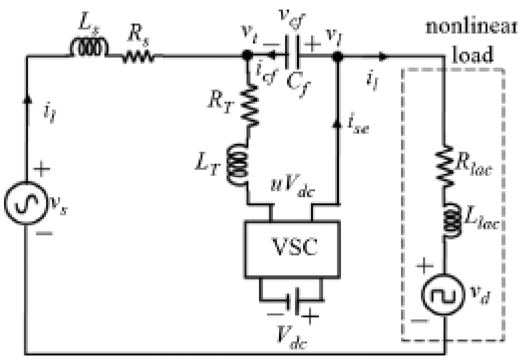

Fig 4: Equivalent circuit of a DVR-compensated distribution system

The single-phase equivalent circuit of a DVR-compensated distribution system is shown in Fig 4. In the direct control scheme presented in this paper, the DVR injects the controllable ac voltage uV_{dc} in order to control the load bus voltage V_l under closed loop. The dc link voltage in this case may be supported by grid-connected rectifier or separate energy storage.The current flowing through the VSC is defined as the series currenti_{sc} . The source current $i_s$is assumed the same as the load current i_l in this case. The remaining system parameters and variables are the same as defined for the DSTATCOM model in Fig.6.3.

III. Voltage Source Converter (VSC):

This could be a 3 phase - 3 wire VSC or 3 phase - 4 wire VSC. The latter permits the injection of zero-sequence voltages. Either a conventional two level converter (Graetz Bridge) or a three level converter isused.

Vsc-Based Shunt and Series Compensators:

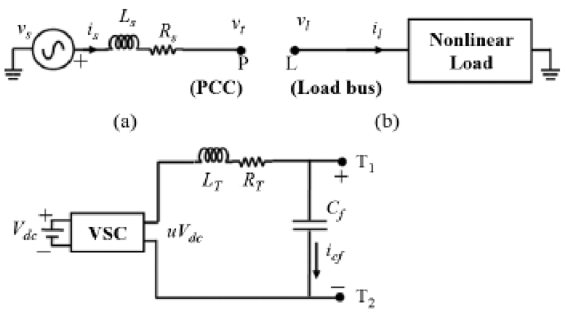

Fig 5: Compensator structure used for load voltage control for a single-phase equivalent of a distribution system. (a) Feeder. (b) Load. (c) Compensator

The single-phase equivalent of a radial distribution system is shown in Fig 5. The feeder and load of the distribution are shown in Fig 5(a) and 5(b), respectively. The source Vs is considered to be the starting point of the radial feeder. The point of common coupling (PCC), represented by point P, is a particular bus of the feeder to which a nonlinear load is connected. The Thevenin's equivalent feeder impedance is represented by inductance L_s and resistance R_s. Restoring the load bus voltage $V_l$at point L under the conditions of sags and swells in the source is an essential requirement for the sensitive loads. Also, it is required to control this voltage against distortions due to the nonlinear load. A VSC-based generalized structure of the compensator used in a single-phase distribution system is shown in Fig.6.1(c). Two types of compensators have been considered in this paper for load voltage control of the distribution system. In case the compensator is shunt type (i.e., DSTATCOM), the terminals P, L, and $T_1$are joined together and T_2 is grounded. In case the compensator is series type (i.e., DVR), the terminal $T_1$is connected to L and T2is connected to P. The compensator consists of a VSC that is interfaced to the distribution system.
The voltage V_{dc} represents the net dc link voltage across the VSC. The variable uis defined as the control input and represents the high-frequency switching of the inverter that assumes discrete values between +1 and -1, depending upon the number of levels used in

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the multilevel converter topology. The symbol L_T represents the equivalent inductance in the converter circuit. The resistance R_T represents the equivalent loss component in the compensator. The filter capacitor C_f is connected across the VSC to support the output voltage and provide filtering to the high-frequency switching components of the VSC. The currents flowing through the different branches are: the source current i_s, the load current, and the current through the filter capacitori$_{cf}$.

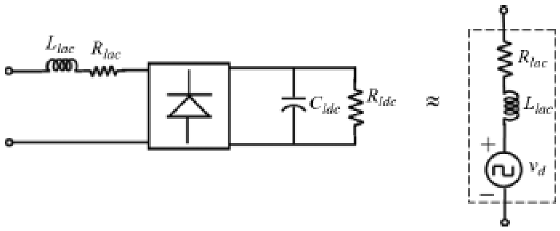

Fig 6: Voltage source type of the nonlinear load

The nonlinear load considered in this paper is assumed to be abridge rectifier type with input impedance(L_{lac}, R_{lac}). For a single-phase load as shown in Fig.6 the output dc voltage of the bridge rectifier is fed to a resistive load R_{ldc} supported by a parallel dc capacitor C_{ldc} . This nonlinear load is calleda voltage source type and is represented by a harmonic perturbation voltage source v_d , where v_d is the The venin equivalent voltage source of this load. For a large dc capacitor C_{ldc} and L_{lac} ac inductance, the input impedance (L_{lac}, R_{lac}) approximately represents the The venin equivalent impedance of this nonlinear load.

The approximate equivalent of this type of nonlinear load is also shown in Fig 6.

IV. MATLABRESULTS:

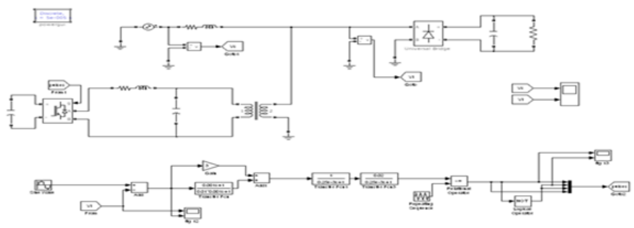

Fig.7: Load voltage control using DSTATCOM for the non-stiff supply system

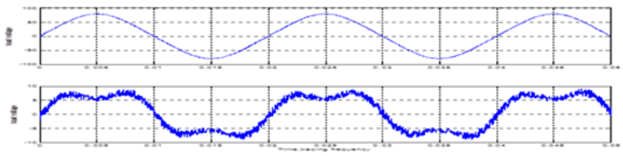

Fig 8: Comparison of load voltage control using DSTATCOM for the non-stiff supply system, showing load voltage and tracking

Fig 8 shows the comparison of the load voltage control using DSTATCOM of switching frequency using a two level VSC. Clearly the voltage tracking characteristic is better with 3-kHz switching frequency showing small tracking error at steady state.

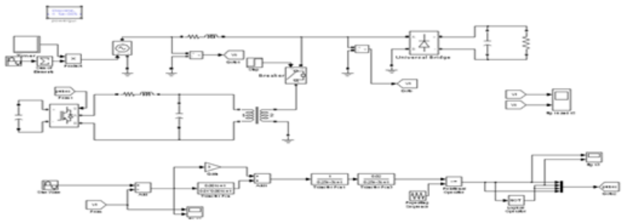

Fig 9: Load voltage control using DSTATCOM for a non-stiff supply system, showing controlled load voltage and distorted source voltage

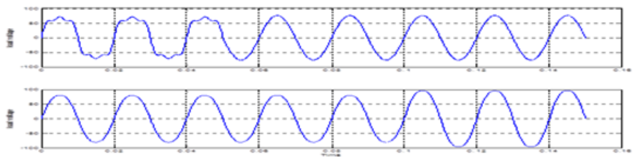

Fig 10(a) Load voltage control using DSTATCOM for a non-stiff supply system, showing controlled load voltage and distorted source voltage (b) Load voltage control using DSTATCOM for a non-stiff supply system, showing the controlled load voltage and a voltage rise condition of the sourceVoltage

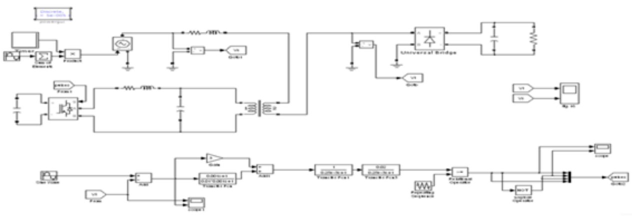

Fig 11: Load voltage control using DVR for a non-stiff supply system

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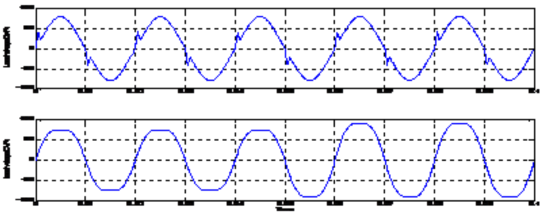

Fig 12: Load voltage control using DVR for a non-stiff supply system,showing the controlled load voltage and voltage dip condition of the source voltage

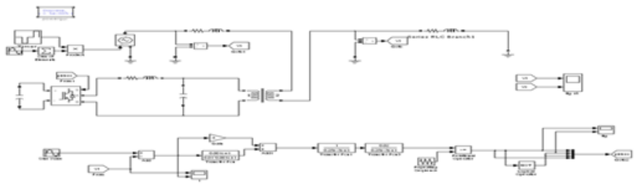

Fig13:Load voltage control using the DVR for a stiff supply system

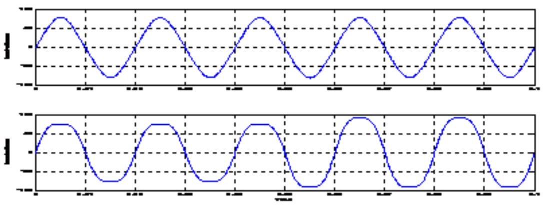

Fig 14: Load voltage control using the DVR for a stiff supply system, showingControlled load voltage and the voltage dip condition of the source voltage

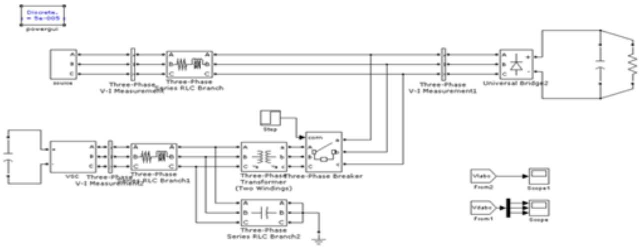

Fig 15: Load voltage control against sag in the source voltage, using DVR for the stiff supply system

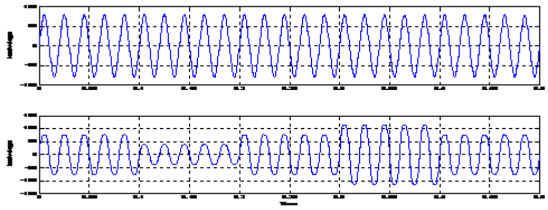

Fig 16: Load voltage control against sag in the source voltage, using DVR for the stiff supply system

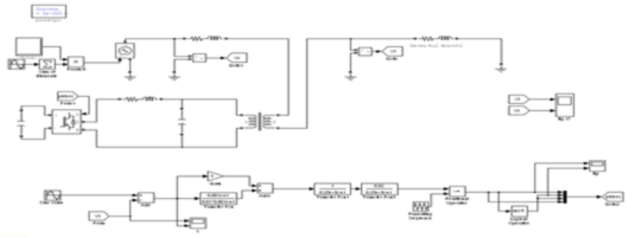

Fig 17: Load voltage for three-phase distribution system DSTATCOM

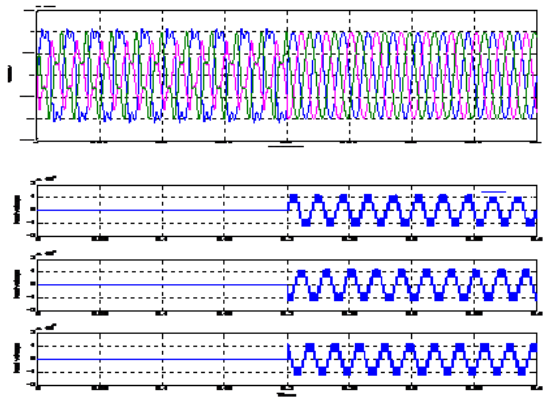

Fig 18: (a) Load voltage for three-phase distribution system, DSTATCOM isconnected at 0.2 s (b) Seven-level inverter output voltages

The seven-level inverter output cascaded at the primary of the transformer is shown in Fig 18(b). The voltage is controlled against unbalancing in the source and harmonic distortion due to the nonlinear load.

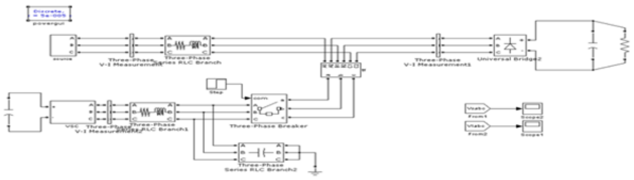

Fig 19: Three-phase load voltage control using the DVR

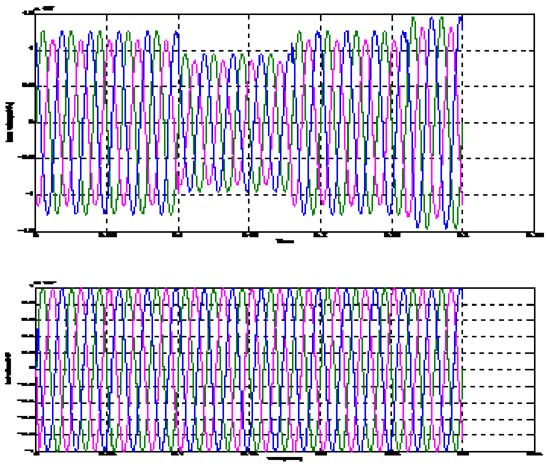

Fig 20: Three-phase load voltage control using the DVR against sag and swellin the terminal voltage, the supply is unbalanced with 25% sag from 0.1 to 0.18s and 15% swell from 0.26 to 0.30 s.

V. CONCLUSION:

The performance of the VSC-based shunt and series compensators (i.e., DSTATCOM and DVR with the presented topology) has been analyzed in voltage control mode through closed-loop frequency-response characteristics. It is shown that for the weak ac supply system, the load voltage control using DSTATCOM has large bandwidth and good attenuation in source voltage and nonlinear load perturbations. However, the DVR in this case passes high-frequency load components almost unattenuated and causes the presence of notches in the load voltage. For the case of a strong ac supply system, the DVR has good bandwidth and attenuation properties. The DSTATCOM in this case cannot control the load bus voltage. The proposed analytical results have been verified through the laboratory experimental model.

The generalized converter topology based on cascaded multilevel inverter using multicarrier phase-shifted PWM can be used for the load voltage control of an MV distribution system, following the proposed control algorithm. The results for the three-phase load voltage control have been verified for an 11-kV distribution system, using seven-level cascaded transformer multilevel converter topology, through simulations.

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