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Performance Analysis of VSC Based Dynamic Voltage Restorer for Mitigation of Voltage SAG in Distribution System

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***Abstract:** In present power system power quality is one of major concerns. It has become important, especially, with the introduction of power electronic devices, whose performance is very sensitive to the variation of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. One of the major problems deal here is the voltage sag and voltage swell. To solve this problem, custom power devices are used. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution network. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. This paper presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB for different types for faults. In this model a PI controller and Discrete PWM pulse generator is used.*

***Keywords:** voltage sag, dynamic voltage restorer, PWM technique.*

I. Introduction

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags and harmonics. Voltage sag are considered to be one of the most severe disturbances to the industrial equipments [1,6].

Voltage support at a load can be achieved by reactive power injection at the load point of common coupling [3]. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sag is not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly.

The primary objective of this paper is to presents benefit of a dynamic voltage restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage [8, 9].

II. Voltage Source Converters (VSC)

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of

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energy storage, 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.

III. SERIES VOLTAGE CONTROLLER

[Dynamic Voltage Restorer, (DVR)]

The series voltage controller is connected in series with the protected load as shown in Fig.1. Usually the connection is made via a transformer, but configurations with direct connection via power electronics also exist. The resulting voltage at the load bus bar equals the sum of the grid voltage and the injected voltage from the DVR. The converter generates the reactive power needed while the active power is taken from the energy storage. The energy storage can be different depending on the needs of compensating. The DVR often has limitations on the depth and duration of the voltage sag that it can compensate.

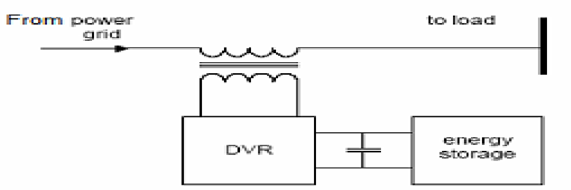

FIGURE-1: EXAMPLE OF A STANDARD CONFIGURATION FOR A DVR.

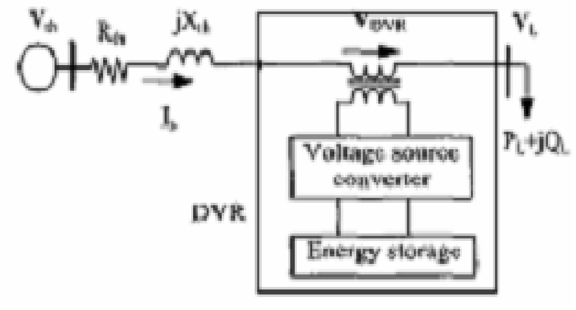

Figure-2: Schematic diagram of a DVR

The circuit on left hand side of the DVR represents the Thevenin equivalent circuit of the system. The system impedance Zth depends on the fault level of the load bus. When the system voltage (Vth) drops, the DVR injects a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude VL can be maintained. The series injected voltage of the DVR can be written as,

$$V_{DVR} = V_L + Z_{TH}.\, I_L - V_{TH}$$

Where

VL is the desired load voltage magnitude

Z_{Th} is the load impedance

IL is the load current

Vth is the system voltage during fault condition

The load current IL is given by,

$$I_L = \frac{|P_L + j\, Q_L|}{V}$$

When V_L is considered as a reference equation can be rewritten as,

$$VDVR < \alpha = VL < 0 + ZTH.IL < (\beta - \theta) - VTH < \delta$$

$$\theta = \tan^{-1} \frac{Q_L}{P_L}$$

The complex power injection of the DVR can be written as,

$$S_{DVR} = V_{DVR} \,.\, I_L^*$$

It may be mentioned here that when the injected voltage V_{DVR} is kept in quadrature with IL, no active power injection by the DVR is required to correct the voltage. It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power. Note that DVR can be kept in quadrature with IL only up to a certain value of voltage sag and beyond which the quadrature relationship cannot be maintained to correct the voltage sag. For such a case, injection of active power into the system is essential. The injected active power must be provided by the energy storage system of the DVR.

IV. A CONTROLLER

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 r.m.s 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 favoured in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

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 the output is the angle δ, 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 PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

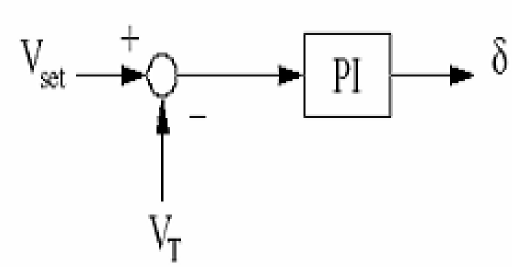

Figure-3: Indirect PI controller

The sinusoidal signal Vcontrol is phase-modulated by means of the angle δ.

i.e.,

$$VA = \text{Sin}(\omega t + \delta)$$

$$VB = \text{Sin}(\omega t + \delta - 2\pi/3)$$

$$VC = \text{Sin}(\omega t + \delta + 2\pi/3)$$

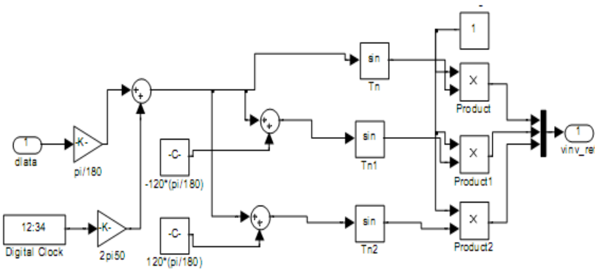

Figure-4: Phase modulation of control angle δ

The modulated signal Vcontrol 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.

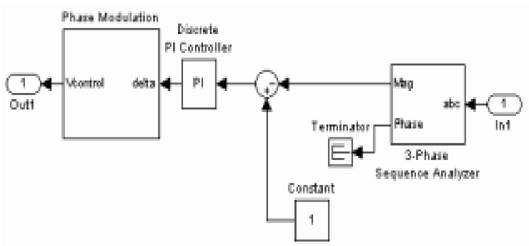

Figure-5: Simulink model of controller of DVR

The amplitude index is kept fixed at 1 pu, in order to obtain the highest fundamental voltage component at the controller output.

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.

V. Test system for DVR

Single line diagram of the test system for DVR is shown in Figure-6 and the test system employed to carried out the simulations for DVR is shown in Figure-7. Such system is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3-winding transformer connected in Y/Δ/Δ, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 115/11 kV.

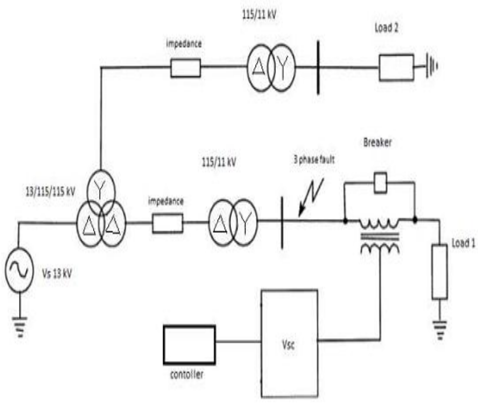

Figure-6: Single line diagram of test system of DVR

To verify the working of a DVR employed to avoid voltage sags during short circuit, a fault is applied at point X via a resistance of 0.66 Ω. Such fault is applied for 0.2sec. Using the facilities available in MATLAB SIMULINK, 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.

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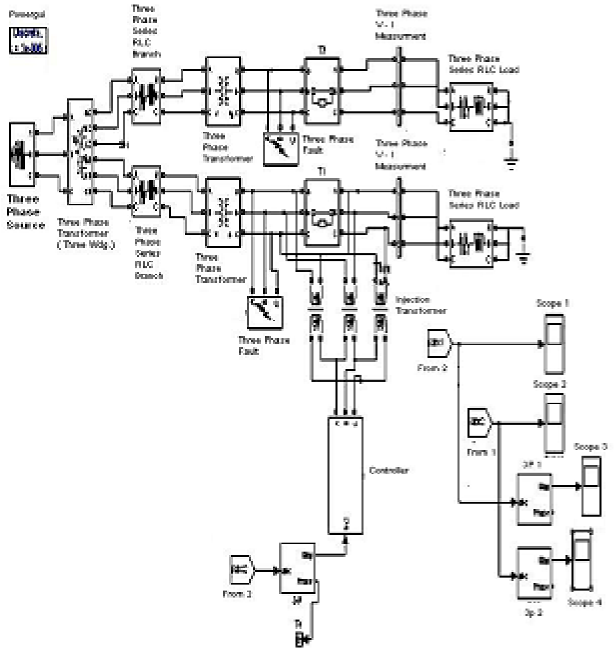

Figure-7: Simulink model of DVR

VI. SIMULATION RESULTS OF DRV

Case 1: Simulation results of voltage sag during single line to ground fault

The first simulation contains no DVR and single line to ground fault is applied to a system with fault resistance of 0.66 Ω, during the period 0.4 to 0.6 s. The second simulation is carried out using the same scenario as above but now with the DVR in operation.

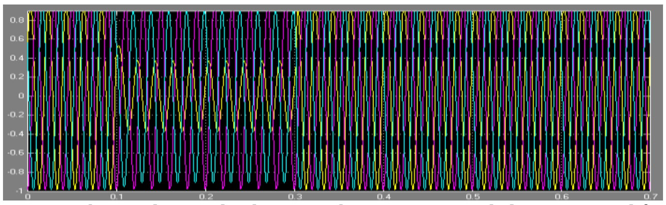

Figure-8: 3phase voltage at load point without DVR at single line to ground fault

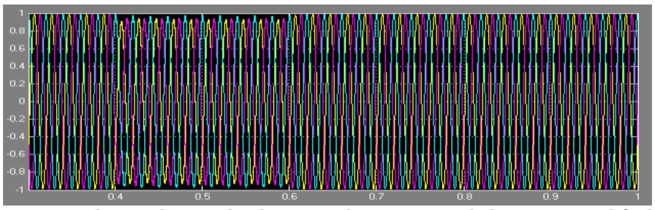

Figure-9: 3phase voltage at load point with DVR at single line to ground fault

Case 2: Simulation results of voltage sag during double line to ground fault

The first simulation contains no DVR and double line to ground fault is applied to a system with fault resistance of 0.66 Ω, during the period 0.4 to 0.6 s. The second simulation is carried out using the same scenario as above but now with the DVR in operation.

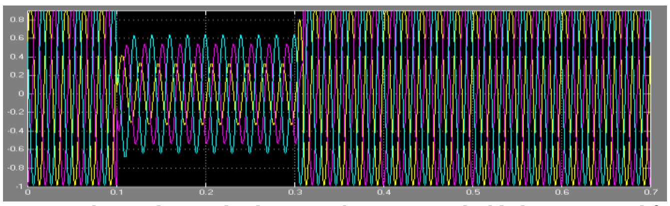

Figure-10: 3phase voltage at load point without DVR at double line to ground fault

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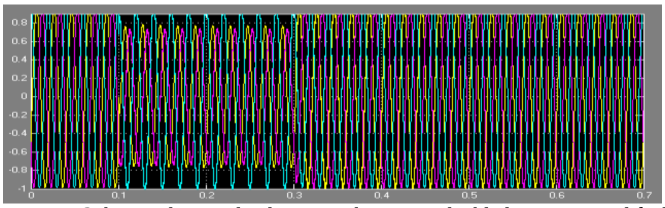

Figure-11: 3phase voltage at load point with DVR at double line to ground fault

Case 3: Simulation results of voltage sag during three phases to ground fault

The first simulation contains no DVR and three phases to ground fault is applied to a system with fault resistance of 0.66 Ω, during the period 0.4 to 0.6 s. The second simulation is carried out using the same scenario as above but now with the DVR in operation.

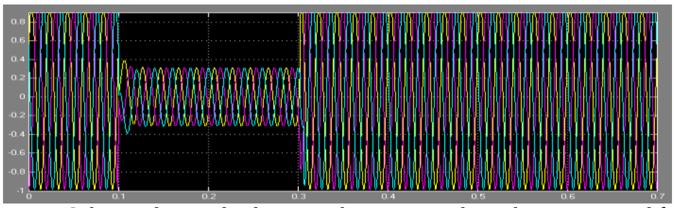

Figure-12: 3phase voltage at load point without DVR at three phases to ground fault

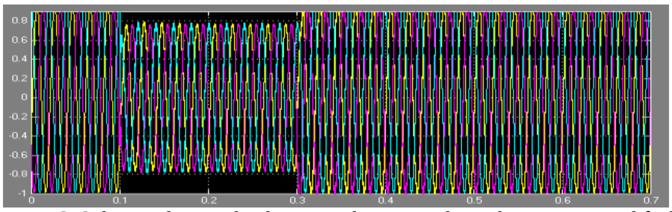

Figure-13: 3phase voltage at load point with DVR at three phases to ground fault

Case 4: Simulation results of voltage sag during two phase's line to line fault

The first simulation contains no DVR and three phases line to line fault is applied to a system with fault resistance of 0.66 Ω, during the period 0.4 to 0.6 s. The second simulation is carried out using the same scenario as above but now with the DVR in operation

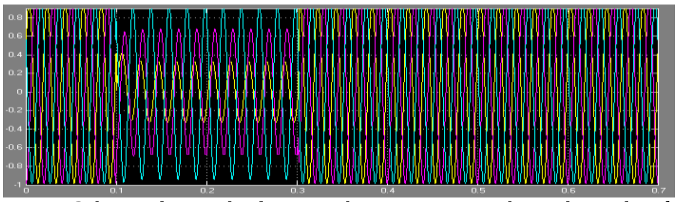

Figure-14.: 3phase voltage at load point without DVR at two phases line to line fault

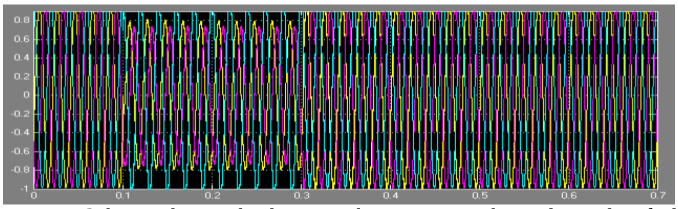

Figure-15: 3phase voltage at load point with DVR at two phases line to line fault

Case 5: Simulation results of voltage sag during three phases line to line fault

The first simulation contains no DVR and three phases line to line fault is applied to a system with fault resistance of 0.66 Ω, during the period 0.4 to 0.6 s. The second simulation is carried out using the same scenario as above but now with the DVR in operation.

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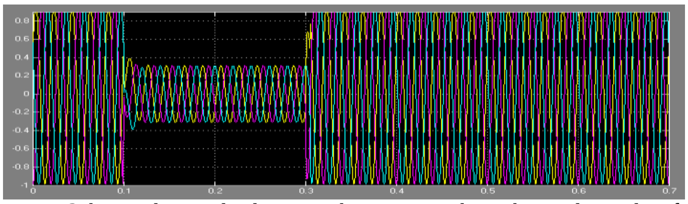

Figure-14: 3phase voltage at load point without DVR at three phases line to line fault

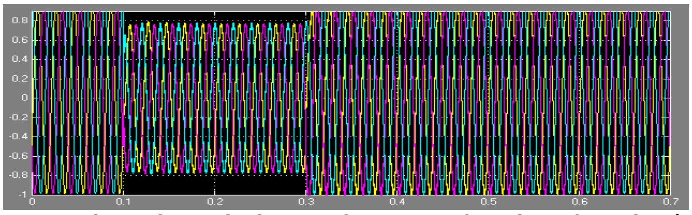

Figure-15: 3phase voltage at load point without DVR at three phases line to line fault

VII. CONCLUSION

This paper has presented the power quality problems such as voltage sag. Compensation techniques of custom power electronic devices DVR is presented. The design and applications of DVR for voltage sags with PWM based control scheme is presented, which opposed to fundamental frequency switching schemes. The PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low voltage custom power applications.

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