Control of a battery supported dynamic voltage restorer

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Abstract: Control of a dynamic voltage restorer (DVR) based on Space Vector PWM is described. The control algorithm is able to compensate for any type of voltage sag and uses a software phase-locked loop to track phase jumps during a fault. The control algorithm restores the depressed voltages to the same phase and magnitude as the nominal pre-sag voltages and then gradually tracks to the phase of the depressed voltages. Experimental results are shown to validate the control algorithm using a three-phase prototype with a power rating of 10 kVA.

List of Symbols

$\vec{V}_S$	supply voltage (V)
$\vec{V}_{load}$	load voltage (V)
$\vec{V}_{inj}$	DVR injected voltage (V)
$\vec{V}_E$	injection voltage space vector (V)
$\vec{V}_{SPLL}$	nominal unity vector (p.u.)
$Vs\alpha$	$\alpha\beta$ transformed supply voltage on α-axis (V)
$Vs\beta$	$\alpha\beta$ transformed supply voltage on β-axis (V)
Vsd	supply voltage on d-axis of SRF (V)
Vsq	supply voltage on q-axis of SRF (V)
Vsd_n	normalised supply voltage on the d-axis of a SRF (p.u.)
Vsq_n	normalised supply voltage on the q-axis of a SRF (p.u.)
θ	SPLL output angle

1 Introduction

A voltage sag is a momentary decrease in rms voltage magnitude (typically lasting 0.5 to 30 cycles) usually caused by faults that originate on transmission and distribution systems. The magnitude and duration of the retained voltage for a particular sag are dependent on a number of electrical system variables, such as fault level, location of the fault, choice of transformer connection and fault clearing time [1]. These disturbances generally cause limited financial impact in residential areas but this is not the case for some industries (e.g. paper mills, semi-conductor plants) where the commercial consequences can be severe. There are a number of methods to mitigate voltage sags and one approach is to use a Dynamic Voltage Restorer (DVR) with energy storage.

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The DVR is a series connected device which injects a set of three-phase AC output voltages in series, and in synchronism with, the distribution feeder voltages. The DVR employs solid-state switching devices in a pulse-width modulated (PWM) inverter to vary the amplitude and the phase angle of the injected voltages, thus allowing control of the real and reactive power exchange between the distribution system and the load. Energy storage is useful as a source of real power. Otherwise only reactive power could be absorbed or injected, and voltage sags to unity and near unity power factor loads could not be fully compensated. The rating required for the energy store is a function of factors external to the DVR, such as the size of the load, sag depth, duration and repetition rate [2].

2 DVR power circuit

Fig. 1 shows the power circuit of the DVR. For use in high voltage distribution systems, an H-bridge converter configuration can be used [3]. However, the voltage source inverter (VSI) used in this work was the simpler Graetz Bridge.

The choice of injection transformer depends on the manner in which the distribution circuit step down transformer is connected. If a delta-star distribution circuit transformer is used, zero-sequence voltages will not propagate through the transformer when earth faults occur on the higher voltage level. Therefore, only restoration of positive sequence and compensation of negative sequence voltages are necessary. Hence, a delta-open injection transformer can be used. The delta/open winding maximises the utilisation of DC link voltage. However, for an earthed star-star distribution circuit transformer, zero sequence voltages have to be compensated. For this case, a star-open injection transformer is used with injection of zero sequence voltages from the DVR [4].

The DVR presented here used an RC filter tuned to the switching frequency. The filter was placed on the circuit side of the injection transformer. This avoids the phase angle shift and voltage drop which would occur if the filter were placed on the inverter side. Moreover, the leakage reactance of the transformer can be used as part of the filter. A similar scheme is described in [3, 5].

Energy storage devices, such as batteries, flywheels, superconducting magnetic energy storage (SMES) and