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Control of reduced-rating dynamic voltagerestorer

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Abstract:A new control algorithm for the DVR is proposed in this paper to regulate the load terminal voltage during sag, swell in the voltage at the point of common coupling (PCC). This new control algorithm is based on synchronous reference frame theory (SRF) along with PI controller is used for the generation of reference voltages for a dynamic voltage restorer (DVR). These voltages, when injected in series with a distribution feeder by a voltage source inverter (VSI) with PWM control, can regulate the voltage at the load terminals contrary to any power quality problem in the source side. It first analyzes the power circuit of the system in order to come up with suitable control limitations and control targets for the compensation voltage control through the DVR. The control of the DVR is implemented through derived reference load terminal voltages.

KEYWORDS-Dynamic voltage restorer (DVR), power quality, unit vector, voltage harmonics, voltage sag, voltage swell.

I. INTRODUCTION

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smoothsinusoidal voltage at the contracted magnitude level and frequency [1] however, in practice, power systems,especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of powersupplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producingmany power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching,motor starting) and unusual (e.g. faults) could also inflict power quality problems[2].Power quality phenomenon orpower quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform.Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a largepart of it. Also, under heavy load conditions, a significant voltage drop may occur in the system. Voltagesag andswell can cause sensitive equipment to fail, shutdown and create a large current unbalance. These effects can incur alot of expensive from the customer and cause equipment damage [1]. The voltage dip magnitude is ranged from 10%to 90% of nominal voltage and with duration from half a cycle to 1 min and swell is defined as an increase in rmsvoltage or current at the power frequency for durations from 0.5 cycles to 1 min. Typical magnitudes are between1.1 and 1.8 p.u[2].

There are many different methods to mitigate voltage sags and swells, but the use of a custom power device isconsidered to be the most efficient method, e.g. FACTS for transmission systems which improve the power transfercapabilities and stability margins. The term custom power pertains to the use of power electronics controller in adistribution system [10], especially, to deal with various power quality problems. Custom power assures customersto get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination ofspecifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, andlow harmonic distortion in load voltage, magnitude and duration of over voltages and under voltages withinspecified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage.

II. DYNAMIC VOLTAGE RESTORER(DVR)

DVR is a Custom Power Device used to eliminate supply side voltage disturbances. DVR also known as StaticSeries Compensator maintains the load voltage at a desiredmagnitude and phase by compensating the voltagesags/swells and voltage unbalances presented at the point of common coupling.

The power circuit of the DVR is shown in Fig. 1.The DVR consists of 6 major parts:-

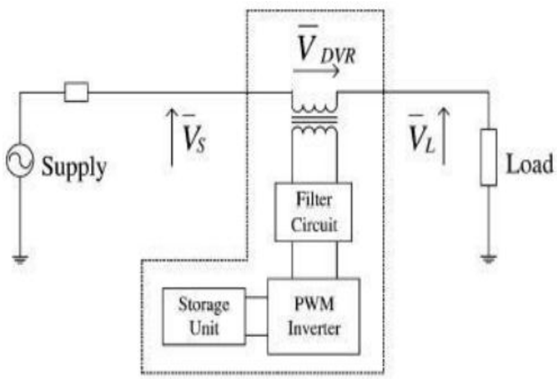

Fig.1: DVR series connected topology

a) Voltage Source Inverter (VSI) : These inverters have low voltage ratings and high currentratings as step-up transformers are used to boost up theinjected voltage.

b) Injection Transformers : Three single phase injection transformers are connected indelta/open winding to the distribution line. Thesetransformers can be also connected in star/open winding. The star/open winding allows injection of positive,negative and zero sequence voltages whereas delta/open winding only allows positive and negative sequence voltageinjection.

c) Passive Filters: Passive filters are placed at the high voltage side of the DVR to filter the harmonics. These filters are placed at thehigh voltage side as placing the filters at the inverter side introduces phase angle shift which can disrupt the controlalgorithm.

d) Energy storage: Batteries, flywheels or SMEs can be used to provide real power for compensation. Compensation using real power isessential when large voltage sag occurs.

e) Capacitor: DVR has a large DC capacitor to ensure stiff DC voltage input to inverter.f) By-Pass SwitchIf the over current on the load side exceeds a permissible limit due to short circuit on the load or large inrush current,the DVR will be isolated from the system by using the bypass switches and supplying another path for current.

III. PROPOSED SYSTEMOPERATION OF DVR

The schematic diagram of a DVR is shown in Fig.2. Three phase source voltages (Vsa, Vsb, and Vsc) areconnected to the 3-phase critical load through series impedance (Za, Zb, Zc) and an injection transformer in eachphase. The terminal voltages (Vta, Vtb, Vtc) have power quality problems and the DVR injects compensatingvoltages (VCa, VCb, VCc) through an injection transformer to get undistorted and balanced load voltages (VLa,VLb, VLc). The DVR is implemented using a three leg voltage source inverter with IGBTs along with a dc capacitor(Cdc).

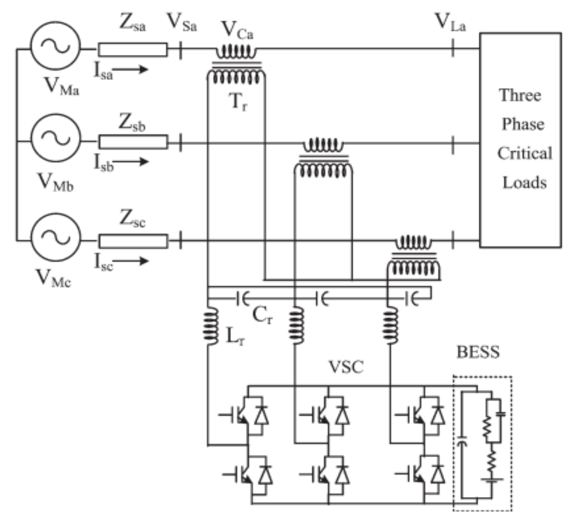

Fig. 2. Schematic of the DVR-connected system.

A ripple filter (Lr, Cr) is used to filter the switching ripple in the injected voltage. The considered load,sensitive to power quality problems is a three-phase balanced lagging power factor load. A self-supported DVR doesnot need any active power during steady state because the voltage injected is in quadrature with the feeder current.

The DVR operation for the compensation of sag, swell in supply voltages is shown in Figure-3. Before sag the loadvoltages and currents are represented as VL (presag) and Isa' as shown in Figure-3(a). After the sag event, theterminal voltage (Vta) is gets lower in magnitude and lags the presag voltage by some angle. The DVR injects acompensating voltage

(VCa) to maintain the load voltage (VL) at the rated magnitude. VCa has two components,VCad and VCaq. The voltage in-phase with the current (VCad) is required to regulate the dc bus voltage and also to meet the power loss in the VSI of DVR and an injection transformer [5]. The voltage in quadrature with the current(VCaq) is required to regulate the load voltage (VL) at constant magnitude. During swell event, the injected voltage(VCa) is such that the load voltage lies on the locus of the circle as shown in Figure-3(b).

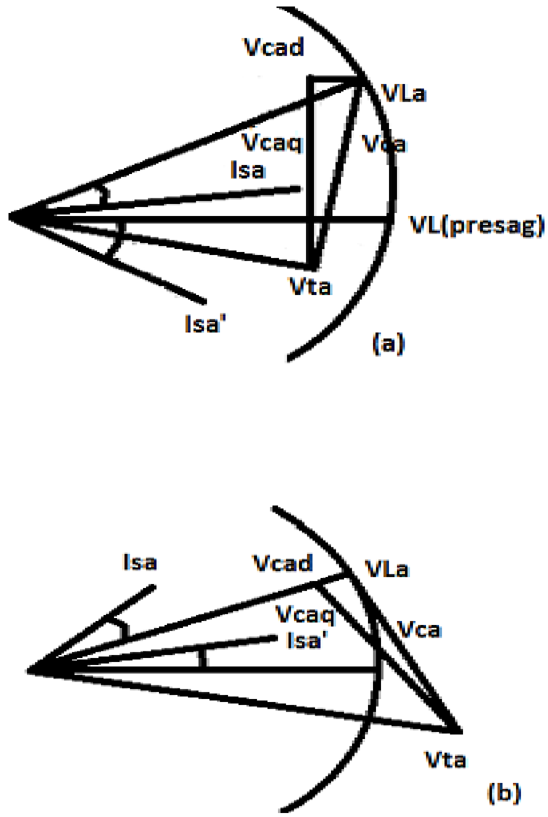

Fig.3: Phasor Diagram for (a) Voltage Sag (b) Voltage Swell

Fig.4 shows the control block of the DVR in which the synchronous reference frame (SRF) theory is used forthe control of self-supported DVR. The voltages at PCC (Vt) are converted to the rotating reference frame using theabc-dqo conversion. The harmonics and the oscillatory components of voltages are eliminated using low pass filters(LPF). The components of voltages in d-axis and q-axis are,

Vsd = Vsd dc + Vsd ac

Vsq = Vsq dc + Vsq ac

The compensating strategy for compensation of voltage quality problems considers that the load terminal voltageshould be of rated magnitude and undistorted.

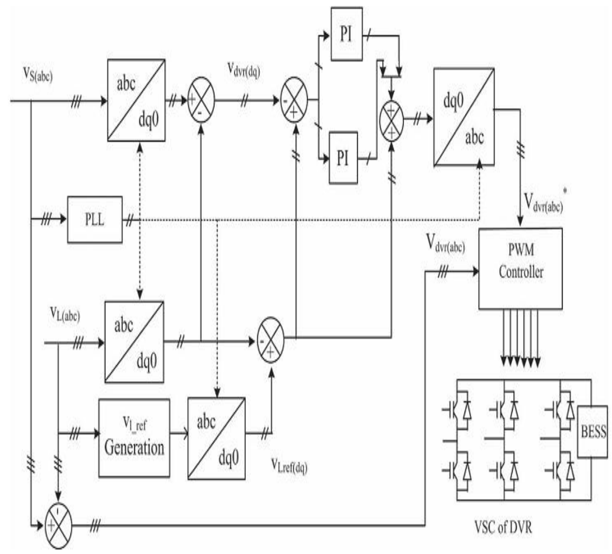

Fig.4: Control Block of DVR

IV. MATLAB MODELLING AND SIMULATION

The DVR is modelled and simulated using the MATLAB and its Simulink and Sim Power System toolboxes. TheMATLAB model of the DVR connected system is shown in fig. below. The three-phase programmable source isconnected to thethree-phase load through the DVR in order to generate sag, swell and harmonics in supply side. Theconsidered load is a lagging power factor load.

The VSI of the DVR is connected to the system using an injectiontransformer. In addition, a ripple filter for filtering the switching ripple in the terminal voltage is connected acrossthe terminals of the secondary of the transformer. The dc bus capacitor of DVR is selected based on the transientenergy requirement and the dc bus voltage is selected based on the injection voltage level. The dc capacitor decidesthe ripple content in the dc voltage.

The control algorithm for the DVR is simulated in MATLAB. The control algorithm shown in Fig.-4 is modelled forDVR control of Fig.-5.

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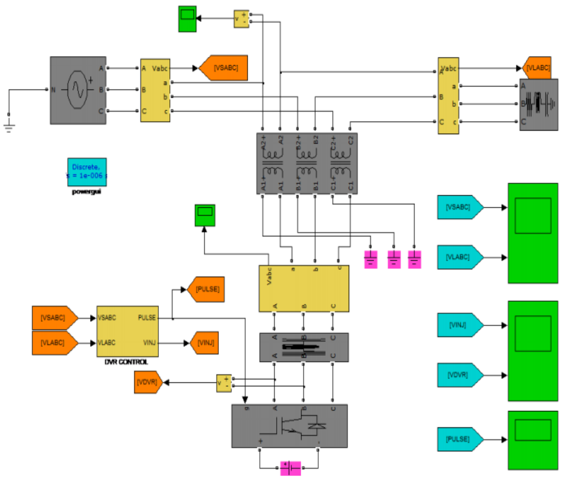

Fig.5: MATLAB model of DVR connected system

V. CONCLUSION

Acomparison of the performance of the DVR with differentschemes has been performed with a reduced-rating VSC, including a capacitor-supported DVR. The reference load voltagehas been estimated using the method of unit vectors, andthe control of DVR has been achieved, which minimizes theerror of voltage injection. The SRF theory has been used forestimating the reference DVR voltages. It is concluded thatthe voltage injection in-phase with the PCC voltage results inminimum rating of DVR but at the cost of an energy source atits dc bus.

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