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Analysis of Dynamic Voltage Restorer with Battery Energy Storage System

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Abstract: A new control technique is proposed to control the capacitor supported DVR. The control of a DVR is demonstrated with a reduced-rating VSC. The reference load voltage is estimated using the unit vectors. The synchronous reference frame theory is used for the conversion of voltages from rotating vectors to the stationary frame. The compensation of the voltage sag, swell, and harmonics is demonstrated using a reduced-rating DVR. This paper presents modeling, analysis (DVR) using MATLAB. In this model a PI controller and Discrete PWM pulse generator was used

Index Terms: Dynamic Voltage Restorer (DVR), voltage source converter (VSC), PI Controller.

I. INTRODUCTION

Power quality problems such as transients, sags, increases, along with other distortions towards the sinusoidal waveform from the supply current modify the performance of these equipment pieces. Technologies for example custom power devices are emerged to supply protection against power quality problems [2]. Power quality problems in our-day distribution systems are addressed within the literature due to the elevated utilization of sensitive and demanding equipment pieces such as communication network, process industries, and precise manufacturing processes. Custom power products mostly are of three categories such as series-connected compensators referred to as dynamic voltage restorers (DVRs), shuntconnected compensators such as distribution static compensators, and a mix of series and shuntconnected compensators referred to as unified power quality conditioner [5]. The Digital recording device can regulate the load voltage in the problems for example sag, swell, and harmonics in the supply voltages. Hence, it may safeguard the critical consumer loads from stumbling and consequent deficits [3]. The custom power products are developed and installed at consumer point to satisfy the power quality standards for example IEEE-519 [4].Current sags within an electrical grid aren't always possible to avoid due to the finite clearing duration of the problems that cause the current sags and also the propagation of sags from the trans mission and distribution systems towards the low-current loads. Current sags would be the common causes of interruption in production plants as well as for finish-user equipment malfunctions in general. Particularly, stumbling of apparatus inside a production line may cause production interruption and significant costs due to lack of production. One fix for your problem is to result in the equipment itself more tolerant to sags, either by intelligent control or by storing “ride-through” energy in the equipment. A different, rather than modifying each component inside a plant to become tolerant against current sags, is to use a plant wide uninterruptible power system for longer power interruptions or perhaps a Digital recording device around the incoming supply to mitigate current sags for shorter periods [1]. DVR scan eliminate the majority of the sags and prevent load tripping for very deep sags, however their primary drawbacks are their standby deficits, the gear cost, as well as the protection scheme needed for downstream short circuits. Many solutions as well as their problems using DVRs are reported, like the voltages inside a three-phase system are balanced and a power-enhanced charge of Digital recording device is talked about in [1].

Industrial good examples of DVRs receive in, and different control techniques are examined for various kinds of voltage sags in [5]. An evaluation of various topologies and control techniques is presented for any Digital recording device. The design of a capacitor-supported Digital recording device that safeguards sag, swell, distortion, or unbalance within the supply voltages is talked about in[5]. The performance of the Digital recording device using the high-frequency-link trans former is talked about in [2]. Within this paper, the control and performance of the Digital recording device are shown having a reduced-rating voltage source ripper tools (VSC). The synchronous reference frame (SRF) theory can be used for that charge of the Digital recording device.

II. DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic Voltage Restorer (DVR) is power electronic device installed in series with distribution system line as can be seen in Figure 1. DVR uses semiconductor device to maintain voltage of sensitive load by injecting voltage whose magnitude, phase, and frequency can be controlled. How a DVR works to compensate harmonics is shown in Figure 2. From Figure 1 and Figure 2 it can be seen that, the topology of DVR as voltage sag compensator is similar to that of as harmonics compensator. Therefore, the DVR can compensate both voltage sag and voltage distortion caused by harmonics.

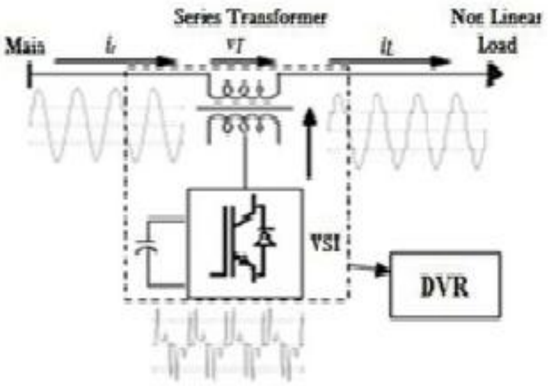

Fig.1 Schematic Diagram of DVR

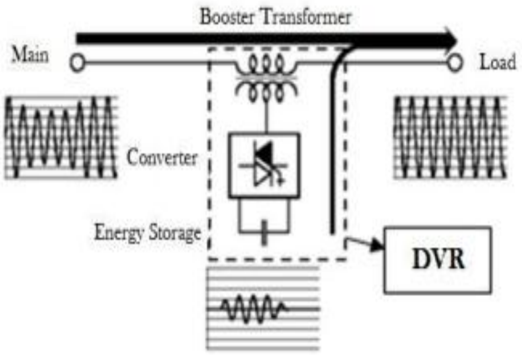

Fig.2 ConfigurationBasic circuit of DVR.

Configuration of DVR

The general configuration of the DVR consists of an Injection transformer, a Harmonic filter, a Voltage Source Converter (VSC), Energy Storage Unit and a Control and Protection unit as shown in Fig 3.Energy Storage Unit in DVR can be external batteries or capacitors charged from the supply line feeder through a rectifier. Generally the energy storage unit of a DVR can be divided into two parts (i.e. Storage devices and DC Charging Circuit). The purpose of energy storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages.Energy Storage Unit in DVR can be external batteries or capacitors charged from the supply line feeder through a rectifier. Generally the energy storage unit of a DVR can be divided into two parts (i.e. Storage devices and DC Charging Circuit). The purpose of energy storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages.

The different kinds of energy storage devices are superconductive magnetic energy storage (SMES),batteries, and capacitors. In fact, the capacity of the stored energy directly determines the duration of the sag which can be mitigating by the DVR. Batteries are the common choice and can be highly effective if a high voltage battery configuration is used. However, batteries in general have a short lifetime and often require some type of battery management system, which can be quite costly. An interesting alternative to batteries is the use of supercapacitors, which have a wider voltage range than batteries and can be directly paralleled across the input bus. Supercapacitors have a specific energy density less than that of a battery, but a specific power greater than a battery, making them ideal for short (up to several seconds) pulses of power. Certain supercapacitors can hold charge over extended periods of time, so as to act like a battery. However, unlike batteries, these supercapacitors have a short charging time and much longer lifetime. The purpose of the DC Charging Circuit is to charge the energy storage devices after the compensation of a voltage sag/swell event as well as maintain a nominal dc link voltage. The charging circuit can be an external power supply or a rectifier fed from the supply mains of the distribution network.A Voltage Source Converter is a power electronic system capable of generating a sinusoidal voltage at any required frequency, magnitude, and phase angle. DVR configurations use the VSC to generate the voltage required to compensate for the voltage sag/swell events. Since the majority of the voltage sags/swells observed on distribution systems are unbalanced, the VSC will often be required to operate with unbalanced switching functions for the three phases and must therefore be able to treat each phase independently. Moreover, sag on one phase may result in swell on another phase, so the VSC must be capable of handling both sags and swells simultaneously. The output voltage of the inverter is varied by using different PWM schemes available.

III. PROPOSED REALIZATION OF COMPENSATION TECHNIQUE

Operating Modes of DVR: The basic function of the DVR is to inject a dynamically controlled voltage VDVR generated by a forced commutated converter in series to the bus voltage by means of a booster transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage V_L. This means that any differential voltages caused by transient disturbances in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer. The DVR has three modes of operation which are: protection mode, standby mode, injection/boost mode.

Protection Mode: If 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 systems by using the bypass switches (S2 and S3 will open) and supplying another path for current (S1 will be closed) as shown in Fig.3.

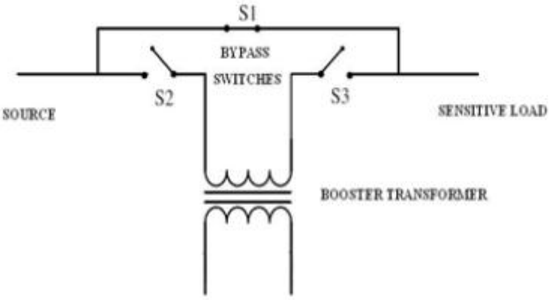

Fig .3. Protection Mod

Standby Mode: (VDVR= 0): In the standby mode the booster transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation and the full load current will pass through the primary as shown in Fig.4.

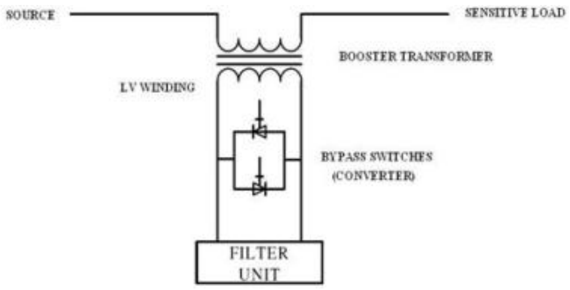

Fig.4. Standby Mode

Injection/Boost Mode: (VDVR>0): In the Injection/Boost mode the DVR is injecting a compensating voltage through the booster transformer due to the detection of a disturbance in the supply voltage.

E. Voltage injection methods of DVR

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as; DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angel jump and some are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics. There are four different methods of DVR voltage injection which are

- Pre-sag compensation method.
- In-phase compensation method.
- In-phase advanced compensation method.
- Voltage tolerance method with minimum energy injection.

In order to mitigate the simulated voltage sags in the test system of each compensation technique, also to compensate voltage sags in practical application, a discrete PWM-based control scheme is implemented, with reference to DVR. The aim of the control scheme is to maintain a constant voltage magnitude at the sensitive load point, under the system disturbance. The control system only measures the rms voltage at load point, for example, no reactive power measurement is required. Fig.5 shows the DVR controller scheme implemented in MATLAB/SIMULINK. The DVR control system exerts a 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 processes the error signal and generates the required angle δ to drive the error to zero, for example; the load rms voltage is brought back to the reference voltage. It should be noted that, an assumption of balanced network and operating conditions are made as shown in Fig.6. The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

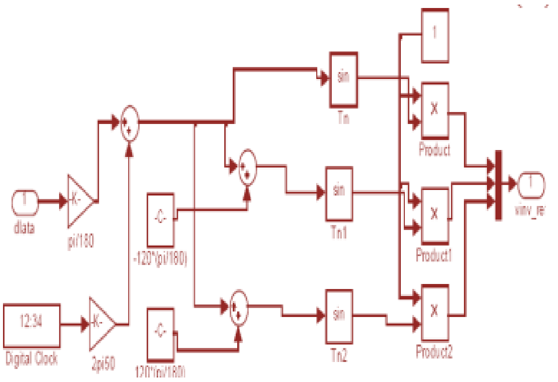

Fig .5. firing angle controller scheme.

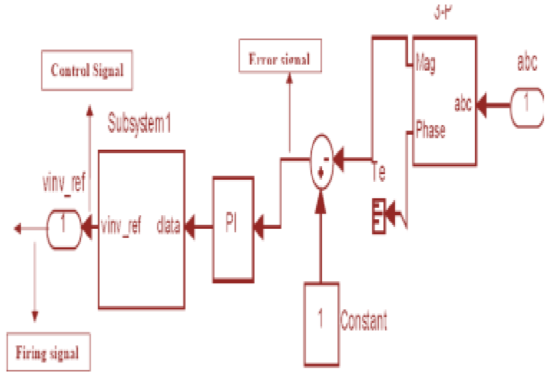

Fig.6.Simulink model of DVR controller

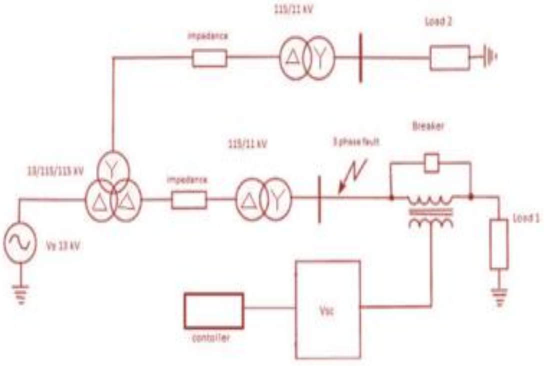

Fig.7.Single line diagram of test system.

Single line diagram of the test system for DVR 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. To verify the working of DVR for voltage compensation a fault is applied at point X at resistance 0.66 U for time duration of 200 ms as shown in Fig.7. The DVR is simulated to be in operation only for the duration of the fault. Matlab-Based Model of the DVR as shown in Fig.8. Simulation Model without DVR as shown in Fig.9.

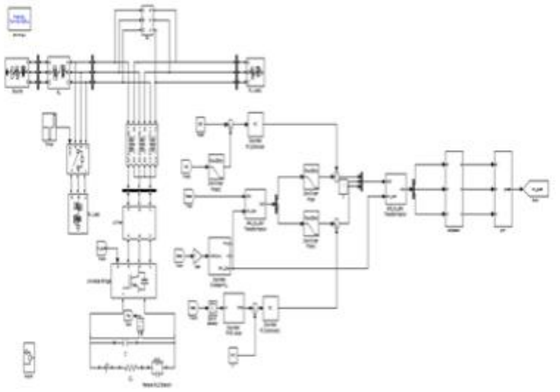

Fig.8. Matlab-Based Model Of The DVR.

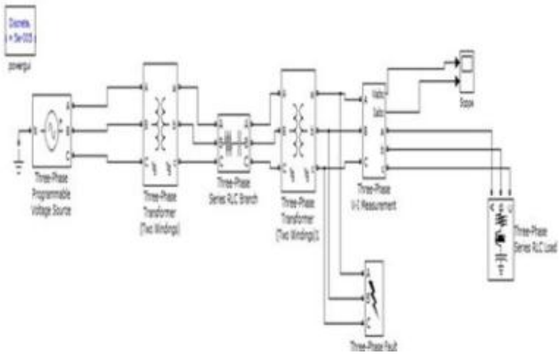

Fig.9. Simulation Model Without DVR.

IV. SIMULATION RESULTS

The first simulation was done with no DVR and a three phase fault is applied to the system at point with fault resistance of 0.01 ohms for a time duration of 600 ms as shown in Figs.10 to 13. The second simulation is carried out at the same scenario as above but a DVR is now introduced at the load side to compensate the voltage sag occurred due to the three phase fault applied. Fig.10 shows the rms voltage at load point when the system operates with no DVR and a three phase fault is applied to the system. When the DVR is in operation the voltage interruption is compensated almost completely and the rms voltage at the sensitive load point is maintained at normal condition.

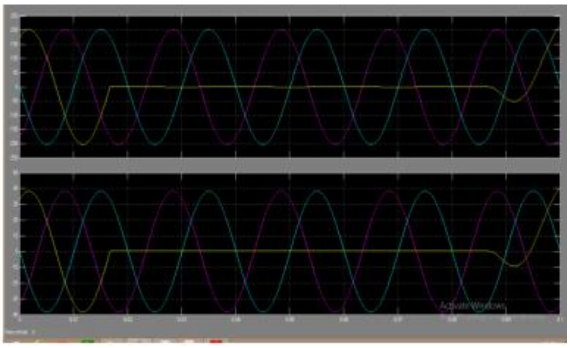

Fig.10..Simulation result: Voltage change only in 1 phase.

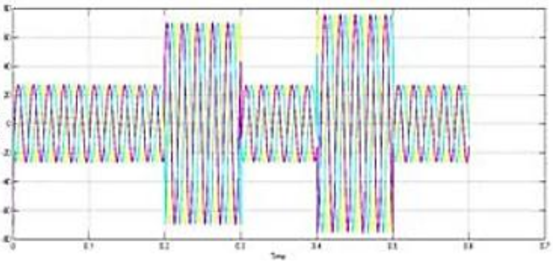

Fig.11. Simulation result: Voltage swells without using DVR

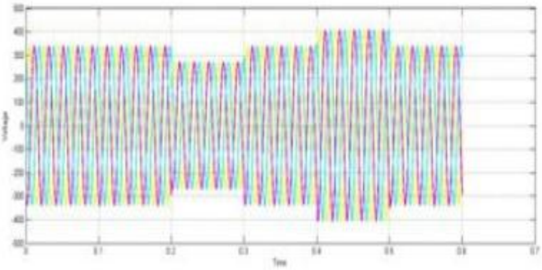

Fig.12.Simulation result: Voltage sags and swells without using DVR

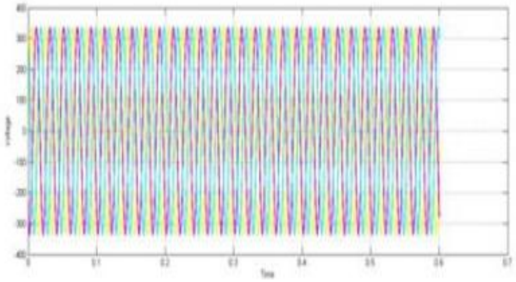

Fig.13. Simulation result: 3-Phase Voltage output using DVR.

V. CONCLUSION

A comparison of the performance of the DVR with different schemes has been performed with a reduced-rating VSC, including a capacitor-supported DVR. The reference load voltage has been estimated using the method of unit vectors, and the control of DVR has been achieved, which minimizes the error of voltage injection. The SRF theory has been used for estimating the reference DVR voltages. It is concluded that the voltage injection in-phase with the PCC voltage results in minimum rating of DVR but at the cost of an energy source at its dc bus.

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