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Dynamic Voltage Restorer for compensating voltage sags and swells

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Abstract —Among various power quality problems, the voltage sags/swells are one of the major issues. A simple Dynamic Voltage Restorer (DVR) is designed here to overcome this issue related to power quality. Dynamic Voltage Restorer (DVR) is one of the FACTs devices which is most efficient and effective device and is used to mitigate voltage sags/swells. This paper presents the Dynamic Voltage Restorer (DVR) with the control strategy using PI controller. DVR is simulated here for the voltage sags/swells mitigation. The MATLAB model and the simulation results are provided with different kind of voltage sags/swells using different faults in the line.

Keywords- Voltage sag/swell, Dynamic Voltage Restorer(DVR), PI controller

I. INTRODUCTION

As the load increases, the demand of power also get increased. There are too many sensitive loads are connected to the grid which needs the continuity of power throughout its work. So, it is necessary to maintain the power quality at its best. There are various power quality issues such as voltage sag/swell, voltage flicker, harmonics, transients, voltage interruption etc [1]. Among all of these power quality issues the voltage sag/swells are the most severe issues. The voltage sag/swell is the issue relative to power quality are described by the magnitude and the duration of that voltage [2]. Whenever the RMS value of supply voltage increases, i.e. 1.1 p.u. to 1.8 p.u., it is known as voltage swell. Also the time period for this swell is of 10 ms to 1 minute [1]. Similar to that whenever the RMS value of supply voltage goes down from its nominal value i.e. 0.9 p.u. to 0.1 p.u., it is known as voltage sag [1]. This short time problem stands for same as swell and is of 10ms to 1 minute. There are many custom power devices are introduced in power system to overcome this type of power quality issues.

Nowadays, the consumer demands the power supply which is reliable and of the best quality. There are mainly used custom power devices are: - Dynamic voltage restorer (DVR), Distribution Static compensator (DSTATCOM), and Unified power quality conditioner (UPQC).

Among all of these, Dynamic Voltage Restorer (DVR) is the most effective and efficient device which is used in power distribution network to overcome the power quality issues. DVR is the solid-state device which is connected in series with the transmission to inject or to absorb the voltage magnitude and the frequency according to the requirement [3].

II. BASIC PRINCIPLE AND STRUCTURE OF DYNAMIC VOLTAGE RESTOER

A. Structure of DVR

Main aim for the DVR is to regulate the load voltage with respect to any distortion like sag/swell or any unbalance in the supply side voltage. The operating principle of the DVR is to inject the voltage through Voltage Source Inverter (VSI) in series with transmission line, which is of required voltage and frequency. In common, a DVR is a static or VSI operated device which injects the controllable AC voltage by using a series transformer at the PCC i.e. Point of common coupling or critical-load bus. The basic dia. of DVR concept is shown as in fig. 1.

Basically, whenever a voltage sag/swell is detected by DVR, it uses a series connected topology to regulate the voltage with respect to the supply. The energy which is delivered to line can be stored in different kinds of energy storage systems i.e. batteries, capacitors, Super Magnetic Energy Storage (SMES) and fly-wheels.

The basic structure of DVR as shown in fig. 1 consists of:

i. An injection/Boost Transformer:

Injection transformer can be connected in delta/open winding or in star/open winding. Here, the delta/open winding only inject the positive and negative voltage sequence voltage in line whereas the star/open winding injects the positive, negative and zero sequence voltages in the line [4][5].

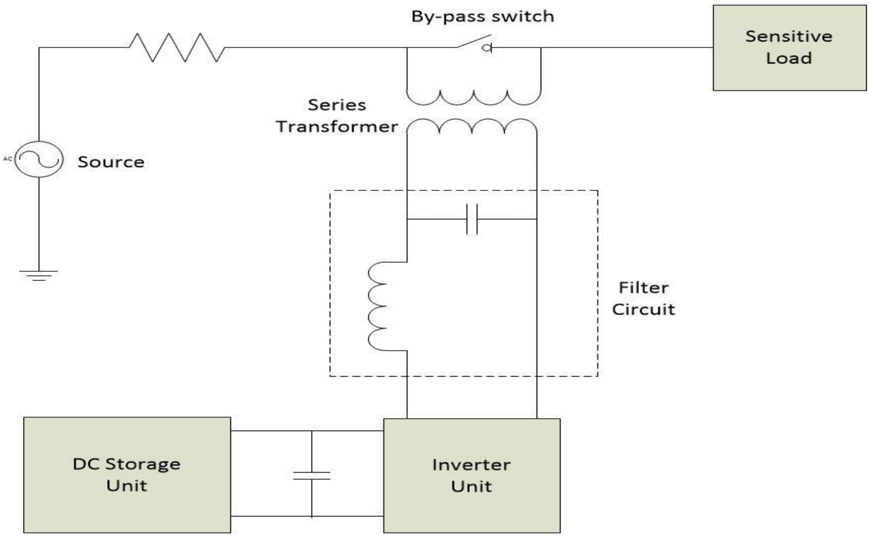

Figure 1: Basic circuit of a DVR.

ii. Filter

Filters can be placed either side of the injection transformer. The inverter side filters can prevent the higher order harmonics to pass through the voltage transformer to reduce its stress but against that it makes phase shift and voltage drop for injected voltage. On other side, i.e. whenever the filter is placed on high voltage side, the higher order harmonics penetrate the high-voltage side of the transformer and hence the higher rated transformer is become necessity.[6][7]

iii. Energy storage device

Energy storage device supports the dc link voltage at constant level. Various energy storage devices like flywheels, lead acid batteries, SMES and super capacitors can be used.[7][5]

iv. Voltage source converter

The voltage source converter (VSC) converts the DC voltage, which was supplied by the energy storage device into required AC voltage waveform, which is of required frequency, magnitude and phase angle[5]. There are few types of switching devices which are used in VSC, Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Gate Turn OFF Thyristor (GTO), Insulated Gate Bipolar Transistor (IGBT), and Insulated Gate Commutated Transistor (IGCT).

v. By-pass switch

Whenever any fault in a downstream will flow through the inverter circuit, this fault current can damage the power electronics devices in that inverter. Therefore, to protect that electronic devices from fault current, the By-pass switch (Mostly Crowbar circuit) is used to bypass the inverter circuit[5][8].

B. *Principle of operation for DVR*

In the normal condition, i.e. without any faulty situation in power system, DVR works in floating mode. Ideally DVR need not to be inject or to absorb any power to or from system. But practically DVR injects a small voltage, which is used to compensate for the voltage drop occurred due to injection transformer and device losses.

When the voltage sag/swell occurs in the system, the Dynamic voltage restorer (DVR) injects both balanced and unbalanced three phase AC voltage as per requirement with certain phase angle and the magnitude in series with the supply voltage[9]. This injection of voltage maintains the load voltage at the desired voltage level. The voltages which are injected, made synchronized with the network voltages. The response time of DVR is about 25ms to respond, and which is very much less than with compared to the traditional method of voltage correction like transformer tap changing method.

III. CONTROL SCHEME FOR DVR

There are different control schemes in different published work on DVR which are achieved using PQR power theory[10], DQ transformation[11], Fuzzy logic control[12], sliding mode control[13], Artificial neural network[14] and software PLL[15]. For reducing the time of the compensation as per requirement, generally the open loop feed forward network is preferred. Also, the LC filter, the voltage drop across inductor and the series boost transformer affects the DVR performance. Sometimes the load voltage cannot be compensated to the desired value in an open loop feed forward control and hence the closed loop control is used. Closed loop control can reduce the damping oscillations but it cannot respond fast with compared to open loop control.

The proposed control of DVR is done by using instantaneous p-q theory. This control scheme consists of two regulators, One is power regulator and the another one is current regulator. The power regulator controller senses the voltage and the current of VSC. The error signal is generated by comparing the active power outed by VSC with the load active power which is actually demanded. This error signal is applied to PI controller and reduced. This gives the direct axis reference current (I_{dref}), which is responsible to control active power. To generate the quadrature axis current (I_{qref}), the RMS value of load voltage is compared with the reference value, and this error value is given to the PI controller. Here the value I_{qref} is responsible for reactive power control.

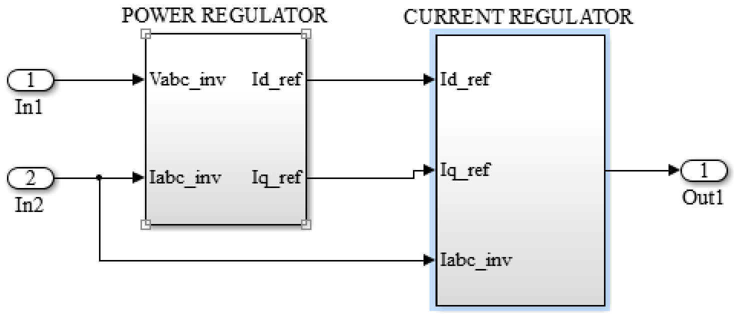

Figure 2: Block dia. Of control for DVR

The current controller is used to generate the gate pulses as per carrier frequency for the IGBT switches used in the VSC. The input for the current controller is VSC output current. Using park's transformation i.e. abc to dq0 transformation, this VSC current converts into I_d and I_q currents, which are compared with the I_{dref} and I_{qref} respectively. These error signals are then modulated by two separate PI controllers. These modulated signals are then converted back into three phase signals using inverse park's transformation. These signals than used to generate the series of gating signals of VSC by comparing with carrier frequency.

IV. SIMULATION OF DVR AND RESULTS

The test system for DVR was developed using the MATLAB/SIMULINK. Fig. 3 shows the simulated system in MATLAB/SIMULINK which comprises of a system which is composed by a 440V, 50Hz generation system feeding a line connected with load of 1KW, 100VAR. The DVR is consisting of a VSI with the switches of IGBTs, and the carrier frequency for VSI is 8KHz.

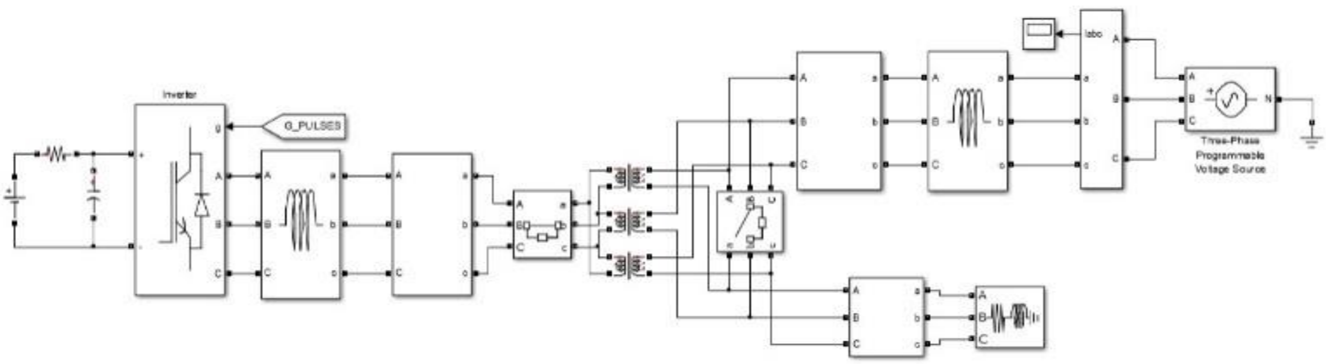

Figure 3: Simulation system of DVR

A. Voltage sag condition:

To operate the system sag, the fault is taken at source side. The fault is operated at instances of 0.3s and 0.4s. At 0.3 s, fault is created and at 0.4 s, fault is being cleared and the voltage is brought back to normal value.

Simulation is carried out for both voltage sag and voltage swell and the simulation is performed with and without DVR. The simulation result for voltage sag considered faults which are: Three-phase to ground fault, Two-phase to ground fault and Single-phase to ground fault.

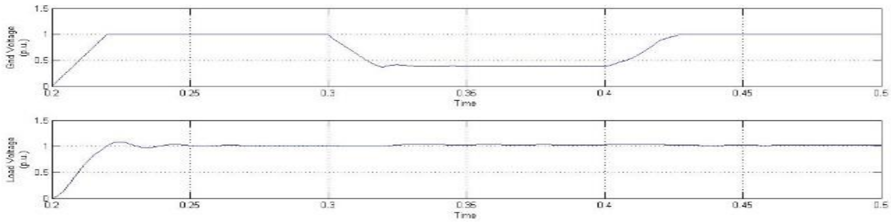

Fig. (a)

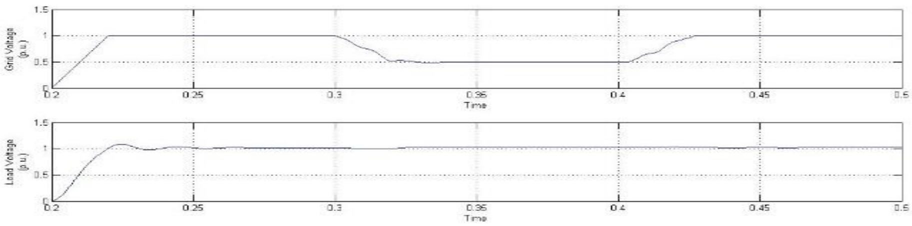

Fig. (b)

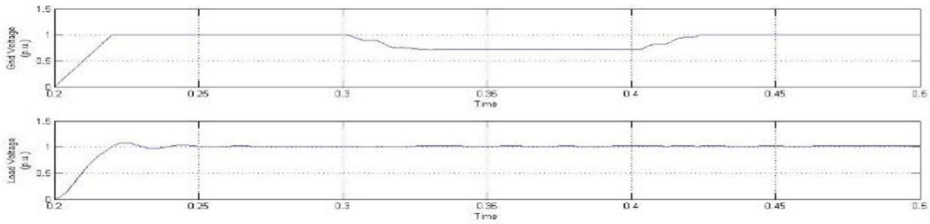

Fig. (c)

Figure 4: (a) 3-phase to ground fault, (b) 2-phase to ground fault, (c) 1-phase to ground fault

B. Voltage swell condition:

With using the controllable source of generation, the voltage swell is produced of various magnitudes. Same timings are taken for the swelling of voltage i.e. The voltage swell is operated at instances of 0.3s and 0.4s. At 0.3 s, swell is created and at 0.4 s, the voltage is brought back to normal value.

The simulation results for different swell values i.e. 1.7p.u., 1.5p.u., and 1.2p.u. is shown here.

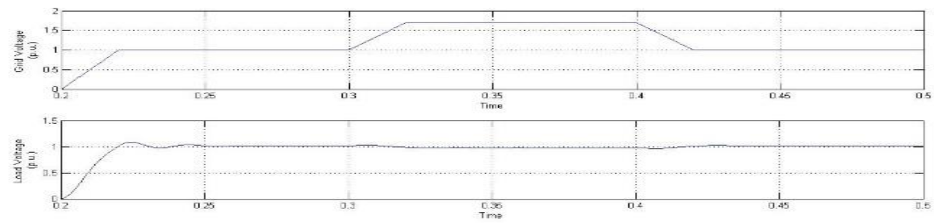

Fig. (a)

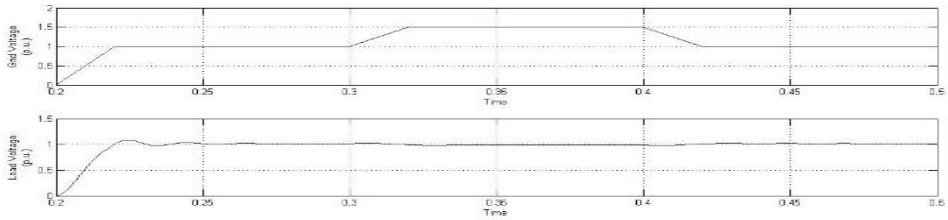

Fig. (b)

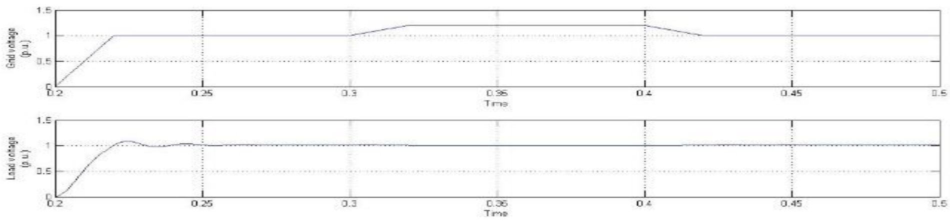

Fig. (c)

Figure 5: (a) 70% voltage swell, (b) 50% voltage swell,

(c) 20% voltage swell

V. CONCLUSION

This paper exhibit the compensation strategy based on PQ theory for the Dynamic Voltage Restorer (DVR). Simulation in MATLAB/SIMULINK work has been done and the experimental results are manifest in this paper with different sags using various imprecise situations and different swell values using controllable source. Here we can deduce that the results of DVR is peerless for mitigating sags and swells.

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