MATLAB Analysis for Power Quality Enrichment Using Dynamic voltage restorer (DVR)

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Abstract- *Power quality is one of major concerns in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality 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 equipment. One of the major problems dealt here is the power sag. 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 networks. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. This paper presents modelling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB. In this model a PI controller and Discrete PWM pulse generator was used. The simulation analysis for improve the power quality is shown in this paper.*

Keywords- PCC, SMES, VSI

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, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. 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 sags are not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly. Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVR is 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/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

II. POWER QUALITY PROBLEMS

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the distribution system have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up produce power quality problems. While power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices makes them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage valuable components. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions [2].

III. DYNAMIC VOLTAGE RESTORER

Among the power quality problems, voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. 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 networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

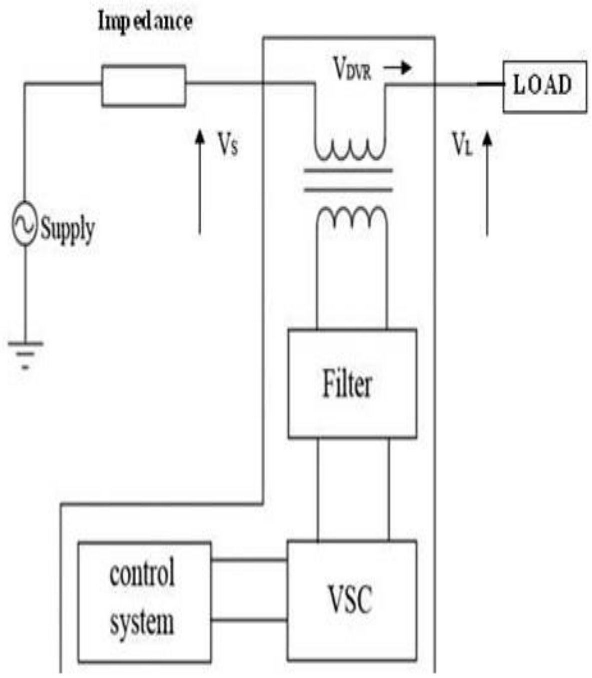

Fig.1. Schematic diagram of DVR

a. Storage Device: This unit is responsible for energy storage in DC form. Flywheels, Batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices. It is supplies the real power requirements of the system when DVR is used for compensation.
b. Harmonic Filters: Filters convert the inverted PWM waveform into a sinusoidal waveform easily. This is achieved by eliminating the unwanted harmonic components generated VSI action. Higher orders harmonic components distort the compensated output voltage.
c. Capacitor: DVR has a large DC capacitor to ensure a proper DC voltage input to Inverter.
d. By-Pass Switch: It is used to protect the inverter from High current in the presence of unwanted conditions. During the occurrence of a fault or a short circuit, DVR changes it into the bypass condition where the VSI inverter is protected against over current flowing through the power semiconductor switches. The rating of the DVR inverters is a limiting factor for normal load current seen in the primary winding and reflected to the secondary winding of the series insertion transformer.
e. Voltage source Inverter: Inverter system is used to convert dc storage into ac. Voltage source inverter (VSI) of low voltage and high current with step up injection transformer is used for this purpose in the DVR Compensation technique.
f. Booster Transformers: In a three-phase system, either three single-phase transformer units or one three phase transformer unit can be used for voltage injection purpose. Basic principal of DVR is to transfer the voltage sag compensation value from DC side of the inverter to the injected transformer after filter. The compensation capacity of a particular DVR depends on the maximum voltage injection capability and the active power that can be supplied by the DVR. When DVR's voltage disturbance occurs, active power or energy should be injected from DVR to the distribution system A DC system, which is connected to the inverter input, contains a large capacitor for storage energy. It provides reactive power to the load during faulty conditions. When the energy is drawn from the energy storage capacitors, the capacitor terminal voltage decrease. Therefore, there is a minimum voltage required below which the inverter of the DVR cannot generate the require voltage thus, size and rating of capacitor is very important for DVR power circuit [2].

IV. OPERATING MODES AND EQUATIONS OF DYNAMIC VOLTAGE RESTORER

The basic function of the DVR is to inject a dynamically controlled voltage of DVR 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 VL. 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.

1. **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).

2. **Standby Mode: (V_{DVR}= 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.

3. **Injection/Boost Mode: (V_{DVR}>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.

- **EQUATION RELATED TO DVR:**

$V_{DVR} = V_L – Z_{TH}.I_L - V_{TH}$

Where,
V_L: The desired load voltage magnitude
Z_{TH}: The load impedance.
I_L: The load current
V_{TH}: The system voltage during fault condition

The load current I_L is given by,

$$I_L = \frac{[P_L + jQ_L]}{V}$$

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

$$V_{DVR}\angle 0 = V_L\angle 0 + Z_{TH}\angle(\beta-\theta) - V_{TH}\angle\delta$$

∝, β, δ are angles of V_{DVR}, Z_{TH}, V_{TH} respectively and θ is Load power angle

$$\theta = tan^{-1}\left(\frac{\theta_L}{P_L}\right)$$

The complex power injection of the DVR can be written as, $S_{DVR}=V_{DVR}I_L^*$

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

V. VOLTAGE INJECTION TECHNIQUES OF DVR

1. Pre-sag/dip compensation method: The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, so that the load voltage can be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle and amplitude sensitive loads would be achieved by pre-sag compensation method. In this method the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions
2. VDVR = Vprefault - Vsag

3. In-phase compensation method: This is the most straight forward method. In this method the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied. One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for a certain voltage sag in comparison with other strategies. Practical application of this method is in non-sensitive loads to phase angle jump.
4. In-phase advanced compensation method: In this method the real power spent by the DVR is decreased by minimizing the power angle between the sag voltage and load current. In case of pre-sag and in-phase compensation method the active power is injected into the system during disturbances. The active power supply is limited stored energy in the DC links and this part is one of the most expensive parts of DVR. The minimization of injected energy is achieved by making the active power component zero by having
5. The injection voltage phasor perpendicular to the load current phasor. In this method the values of load current and voltage are fixed in the system so we can change only the phase of the sag voltage. IPAC method uses only reactive power and unfortunately, not al1 the sags can be mitigated without real power, as a consequence, this method is only suitable for a limited range of sags.
6. Voltage tolerance method with minimum energy injection: A small drop in voltage and small jump in phase angle can be tolerated by the load itself. If the voltage magnitude lies between 90%-110% of nominal voltage and 5%-10% of nominal state that will not disturb the operation characteristics of loads. Both magnitude and phase are the control parameter for this method which can be achieved by small energy injection [1].
7. feed forward control technique for DVR based on dqo transformation

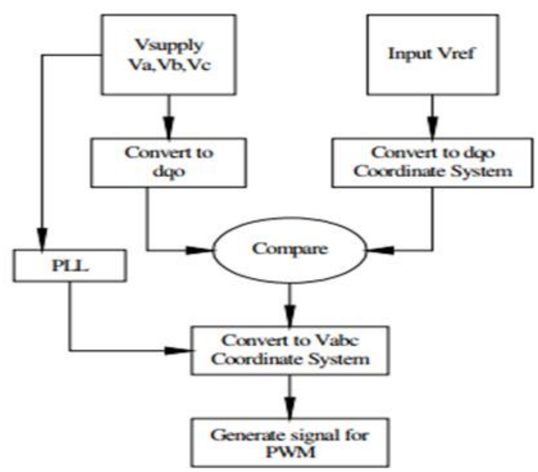

Fig.2 Flow chart of feed forward control technique for DVR based on dqo transformation

Fig. 2 illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases. The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va, Vb, Vc).The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value.

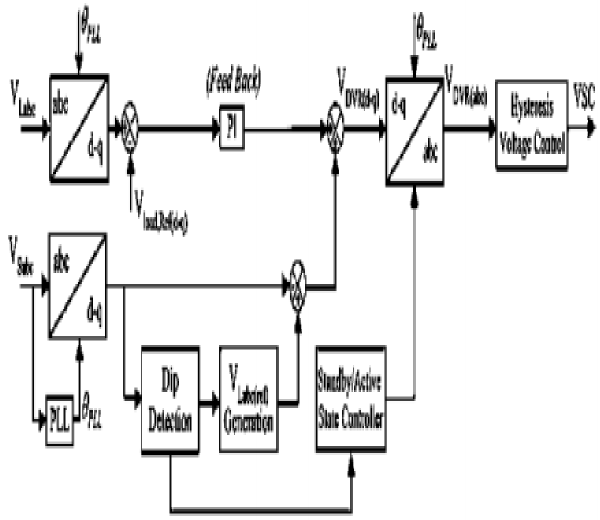

Fig.3 Control Structure of DVR

Control of DVR is performed by using d-q coordinate system. This transformation allows DC components, which is much simpler than AC components. The dqo transformation or Park's transformation is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors [6]. Figure shows Simulink model of feed forward control technique based on dq transformation. The feed forward control scheme is based on comparison of PCC voltage and reference voltage. The phase logic loop (PLL) circuit is used to generate sinusoidal wave in phase with main terminal voltage [1].

The PWM generator is used to generate firing pulses to control compensating voltage injected by three phase voltage source converter (IGBT) in series with sensitive load. The voltage sag is detected when voltage is reduced from 10 to 90% in between duration from 0.5 cycle to 1 minute.

Simulation

A 440V, 50Hz, power distribution system configuration is simulated using Math works Matlab/Simulink to study the effectiveness and response of suggested DVR control strategy under different supply disturbances. To verify the working of DVR for voltage compensation a fault is applied at point X at resistance 0.68 Ω for time duration of 202 ms. The DVR is simulated to be in operation only for the duration of the fault.

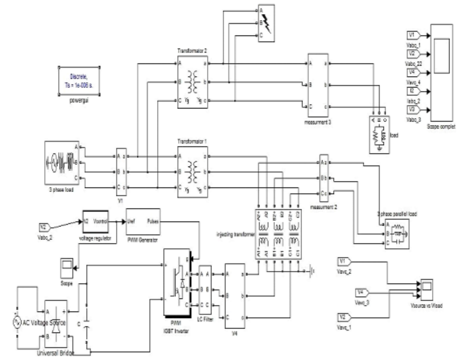

Fig.4 Matlab/Simulink of proposed scheme

VI. SIMULATION RESULTS

Here single line to ground fault is created in one of the feeder .here the fault resistance is .068 ohm and the ground resistance is .1 ohm the fault time is .020 to .051 sec .the result of the DVR to the load voltage is given below.1) source voltage(pu) 2) load voltage with compensation(pu) 3) injection voltage 4) load current(pu) 5) load voltage without compensation

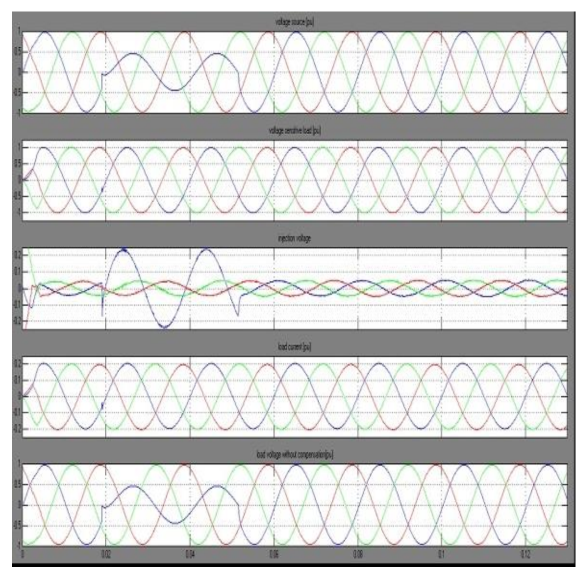

Fig.5 Simulation result of single line to ground fault

Here tripple line to ground fault is created in one of the feeder .here the fault resistance is .068 ohm and the ground resistance is .1 ohm the fault time is .020 to .051 sec .the result of the DVR to the load voltage is given below.1)source voltage(pu) 2)load voltage with compensation(pu) 3)injection voltage 4)load current(pu) 5)load voltage without compensation

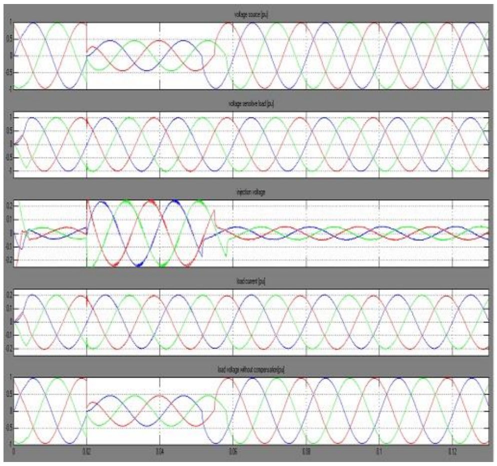

Fig.6. Simulation result of triple line to ground fault

The simulation results of different types of fault in the system shown in figure 5 and 6. Figure 5 shown that Simulation result of single line to ground fault and load voltage is compensated by DVR. Source voltage profile is disturbed for period of time and required injected voltage which shown in third waveform is added using DVR. Figure 6 shown that Simulation result of triple line to ground fault and it's compensated by DVR. Source voltage profile is disturbed for period of time and required injected voltage which shown in third waveform is added using DVR. All the result shows that in fault condition required source voltage is injected and voltage profile is balanced.

VII. CONCLUSION

The simulation of proposed DVR in mitigating multiple voltage sags/swells is presented. A controller based on a feed-foreword technique is used to trigger the switches of an inverter using a Pulse Width Modulation (PWM) scheme. The presented controller strategy uses the d-q-0 rotating reference frame i.e. parks transformation, as it offers higher accuracy as compared to other techniques. In the case of voltage sag/swells, the DVR injects an equal positive/negative voltage component in all three phases to compensate for the supply system. It is also observed that if the sag on one phase results in a swell on another phase, such PQ disturbances in the distribution system is also compensated. The simulation result shows that proposed DVR scheme compensate voltage sag/swell quickly and provide better performance.

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