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A CONTROL TECHNIQUE FOR INSTANT MITIGATION OF VOLTAGE SAG/SWELL BY DYNAMIC VOLTAGE RESTORER

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Abstract- This paper presents a control technique using Synchronous Reference Frame (SRF) theory to compensate the voltage sag/swell by using Dynamic Voltage Restorer (DVR). DVR is the best known device for mitigation of voltage sag/swell occurred in the system. Nowadays voltage sag is the most common problem customers are facing repeatedly. There is a need for instant mitigation of voltage sag/swell and maintains the load voltage constant. Some simulations are performed in MATLAB/Simulink and results are discussed to validate this theory for instant calculation of reference voltage and quick mitigation of voltage sag or swell from the system.

Keywords- Voltage sag/swell, Power Quality, Custom Power Technology, VSC, SRF Theory, Hysteresis controller, injection transformer.

I. INTRODUCTION

Nowadays everyone is demanding for reliable and quality of power supply which can be accomplished by custom power technology, which will take care of reliability and quality of power supplied to the customer. Mainly there are three devices in custom power technology which are – Dynamic Voltage Restorer (DVR), Distribution STATCOM (DSTATCOM) and Unified Power Quality Conditioner (UPQC). Among which DVR is the best suitable device to mitigate the voltage sag or swell and maintains the load voltage constant [1]. Generally DVR is used to protect the sensitive load from common type of voltage disturbances. DVR is connected in series to protect the load from abnormal voltage conditions in the supply voltage by inserting the voltage of required magnitude and frequency [2].

Voltage sag/swell are characterized by magnitude and duration of sag/swell. Standard definition of voltage sag and swell are given in [3]. A decrease to between 0.1 to 0.9 pu in RMS voltage at the power frequency for duration from 0.5 cycles to 1 minute is called voltage sag and common problems for such situation are system faults, addition of large load, starting of large motors, etc. And voltage swell is defined as “An increase to between 1.1 and 1.8 pu in RMS voltage at the power frequency for duration from 0.5 cycles to 1 minute.” Common causes for voltage swell are switching off a large load, energization of a capacitor bank, etc [3], [4].

There are different conventional methods for mitigation of voltage sag like constant voltage transformer (CVT), UPS, motor generator set but all these techniques have some disadvantages like frequent maintenance, noise, and bulky system [3]. There are some modern techniques which uses power electronic devices and different control techniques.

Paper [5] describes the different methods to mitigate voltage sag in the system. Paper [6] shows the simulation of DVR using PWM technique. Paper [7] uses PI controller and Fuzzy logic control technique for voltage sag compensation. Paper [8] shows the different topologies for DVR.

Control circuit is the main part of the DVR. Which will monitor the source voltage continuously and take a instant action after detecting any abnormality in the supply voltage. This controller is achieved by using SRF transformation and hysteresis controller. To check the accuracy and speed of compensation different conditions are simulated in MATLAB/Simulink. First simulation is done without DVR and then system with DVR.

II. STRUCTURE AND OPERATION OF DVR

Dynamic Voltage Restorer is one of custom power device specially used to maintain the load voltage constant in the distribution system. DVR has two operating modes. In normal operation mode it is in standby mode in which voltage injection by DVR is zero. Most of the time DVR will be in standby mode and hence reduces the losses.

As soon as control circuit detects the any voltage disturbance, reference voltage is generated for required magnitude, duration and phase and is injected through injection transformer. This mode of DVR is known as injecting mode [1]. This injection should satisfy the equation (1)[6]

$$V_L = V_S + V_{inj} \quad (1)$$

Where V_S is the source voltage, V_{inj} is the injected voltage by DVR and V_L is the load voltage.

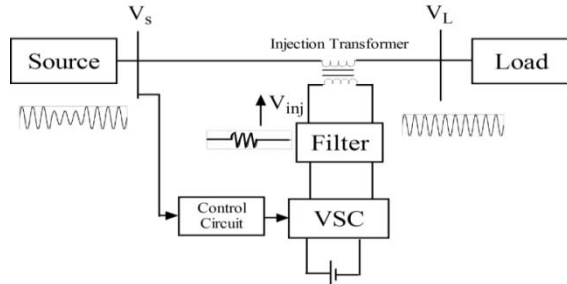

Fig.1 Structure of DVR

Fig.1 shows the basic configuration and operation of DVR which consist of an injection transformer, Voltage Source Converter (VSC), harmonic filter, storage device and control system

A. Injection Transformer

Injection transformer is used to connect the DVR to the distribution network via High Voltage winding and injects the compensating voltage generated by VSC after the detection of any disturbance in supply voltage by control circuit. Another main task of injection transformer is that it will limit the coupling of noise and isolate VSC and control circuit from the system [9].

B. Voltage Source Converter (VSC)

VSC is a power electronic device consists of storage device and switching devices used to generate the compensating sinusoidal voltage of required magnitude, duration, in phase as that of system and instantaneously. In DVR voltage source converter provides the missing voltage during voltage sag [10]. In this paper IGBT's are used as switching device.

C. Harmonic filter

Output of VSC contains large content of harmonics. Harmonic filter is used to keep this harmonic content in permissible limit [9].

D. Storage device

It is basically used to supply the necessary energy to VSC to generate the compensating voltage [9], [10]. In this paper DC voltage source is used for this purpose.

E. Control circuit

Control circuit continuously monitors the supply voltage. The function of control system is to detect the disturbance in the supply voltage, compare it with the set reference value and then generate the switching pulses to the VSC to generate the DVR output voltages which will compensate the voltage sag/swell [9], [10].

III. SRF THEORY

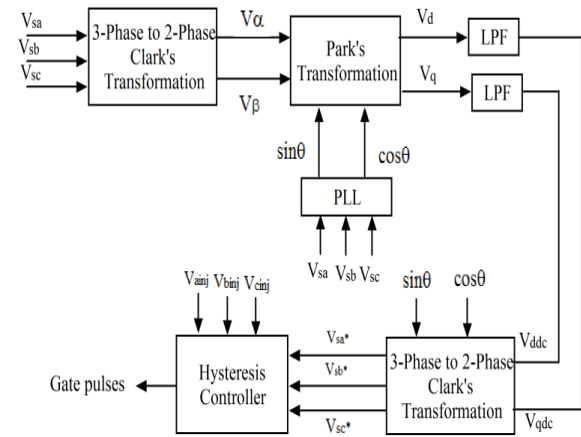
In this paper this theory is used to generate the reference voltage required to compensate the voltage sag/swell. This technique converts coordinates from a-

b-c stationary coordinate system to o-d-q rotating coordinate system. Signals are converted in o-d-q frame because it is easy to control and process on signals in d-q frame [11], [12]. Then again these signals are converted in a-b-c coordinate system. Fig 2 shows the block diagram for SRF theory. In this transformation there are following steps [11],[12].

i. Clark's Transformation

It transforms sensed source voltage signal from a-b-c stationary to α - β stationary coordinate system by following equation

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\left(\frac{2}{3}\right)} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (2)$$


Fig.2 SRF Theory

ii. Park's Transformation

Now this stationary signal is converted in rotating o-d-q frame by using equation 3.

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} \quad (3)$$

For this transformation θ is obtained from phase lock loop (PLL) block. v_d and v_q contain both dc and ac component. Low pass filter is used to filter out the ac component and only dc component is used further.

Now sagged source voltage in d-q frame which is subtracted from set reference voltage in d-q frame and which gives the compensating voltage in d-q frame. Now by applying inverse Park's and Clark's Transformation respectively signal is transformed in a-b-c coordinates system as

iii. Reverse Park's Transformation

$$\begin{bmatrix} V_{s\alpha}^* \\ V_{s\beta}^* \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} V_{dc} \\ 0 \end{bmatrix} \quad (4)$$

iv. Reverse Clark's Transformation

$$\begin{bmatrix} V_{sa}^* \\ V_{sb}^* \\ V_{sc}^* \end{bmatrix} = \sqrt{\left(\frac{2}{3}\right)} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_0^* \\ V_{s\alpha}^* \\ V_{s\beta}^* \end{bmatrix} \quad (5)$$

V_{sa}^* , V_{sb}^* and V_{sc}^* are the reference source voltages.

IV. HYSTERESIS CONTROLLER

Comparing with other PWM methods hysteresis controller is easy to implement, has simple operation and very fast response. Hysteresis controller work on the error signal between an injection voltage and a reference voltage of DVR and produces proper gate pulses for inverter [13]. Based on these gate pulses VSC produces required compensating voltage. Fig. 3 shows the principle of hysteresis controller. Where dotted line shows the upper and lower limit, middle line is the reference voltage obtained after transformation and triangular line is the output voltage of VSC. Upper and lower hysteresis limits are 1 and -1 respectively.

When the error is going from lower limit to upper limit switch 1 is 'on' for that duration and switch 2 is 'off'. And when error is going from upper limit to lower limit switch 2 is 'on' and switch 1 is 'off'. Fig 2 shows the gate pulse generation for one leg of inverter. Fig 4 shows the simulation of Hysteresis controller in MATLAB simulink [14].

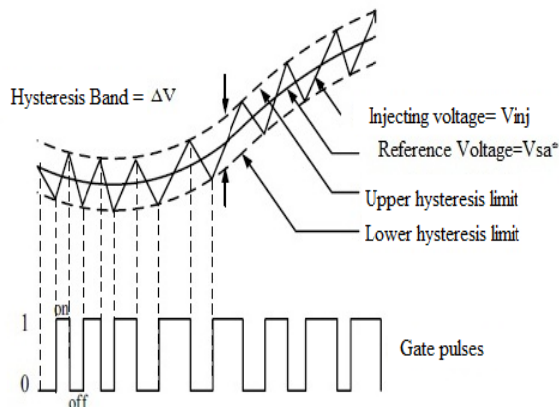


Fig.3 Principle of Hysteresis Controller

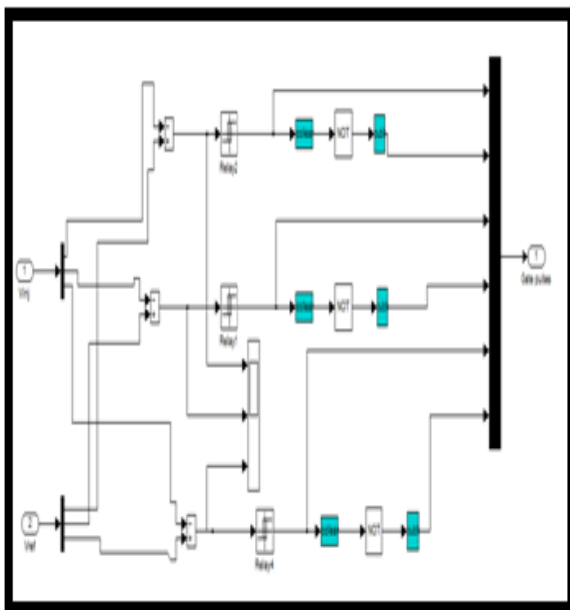


Fig.4 Simulation for Hysteresis controller

V. SIMULATION RESULTS AND ANALYSIS

A. Simulation for voltage sag without DVR

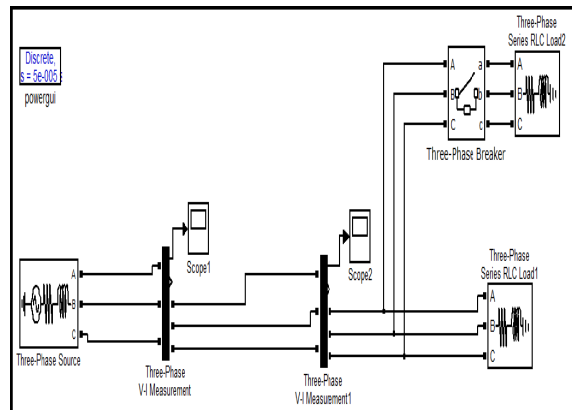


Fig 5 Simulation for voltage sag

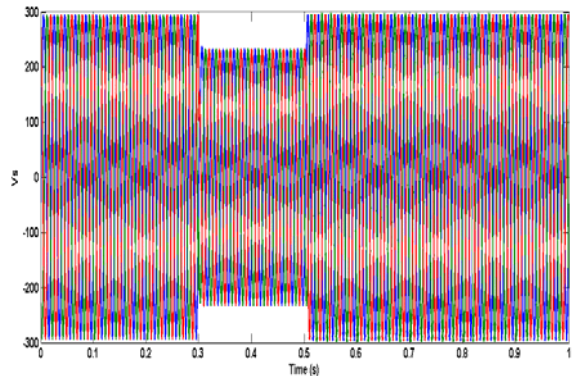


Fig 6 Saggged load voltage

To check the performance of DVR a simple distribution network is simulated in MATLAB Simulink. Voltage sag is created by addition of load. Multi-sag and multi-sag with different magnitude conditions are checked using DVR. Fig 5 shows the simulation for voltage sag without DVR and Fig 6 shows the saggged load voltage due to addition of load in the network.

B. Multi sag condition

Fig. 7 shows the simulation of DVR for the compensation of multi sag caused by addition of load. In this simulation three phase load-1 is added for the duration from 0.2s to 0.3s and removed with the help of three phase circuit breaker. Again at 0.5s circuit breaker is switched and closed at 0.7s. Due to these there are two voltage sag condition as shown in Fig. 8(a). Control circuit convert the source voltage in d-q frame and is subtracted from another constant voltage d-q component. Then by the inverse transformation it is converted back in a-b-c frame. Control circuit calculates the reference voltage instantaneously. Fig. 8(b) shows the reference voltage of required magnitude, phase and duration. This voltage is compared with the output voltage of inverter and error is given to hysteresis relay which will generate gate pulses for inverter.

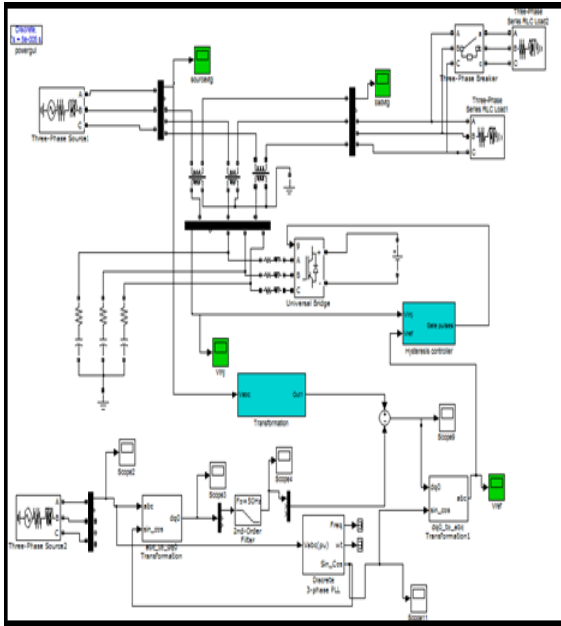


Fig 7 Simulation of DVR for Multi-sag condition

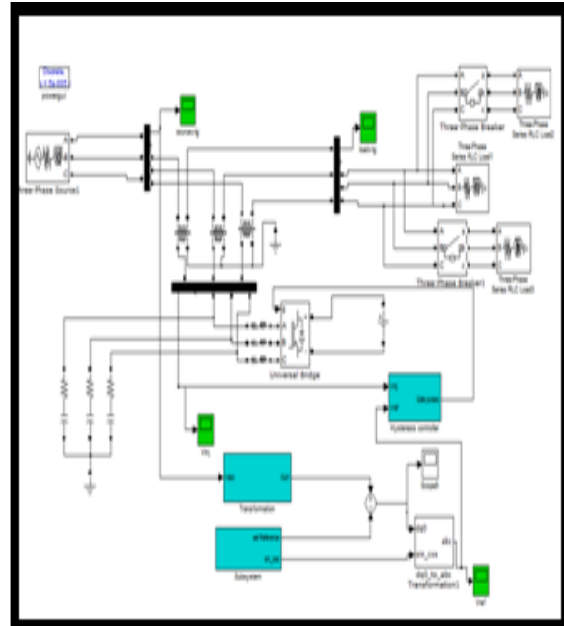


Fig.9 Simulation of DVR for Multi-sag with different magnitude

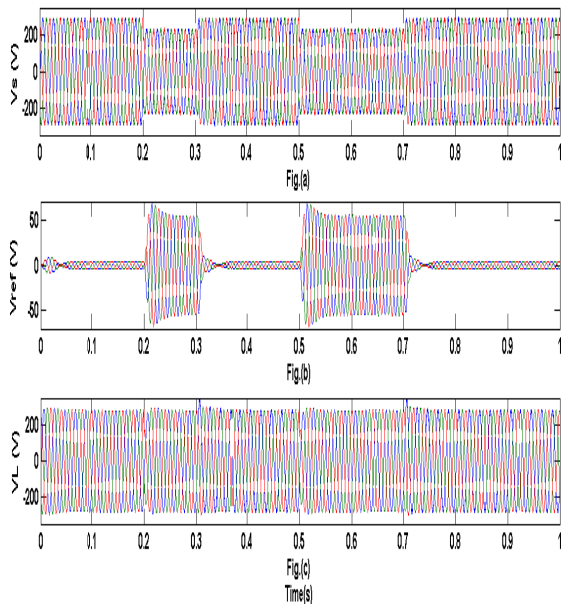


Fig 8 (a) Source voltage, (b) Reference voltage and (c) Load voltage

Fig. 8(c) shows the compensated load voltage. Passive filter is used to filter out the distortion in the output voltage of inverter.

C. Multisag with different magnitude

In this simulation sag with different magnitude is created by adding different load. First at 0.2s load 2 is added for some duration and at time 0.5s load 3 is added. Due to this sag is created but with different depth. Even though DVR control circuit is able to calculate the reference voltage and compensate such type of sag. Fig. 9 shows the simulation of DVR for such situation and Fig. 10 shows the source voltage, reference voltage and compensated load voltage respectively. Table 1 gives the system parameters used in simulation.

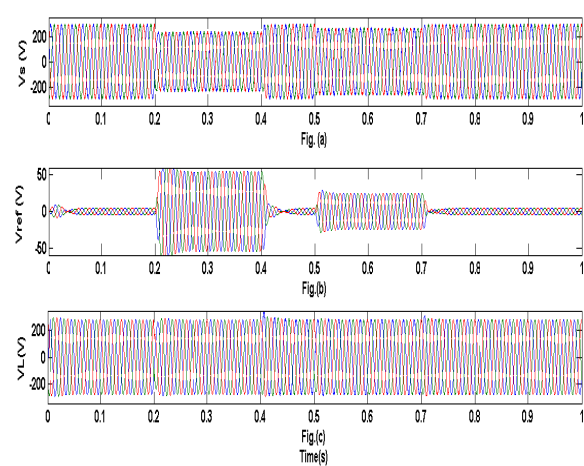


Fig 10 (a) Source voltage, (b) Reference voltage and (c) Load voltage

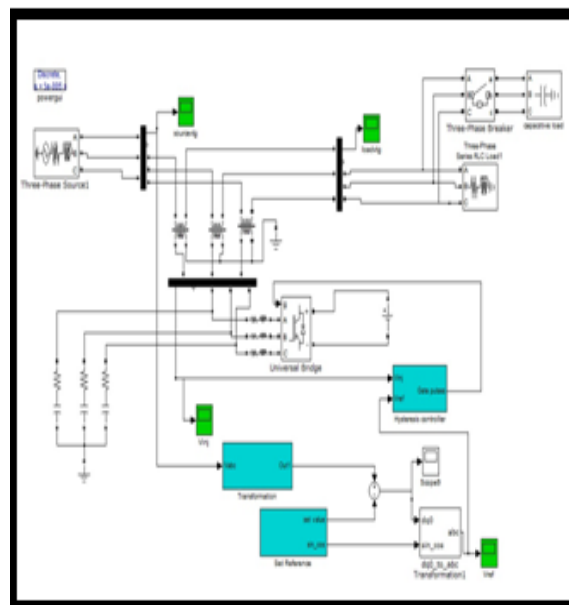


Fig.11 Simulation of DVR for voltage swell

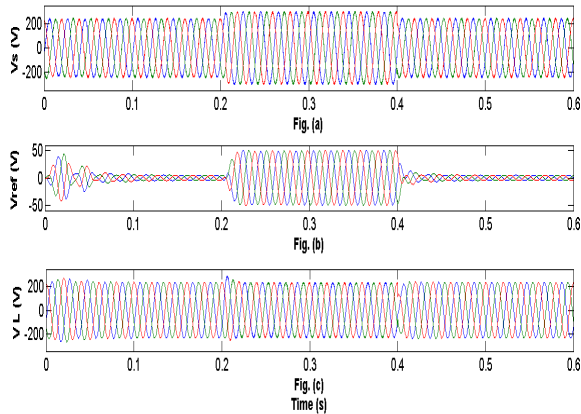


Fig. 12 (a) Source voltage, (b) Reference voltage and (c) Load voltage

TABLE 1 System Parameter

| System Parameter | Rating |
|-----------------------------|--------------------|
| Three Phase Source 1 | 400V, 50Hz |
| Three Phase Source 2 | 350V, 50Hz |
| Three Phase Load 1 | P= 10KW, Q= 100VAR |
| Three Phase Load 2 | P= 10KW, Q= 100VAR |
| Three Phase Load 3 | P=5KW, Q= 100VAR |
| Capacitive Load | Q= 4KVAR |
| DC Voltage Source | 700V |
| Switching Frequency | 50μs |
| Injection Transformer Ratio | 320/400V |

D. Simulation of DVR for voltage swell

In this simulation a capacitive load is added for some duration. Addition of capacitive load results in the voltage swell. For this simulation. Control technique will detect the voltage swell and give appropriate signals to VSC to generate the required voltage component with anti-phase to to supply voltage to compensate voltage swell. Fig. 11 shows the simulation of DVR and Fig. 12 shows the source voltage, reference voltage and constant load voltage respectively.

VI. CONCLUSION

This paper presents a control technique for Dynamic Voltage Restorer (DVR) for instant mitigation of voltage sag or swells from the system. Control technique comprises of SRF transformation and Hysteresis controller. Transformation of signal and principle of hysteresis controller is discussed. Some simulations are carried out in MATLAB/Simulink to validate these theories. Results shows that the DVR is best device in order to mitigate the voltage sag or swell instantly

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