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Mitigation of voltage sag/swell using dynamic voltage restorer

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ABSTRACT

In this paper complete design procedure of the DVR is described. Among the power quality problems, sag/swell are occur both on the transmission and distribution side. These power quality problems are solved by the DVR. DVR is the series connected device to compensate the voltage sags and swells on the distribution side. Here the detection of voltage sag and swell is carried out by the SRF theory, whereas the control of the voltage injected by DVR is done by the SPWM technique. IGBT based full bridge voltage source inverter fed by the constant DC voltage source is used to convert the DC voltage to AC voltage at the desired voltage and desired frequency.

Keywords—*Dynamic voltage restorer, Voltage sag, Voltage swell, PLL, SRF theory, SPWM.*

1. 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 of 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 equipment. In automation industries, many sectors are synchronized with each other. Once the synchronyzm failed more time is required to restore the automation plant. Nowadays, undervoltage and overvoltage protection are used, but they provides protection by disconnecting the motor, but we need a continuous supply. Of all the power quality problems, 92 percent of the interruption in industrial installations are due to voltage sags. according to IEEE Std. 1159-1995, sag is defined as a decrease in rms voltage between 0.1 pu and 0.9 pu at the power frequency for half cycle to one min and swell is defined as the increase in rms voltage between 1.1 pu and 1.9 pu for half cycle to one min. 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 voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are 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.

2. DVR CONFIGURATION

A dynamic Voltage Restorer is a series connected device that injects missing voltage into the system for regulating the load side voltage. DVR is located between the supply and the sensitive load. It continuously and quickly regulates the load side voltage in the case of any power quality problem like voltage sag or voltage swell to preventing power interruption to the sensitive load.

2.1 Operating principle

The fundamental principle behind DVR operation is that it injects a voltage through an injection transformer that is the difference between pre-sag and sagged voltage this is depicted in the fig. this is made possible by the supply of required real/active power from an energy storage device.

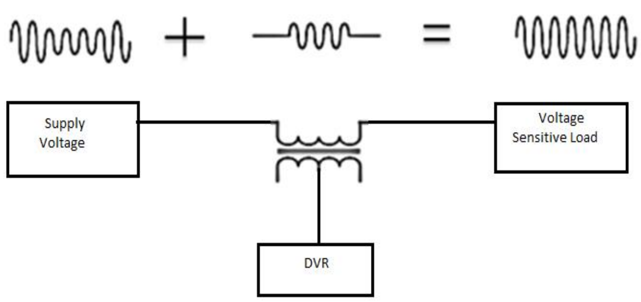


Fig. 1: Operation of DVR

2.2 Fundamental components of DVR

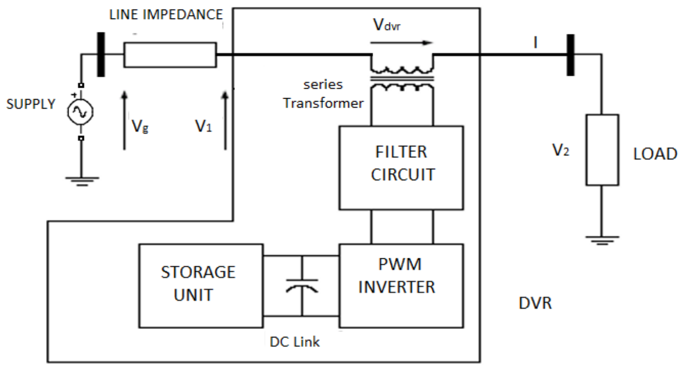


Fig. 2: Block diagram of DVR

2.2.1 An injection transformer: The primary of the injection transformer is connected between the supply and the sensitive load, and the secondary is connected to the voltage source inverter. For a single phase system single transformer is used, and for three-phase system, three phase transformer is used. Transformation ratio is decided by the DC link voltage of the inverter. That means for 1 put DC link voltage transformation ratio is 1:1 is selected.

2.2.2 A harmonic filter: Harmonic passive filter are placed between the injection transformer and the voltage source inverter to filter out the harmonics produced by the voltage source inverter. Size of the filter depends upon the switching frequency and the load. As the switching frequency increase will reduce the size of the filter

2.2.3 Storage devices: Batteries can be used to provide real power for compensation. Compensation using real power is essential when large voltage sag occurs. In self-supported DVR capacitor are used as a DC link voltage. But it is not able to compensate long duration voltage sag and swell.

2.2.4 A Voltage Source Converter (VSC): A voltage source inverter is the IGBT based three phase bridge inverter fed by the DC voltage source and the output is given to the secondary of the injection transformer through the harmonic filter. IGBT has the advantage of both BJT and the MOSFET, BJT has low conduction loss and MOSFET has the low switching loss.

2.3 Operating modes of DVR

- Protection mode
- Standby mode
- Injection mode

Whenever there is a fault on the line, very high fault currents will flow through the primary winding of the injection transformer. The DVR should be protected from this large current through the bypass switches disconnect the primary winding of the transformer. In standby mode, primary winding carries the full load current, and DVR will not inject any kind of the voltage. The DVR goes into injection mode as the voltage sag or swell is detected, and inject the required amount of the voltage in series with the system to maintain the constant load voltage.

2.4 Voltage compensation methods of DVR

- Presage compensation
- in phase compensation
- energy-optimization technique

Compensation is achieved by real power and reactive power injection. There are three types of compensation methods are used. (1)Presage compensation: For non-linear loads required both magnitudes as well as phase angle compensation. In this technique, DVR injects the difference between pre-sag and sag voltage thus restoring the voltage as well as the phase angle to that of the pre-sag value. Therefore this method is suitable for linear as well as non-linear load. (2) Inphase compensation: in this compensation technique DVR inject voltage in the same phase with the supply voltage, so it does not restore the phase angle only restore the magnitude. So, this method is suitable only for a linear load. (3) In this control technique, the use of real power is minimized (or made equal to zero) by injecting the required voltage by the DVR at a 90° phase angle to the load current. But in this technique injected voltage will become higher than that of the in-phase compensation technique. Hence this technique needs a higher rated transformer and an inverter.

3. CONTROL SCHEME OF DVR

The simulation block diagram based on the dq0 transformation technique is shown in figure 3.

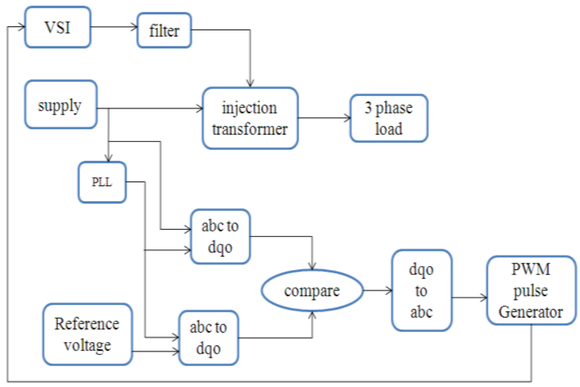


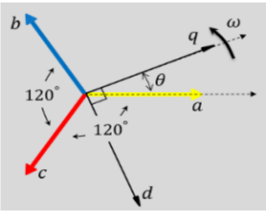
Fig. 3: Control scheme of DVR

The control scheme implemented here is based on the dq0 transformation. Before comparing two quantity, we have to convert first it into DC quantity. By comparing these two quantity reference signal and system load voltage we get the error signal in dq0 form. Once a voltage disturbance occurs, the output of the inverter can be adjusted in phase with the ac source while the load voltage is regulated. The output of the inverter is equipped with inductors and capacitors for filtering purpose. The role of DVR controller is the detection of voltage sag/swell in the power system; calculation of the compensation voltage, trigger pulse creation for the sinusoidal PWM inverter, correction of any error of any errors in the series voltage injection and extinction of the trigger pulses once the fault is cleared.

Synchronous fundamental dq-frame is derived from the space vector transformation of the input signals, which are in abc – coordinate and then transformed into the dq-coordinates by means of the park transformation. The park transformation converts the time-domain components of three phase system in abc reference frame to direct, quadrature and zero components in a rotating reference frame. The block can preserve the active and reactive powers with the powers of the system in the *abc* reference frame by implementing an invariant version of the Park transform. For a balanced system, the zero component is equal to zero.

The error signal generated by the above comparison is used as a control signal that generates the gate signal of the VSI using sinusoidal Pulse Width Modulation technique (SPWM); voltages are controlled by modulation. The PLL circuit is used for the generation of a unit sinusoidal wave.

The equation that transforms the three-phase a-b-c system to stationary dq0 frame is given by the below equation.



Angle θ = wt

$$\begin{bmatrix} d \\ q \\ 0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin(\theta) & \sin(\theta-\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) \\ \cos(\theta) & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

Transformation matrix

In this transformation, phase A is aligned to the d-axis that is in quadrature with the q-axis.

Where, w = is the rotational speed of the *d-q* reference frame.

θ = angle between the *a* and *q* axes

t = time in

- *a*, *b*, and *c* are the components of the three-phase system in the *abc* reference frame.
- *d* and *q* are the components of the two-axis system in the rotating reference frame.
- *0* is the zero component of the two-axis system in the stationary reference frame.

4. DESIGN PARAMETERS

The voltage source inverter should be controlled in such a way as to generate the voltages which are the same as the reference voltages generated by the control circuit. Here SPWM technique is used as the switching pulse generation. The following reasons will justify the selection of SPWM as the control strategy for the VSI.

- The output of the inverter should be the same as the reference voltage generated by the detection and control block.
- From the theory of SPWM, we know that the fundamental of the output of the inverter will be the same as the modulating waveform used to compare the triangular carrier.

The reference voltage generated by the control circuit are given as the modulating signal for the inverter then the fundamental output of the inverter will be the same as the modulating signal The modulation index Ma is equal to

$$M_a = \frac{\text{the amplitude of the modulating waveform}}{\text{the amplitude of the carrier waveform}}$$

Amplitude of carrier set = 1 pu

Therefore, Ma = magnitude of sag

V inv out = Ma * V DC

But, desired V inv out = Ma

Therefore, V DC = 1 pu

In the simulation, the frequency of the modulating waveform is 50 Hz and the frequency of the carrier waveform is in kHz. There is nothing special in choosing carrier frequency, the only constraint is that carrier frequency should be as high as possible. But there is an upper limit of carrier frequency because as we keep on increasing carrier frequency the switching losses also increase. In this simulation, 4 kHz switching frequency are selected.

4. SIMULATION AND RESULTS

4.1 Simulation circuit

Here simulation circuit with a sensitive load of 2 KW, 415 volt three phase supply, 50 Hz frequency. All the voltage signal are converted into pu (per unit). Three phases full bridge Inverter fed by DC link voltage source 600 volt (1 pu) and switching frequency of 4 kHz. Transformer turn ratio set 1:1 as the DC voltage equal to 1 pu. Filter inductance set 30 mh and filter capacitor set to 1000 uf based on the filter design calculation.

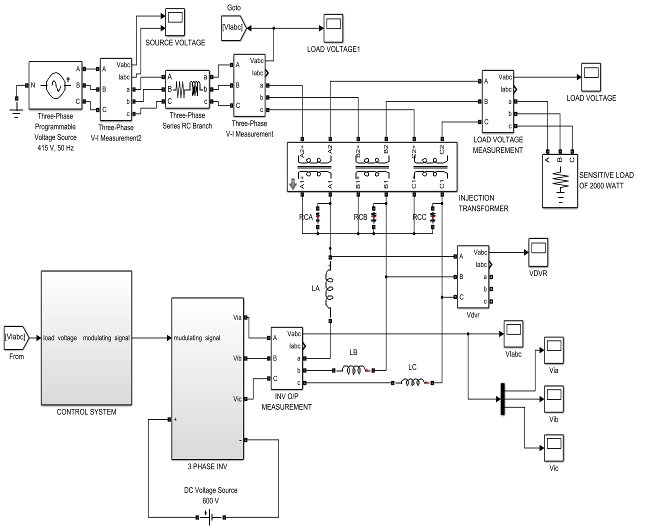


Fig. 4: Simulation circuit

4.2 Control circuit

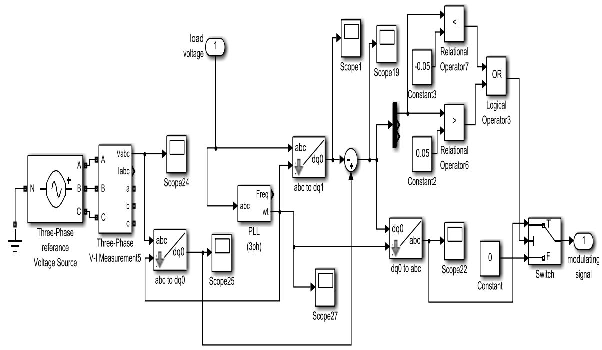


Fig. 5: Control circuit

4.3 Gate pulses of the inverter

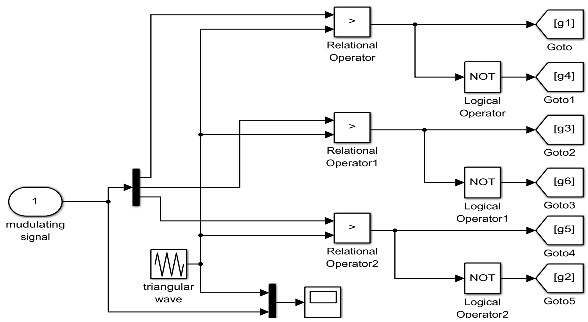


Fig. 6(a): Gate pulses of the inverter

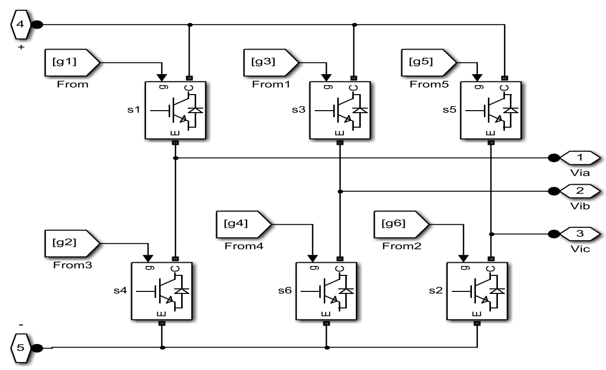


Fig. 6(b): Gate pulses of the inverter

Case 1: voltage sag result

A balanced sag of magnitude 0.5 pu occurs from t= 0.1 sec to t=0.15 sec, fig shows the waveform of load voltage.

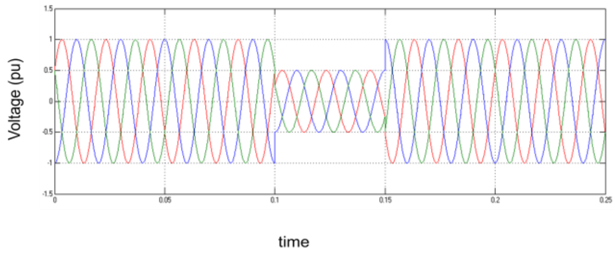


Fig. 7: Voltage sag result

Error/modulating signal in abc form

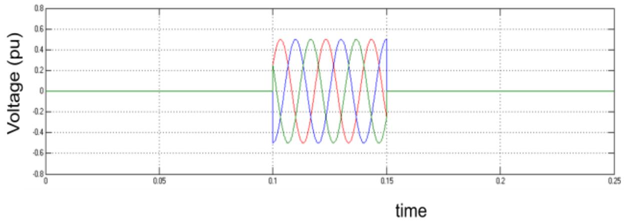


Fig. 8: Error/modulating signal in abc form

Enable signal to converter

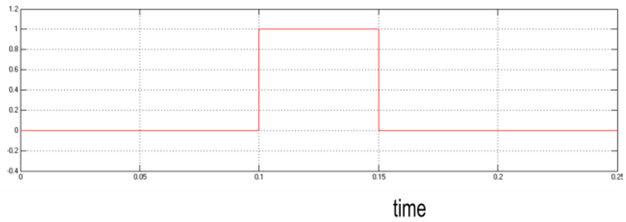


Fig. 9: Enable signal to converter

Voltage injected by DVR

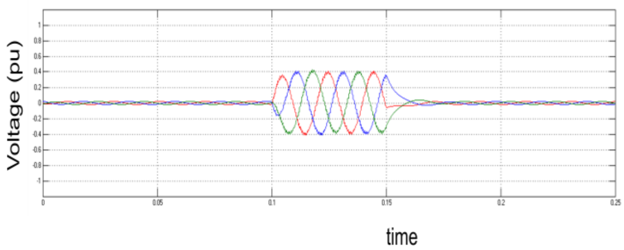


Fig. 10: Voltage injected by DVR

Load voltage waveform

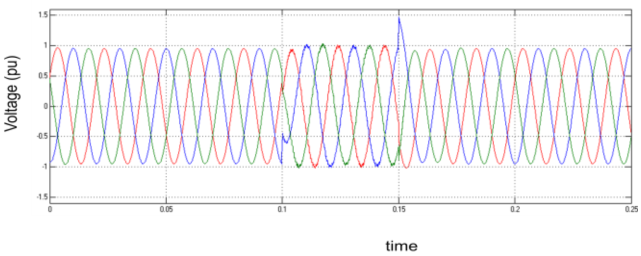


Fig. 11: Load voltage waveform

Case 2 : voltage swell result

A balanced swell of magnitude 1.3 pu occurs from t= 0.15 sec to t=0.2sec, fig shows the waveform of load voltage.

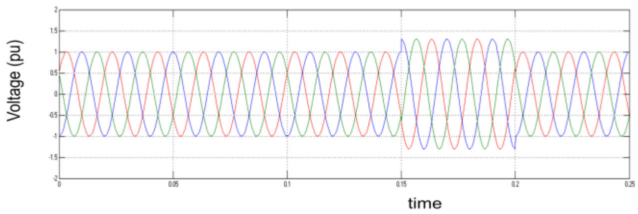


Fig. 12: voltage swell result

Voltage injected by DVR

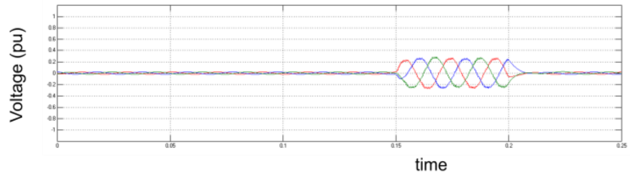


Fig. 13: Voltage injected by DVR

Load voltage waveform

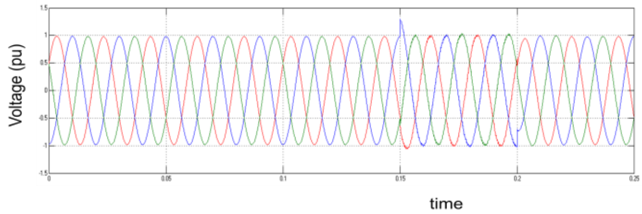


Fig. 14: Load voltage waveform

5. CONCLUSION

To detect voltage sag/swell using peak value of supply voltage makes the DVR to wait for a half cycle. RMS value and Peak value method isn't able to restore the phase angle. Synchronous reference frame detector quickly detects the voltage sag/swell and sends the enable signal to the inverter to mitigate the depressed voltage. DVR operates only during the abnormal conditions remains idle during normal operating conditions. DVR continuously and quickly regulate the load side voltage.

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