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Power Quality Improvement Using A DVR (Dynamic Voltage Restorer)

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***Abstract*—Power quality is one of major problems in the today's scenario. It has become important with the introduction of complex devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence developed as a nonstandard voltage, current or frequency that results in a failure of end use equipments. Some of the major problems dealt here is the power sag and swell. This paper describes the effectiveness of using dynamic voltage restorer (DVR) in order to mitigate voltage sags and swells in low voltage distribution systems. Dynamic Voltage Restorer can provide the most cost effective solution to mitigate voltage sags and swells that is required by customer. The Dynamic Voltage Restorer (DVR) is a rapid, flexible and resourceful solution to power quality problems.**

***Keywords*— DVR (Dynamic Voltage Restorer), Harmonic Elimination, Power Quality, Voltage Sag, Voltage Swell.**

I. INTRODUCTION

Power quality is of great importance in all modern environments where electricity is involved, power quality can be essentially influenced by an important factor like quality service. One of the major concerns in electricity industry today is power quality problems. Presently, most of the power quality problems are due to different fault conditions. These conditions cause voltage sag, voltage swell, transients, voltage interruption and harmonics. These problems may cause the apparatus tripping, shutdown commercial, domestic and industrial equipment, and miss process of drive system.

Dynamic voltage restorer (DVR) can provide the lucrative solution to mitigate voltage sag by establishing the appropriate voltage quality level, necessary. It is recently being used as the active solution for mitigation of power quality problems.

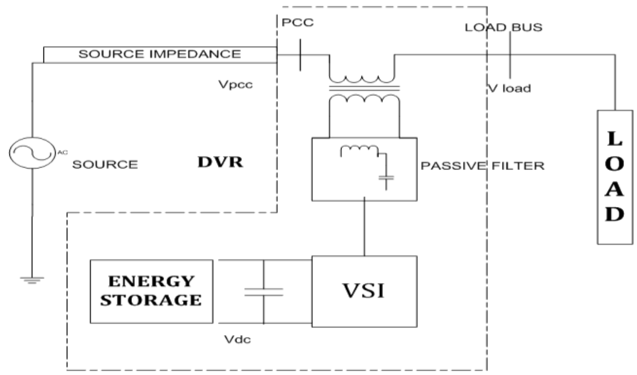

Fig. I. Basic Structure of A DVR

II. DVR (DYNAMIC VOLTAGE RESTORER)

The basic construction of a DVR is shown in Fig. I.

(i) *Energy Storage Unit:*

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.

(ii) *Capacitor:*

DVR has a large DC capacitor to ensure a proper DC voltage input to Inverter.

(iii) *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.

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(iv) *Passive 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.

(v) *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.

(vi) *Voltage Injection 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.

III. Power Quality Problems, Causes And Effects

The various power quality problems are as followed:

1. Transients- A transient is a temporary occurrence of a fault which is of a very short duration in a system caused by the sudden change of state.

2. Voltage sags- A voltage sag or voltage dip is a short duration reduction in rms voltage which can be caused by a short circuit, overload or starting of electric motors.

A voltage sag happens when the rms voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute

3. Voltage swells- Voltage swell, which is a momentary increase in voltage, happens when a heavy load turns off in a power system.

4. Voltage interruption- Interruptions are classified as short-duration or long-duration variation. The term "interruption" is often used to refer to short-duration interruption, while the latter is preceded by the word "sustained" to indicate a long-duration. They are measured and described by their duration since the voltage magnitude is always less than 10% of nominal.

5. Harmonics- Harmonics is the integral multiple of frequencies voltages and currents in an electric power system due to non linear loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems.

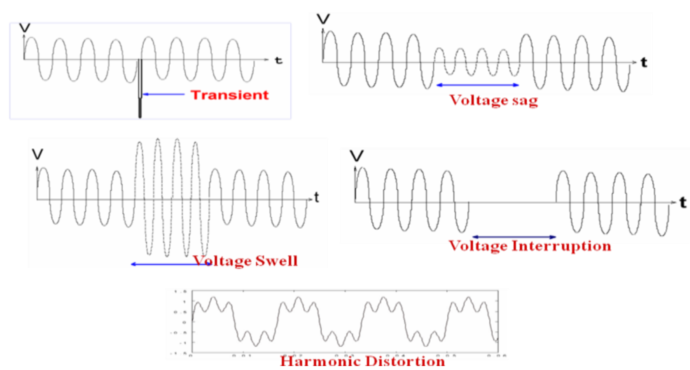

Fig. II. Power Quality Problems

Causes of Power Quality Problems:

- Transient – Due to Lightning, Turning major equipment on or off, back to back capacitor energization.
- Voltage Sags – Due to starting of large Motors, Energization of heavy loads, incorrect VAR compensation.
- Voltage Swells – Energizing a large capacitor bank, Switching off a large load, incorrect VAR compensation
- Interruption – Faults (Short circuit), Equipment failures, Control malfunctions (attempting to isolate electrical problem).

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- Harmonics – IT equipment, Variable frequency drives, Electro Magnetic Interference from appliances, fluorescent lighting, Arc Furnace (Any non linear load).

Effects of Power Quality Problems:

- Transient – Tripping, Processing error, Data loss, hardware reboot required, Component failure.
- Voltage Sags--Dim lights, Equipment shutdown, Data error, shrinking display screens, Memory loss.
- Voltage Swells –Bright lights, Data error, shrinking display screens, Memory loss.
- Interruption – Faults, Equipment failures, Control malfunctions
- Harmonics – Line current increases, Losses increase, transformer and neutral conductor heating leading to reduced equipment life span.

IV. DVR Operating States

1. During a voltage sag/swell on the line: The DVR injects the difference between the pre-sag and the sag voltage, by supplying the real power requirement from the energy storage device together with the reactive power. The maximum injection capability of the DVR is limited by the ratings of the DC energy storage and the voltage injection transformer ratio. In the case of three single-phase DVRs the magnitude of the injected voltage can be controlled individually. The injected voltages are made synchronized (i.e. same frequency and the phase angle) with the network voltages.

2. During the normal operation: As the network is working under normal condition the DVR is not injecting any voltages to the system. In that case, if the energy storage device is fully charged then the DVR operates in the standby mode or otherwise it operates in the self-charging mode. The energy storage device can be charged either from the power supply itself or from a different source.

3. During a short circuit or fault in the downstream of the distribution line: In this particular case the by-pass switch is activated to provide an alternate path for the fault currents. Hence the inverter is protected from the flow of high fault current through it, which can damage the sensitive power electronic components.

V. DVR Compensation Techniques

The compensation control technique of the DVR is the method used to track the supply voltage and synchronized that with the pre-sag supply voltage during a voltage sag/swell in the upstream of distribution line. Generally voltage sags are associated with a phase angle jump in addition to the magnitude change. Therefore the control technique adopted should be capable of compensating for voltage magnitude, phase shift and thus the wave shape. But depending on the sensitivity of the load connected downstream, the level of compensation of the above parameters can be altered. Basically the type of load connected influences the compensation strategy. For example, for a linear load, only magnitude compensation is required as linear loads are not sensitive to phase angle changes.

Further when deciding a suitable control technique for a particular load, the limitations of the voltage injection capability and the size of the energy storage device should be considered.

Compensation is achieved through real power and reactive power injection. Depending on the level of compensation required by the load, three types of compensation methods are defined and discussed below namely pre-sag compensation, in-phase compensation and energy optimization technique.

The circuit for a simple power system with a DVR is shown in Figure III below. The supply voltage, Load voltage, Load current and the voltage injected by the DVR are denoted by Vs , Vload , Iload and VDVR respectively.

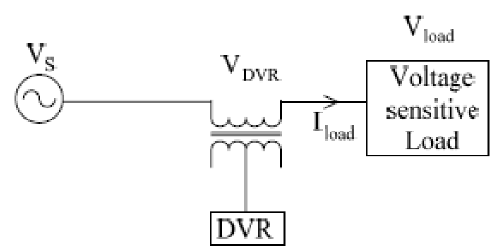

Fig III. Simple Power System Using a DVR

In a system under the normal condition, the supply voltage (Vs) is identified as pre-sag voltage and denoted by Vpre-sag. In such state since the DVR is not injecting any voltage to the system, load voltage (V_{load}) and the supply voltage will be alike.

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During the voltage sag, magnitude and the phase angle of the supply voltage can be altered and it is denoted by V_{sag}. The DVR is in functioning state in this case and the voltage injected will be VDVR. If the voltage sag is fully compensated by the DVR, the load voltage during the voltage sag will be Vpre-sag.

A) Pre-sag compensation:

This compensation approach is suggested for the non-linear loads (e.g.: thyristor controlled drives) which requires both the voltage magnitude as well as the phase angle to be compensated. In this technique the DVR supplies the difference between the pre-sag and the sag voltage, thus restore the voltage magnitude and the phase angle to that of the pre-sag value. Figure IV below describes the pre-sag compensation technique. However this technique needs a higher rated energy storage device and voltage injection transformers.

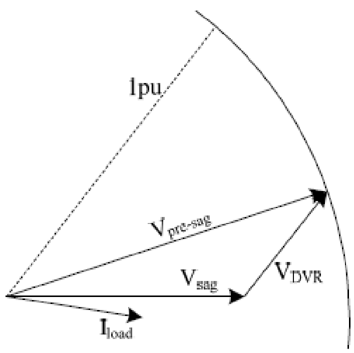

Fig. IV Pre Sag Compensation

B) In-phase compensation :

The DVR compensates only for the voltage magnitude in this particular compensation method, i.e. the compensated voltage is in-phase with the sagged voltage and only compensating for the voltage magnitude. Therefore this technique minimizes the voltage injected by the DVR. Hence it is recommended for the linear loads, which need not to be compensated for the phase angle. This particular compensation technique is shown in Figure V. It is clear from the Figure V. that there is a phase shift between the voltages before the sag and after the sag.

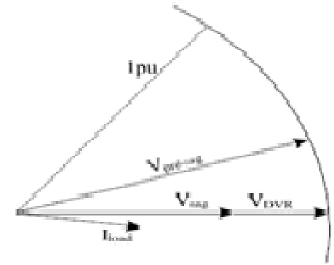

Fig. V. In Phase Compensation

C) Energy optimization technique

In this particular 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. Figure VI depicts the energy optimization technique. However in this technique the injected voltage will become higher than that of the in-phase compensation technique. Hence this technique needs a higher rated transformer and an inverter, compared with the earlier cases. Further the compensated voltage is equal in magnitude to the pre sag voltage, but with a phase shift.

The reactive power is generated by converting part of the real power supplied into reactive power (by the reactive components used for the DVR).

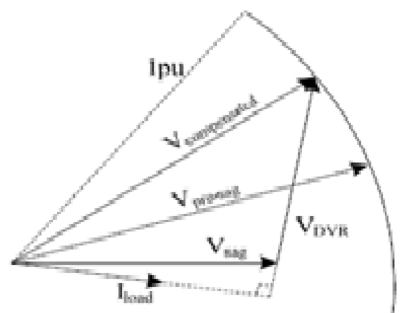

Fig. VI. Energy Optimization Technique

It is even possible to combine different compensation techniques described earlier, to achieve better efficiency and ease of controllability. One such technique is combining both the pre-sag and in-phase compensation method.

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In the combined technique the system initially restores the load voltage to the same phase and magnitude of the nominal pre-sag voltage (pre-sag compensation) and then gradually changes the injected voltage towards the sag voltage phasor. Ultimately the compensated voltage is in same magnitude and phase angle with the pre-sag voltage and slowly its phase angle transferred to to the sagged voltage.

VI. Control Techniques Used In Commercially Available DVRs

Most of the commercially available DVRs use either the in-phase compensation technique or energy optimization technique considering the minimum requirement of real power injection thereby reducing the capacity of the energy storage needed. In simple terms it detects the occurrence of voltage sag. Some common control techniques used by DVR manufacturers are described over here.

Irrespective of the compensation techniques used, there should be a method to track the phase angle and the magnitude of the supply voltage during normal operation and to detect the occurrence of voltage sag. In other words there should be a voltage sag detection technique. Following are the common voltage sag detection techniques described:

Voltage sag/swell detection techniques

(i) Fourier transforms

(ii) Phase Locked Loop (PLL)

(iii) Vector control (Software Phase Locked Loop –SPLL)

(iv) Peak value detection

(v) Applying the wavelet transform to each phase

Out of the techniques mentioned above only the Fourier transform, Vector control and wavelet transform methods provide both the voltage magnitude and phase shift information. PLL method can provide only the phase shift information while the peak value detection technique helps to get the magnitude change (voltage sag) information. Hence it is possible to combine one or more techniques mentioned above to obtain accurate voltage sag compensation.

1. Fourier Transform

By applying Fourier transform to each supply phase, it is possible to obtain the magnitude and phase of each of the frequency components of the supply. This is the advantage of this method compared with other sag detection techniques.

2. Phase Locked Loop

Generally the DVRs use Phase Locked Loop (PLL) to keep a track of the frequency and the phase angle of the healthy supply voltage, and thereby any change from the normal operating condition can easily be detected . Phase locked loop is a closed loop feedback control system, that generates a signal with the same frequency and the phase angle of the input signal. It consists of an oscillator which provides the output signal. The PLL can function as a phase detector, as a variable oscillator and as a feedback path. PLL responds to frequency changes and phase angle changes of the input signal by increasing or decreasing the frequency of the oscillator until it is matched with those of the reference input signal.

Simplified PLL is shown in Figure VII. Here the phase angle of the input signal is compared with the feedback output of the oscillator which produces an error signal which is generated in the form of voltage signal, proportional to the phase angle difference between the input and output. The output of the phase detector consists of harmonic components so it has to be passed through a low pass filter. But this filtering can introduce transient delays in detecting the voltage sags, which is disagreeable.

The loop filter controlled output voltage is fed to voltage controlled oscillator which provides phase output. This output signal is negatively feedback into the phase detector. The output of the oscillator is compared with the input and if the two frequencies differ with each other, the frequency of the oscillator is adjusted to match with the input frequency.

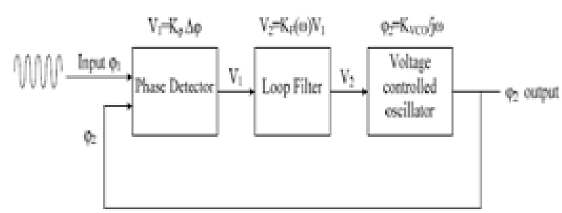

Fig. VII. PLL

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