Power Quality Improvement on Dynamic Voltage Restorer for Mitigation of Voltage Sag

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Abstract

Power Quality has become a major area of concern in present era due to increase in modern sensitive and sophisticated loads connected to the distribution system. This paper highlights voltage sag as one of a power quality issue and DVR is using for mitigation of voltage sag. One of the major problems dealt here is the voltage sag. To solve this problem, custom power devices are used. One of those devices is the DVR, which is most efficient and effective modern custom power device used in power distribution networks. This paper introduces power quality problems and total overview of DVR and mitigation of voltage sag so that young electrical engineers come to know about such a modern custom power device for power quality improvement in future era.

1. Introduction

Power Quality issues are of vital concern in most industries today, because of the increase in the number of loads sensitive to power disturbances. The power quality is an index to qualify of current and voltage available to industrial, commercial and household consumers of electricity. The problem regards both the utilities and customers. For the utilities, to provide adequate power quality is moving objective because of changes in user equipment and requirements. The power quality is concerned with deviations of the voltage from its ideal wave form (voltage quality) and deviations of the current from its ideal wave form (current quality).Such a deviation is called a "Power quality phenomenon" or a "power quality disturbance". Power quality phenomena can be divided in to two types , which need to be treated in a different way.

1. A characteristic of voltage or current (e.g., frequency or power factor) is never exactly equal to its nominal or desired value. The small deviations from the nominal or desired value are called "voltage variations" or "current variations". A property of any variation is that it has a value at any moment in time.

2. Occasionally the voltage or current deviates significantly from its normal or ideal wave shape. These sudden deviations are called "events".

This study introduce various power quality problems and basic concept of DVR (Dynamic Voltage Restorer).This study deals with overview of a Dynamic Voltage Restorer (DVR) for mitigation of voltage sags. Most common power quality problems are:

1. Voltage sag (or dip): A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0.5cycle to 1 minute.
Causes: Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors.

2. Very short Interruptions: Total interruption of electrical supply for duration from few milliseconds to one or two seconds.
Causes: Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.

3. Long interruptions: Total interruption of electrical supply for duration greater than 1 to 2 seconds.

Causes: Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines, fire, human error, bad coordination. **Consequences**: Stoppage of all equipment.

4. Voltage spike: Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

Causes: Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads.

5. Harmonic Distortion: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes: Classical sources: Electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors.

Modern sources: All non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

6. Voltage fluctuation: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.

Causes: Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.

Consequences: Most consequences are common to under voltage. The most perceptible consequence is the Flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

7. Noise*:* Superimposing of high frequency signals on the waveform of the power-system frequency.

Causes: Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.

8. Voltage Unbalance: A voltage variation in a three-phase system in which the three voltage magnitudes or the phase angle differences between them are not equal.

Causes: Large single-phase loads, incorrect distribution of all single phase loads by the three phases of the system.

2. DVR (Dynamic Voltage Restorer) :

A Dynamic voltage restorer is a power electronic converter based device that has been designed to protect critical loads from all supply-side disturbances other than outages. It is connected in series with a distribution feeder and is capable of generating or absorbing real and reactive power at its ac terminals. DVR developed in the early 1990's, with its excellent dynamic capabilities, when installed between the supply and a critical load feeder, can compensate for voltage sags, restoring line voltage to its nominal value with in a few milliseconds and hence avoiding any power disruption to that load. A power electronic converter based series compensator that can protect critical loads from all supply side disturbances other than outages is called a "Dynamic Voltage Restorer".

2.1 Principle And Operation Of DVR:

The basic principle of a DVR is simple by inserting a voltage of required magnitude and frequency, the DVR can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. DVR is connected in between the supply and the load. The main function of the DVR is to boost up the load side voltage so that load is free from any power disruption. Besides voltage sag compensation DVR also carry out other function's such as line voltage harmonic compensation, reduction of transients in voltage and fault current limitation.

2.2 Basic Configuration Of DVR:

Among the power quality problems like sag, swell, harmonic, transients etc, voltage sag i.e., sudden voltage dip is the most severe disturbance in power system, generally caused by faults. It last for duration ranging from

3 cycles to 30 cycles. Starting of large induction motors can also result in voltage sag as it draws a large amount of current during starting. In order to mitigate this problem DVR is one of the efficient and effective custom power devices. DVR injects voltage in to the system in order to compensate the voltage dip in the load side and maintains the load voltage at nominal magnitude. Power circuit and the control circuit are the two main parts of the DVR. There are various critical parameters of control signals such as magnitude, phase shift, frequency etc, which are injected by DVR. These parameters are derived by the control circuit. This injected voltage is generated by the switches in the power circuit based on the control signals.

2.3 DVR Components:

DVR is a solid state power electronic switching device which is connected in series to the power system. It comprises of the following components.

2.3.1 Energy Storage Device:

The purpose of the energy source is to supply the necessary energy to the VSI which will be converted to alternating quantity and fed to the injection transformer. Batteries are most commonly used and the capacity of the battery determine the duration of the sag which can be compensated by the DVR.

2.3.2 Inverter Circuit:

The Voltage Source Inverter (VSI) or simply the inverter converts the dc voltage from the energy storage unit (or the dc link) to a controllable three phase ac voltage. The inverter switches are normally fired using a sinusoidal Pulse Width Modulation (PWM) scheme.

Since the vast majority of voltage sags seen on utility systems are unbalanced, the VSI will often operate with unbalanced switching functions for the three phases, and must therefore treat each phase independently. Morever, sag on one phase may result in a swell on another phase, so the VSI must be capable of handling both sags and swells.

2.3.3 Filter Unit:

Non-linear characteristics of semiconductor devices cause distorted waveforms associated with high frequency harmonics at the inverter output. To overcome this problem and provide high quality energy supply, a harmonic filtering unit is used. These filters can be placed either in the inverter side as or in the line side.

2.3.4 Series Injection Transformer:

Three single phase injection transformers are used to inject the missing voltage to the system at the load bus. To integrate the injection transformer correctly in to the DVR, the MVA rating, the primary winding voltage and current ratings, the turn-ratio and the short-circuit impedance values of transformers are required. The existence of the transformers allow for the design of the DVR in a lower voltage level, depending upon the stepping up ratio.

3. Compensation Strategies:

Three compensation strategies are normally used for sag compensation.

A. Pre-sag Compensation:

The DVR injects the difference voltage between during-sag and pre-sag voltages to the system, the DVR must compensate for both magnitude and angle. It is the best solution to obtain the same load voltage as the pre-fault voltage and is best suited for loads sensitive to phase angle jumps like angle-triggered thyristor controlled loads. The method gives nearly undisturbed load voltage, but can often exhaust the rating of the DVR.

B. In-phase Compensation:

The generated DVR voltage is always in phase with the measured supply voltage regardless of the load current and pre-sag 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 is satisfied. In this configuration, the DVR is designed to compensate the voltage magnitude only. This method is suitable for loads that can withstand phase angle jumps.

C. Minimum (optimized) Energy Injection:

The third strategy is the minimum energy injection, which depends on maximizing the active power supplied by the network by minimizing the active power supplied by the compensator. This compensation is to fully utilize the energy storage; information about the load current is used to minimize the depletion of the energy storage.

4. Sag Detection Techniques:

A voltage sag detection technique detects the occurrence of the sag, the start point, the end point, sag depth and phase-shift. Common voltage sag detection techniques are as follows.

A. Peak value method:

The simplest method of monitoring the supply is to monitor the peak, or amplitude, of the supply voltage, then comparing it with a reference. A controller could be set to recognise if there is a difference greater than a specified value and switch in the inverter.

B. Root Mean Square (rms) method:

The start time of the sag can be defined as the first point of Vrms when drops below 0.9pu.To find the end time of the sag, search for an interval where Vrms drops below 0.9pu for at least half a cycle. The recovery time is then chosen as the first point in this interval.

C. Fourier Transform (FT):

The FT is achieved through orthogonal decomposition of power system signal. In general, a trigonometrically orthogonal function set or exponential orthogonal function set is utilized. By applying FT to each supply phase, it is possible to obtain the magnitude and phase of each of the frequency components of the supply waveform. For practical digital implementation Windowed Fast Fourier Transform (WFFT) is used, which can easily be implemented in real time control system. The only drawback of this method is that it takes one cycle to return the accurate information about the sag depth and its phase, since FT uses an averaging technique.

D. Space Vector Method:

The three phase voltages Vabc are transformed into a two dimension voltage Vdq, which in turn can be transferred into magnitude and angle. Any deviation in any quantity reveals the occurrence of an event. Comparing these quantities with reference ones will quantify the disturbance in the dq-frame, which had to be transformed back to the abc frame. This method has no time delay, yet requires complex controller.

5. Mitigation of voltage sag:

When a certain customer or installation suffers from voltage sags, a number of mitigation methods are available. These can be grouped as follows:

1. Reducing the number of events.
2. Improvements in the power system.
3. Mitigation at the interface between system and load.
4. Improving end-use equipment.

Reducing the number of faults tackles the problem at the source. It will not only reduce the number of voltage sags but, especially for distribution systems, also the number of interruptions and also costs could be very high. Improving the power system does not reduce the number of voltage sags, but it makes it severe. Another rather new solution is the very fast medium-voltage transfer switch. When a voltage sag occurs in the supply, the load is switched to the alternate supply. Using thyristors will give a transfer time less than one cycle where as using vacuum switches will take one or two cycles for the transfer. The transfer switch cannot mitigate sags that originate in the transmission system.

6. PROPOSED CONTROLLER FOR DVR:

DVR control strategy is based on in-phase compensation strategy, as it will be much simpler and hence, the controller and consequently the response time will be faster. It is worth mentioning that, although the proposed DVR does not compensate for the phase angles, it tracks them. A simple feed-forward controller acquires its voltage values from the source, with no feedback from the load, aiming at simple and fast response.

A. Sag Detector:

In this study, the FT technique is used. It requires at least one operating cycle to detect the sag start/end events. The DVR will not operate on small voltage variation events to keep the operational losses to a minimum. The output of the comparator determines the voltage required to be injected by the DVR, and is called the error signal.

B. Generation of the Compensating Voltage:

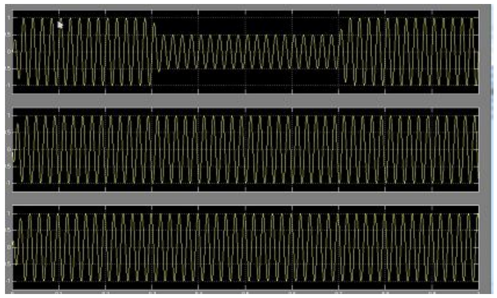
In the proposed DVR, a sinusoidal PWM scheme will be used. The inverter used in this study is a six-pulse inverter, the carrier waveform is a triangular wave with high frequency. The basic of PWM is to compare a sinusoidal control signal of normal 50 Hz frequency with modulating triangular pulses of higher frequency.

C. Injection of the compensating voltage:

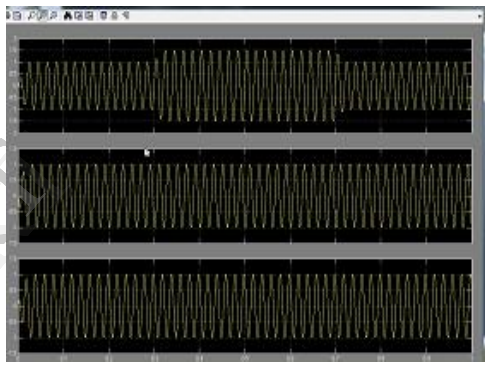
Once the error signal magnitude exceeds the tolerance for dynamic voltage variation, the circuit breakers close to connect the DVR in to the circuit via the injecting series transformers. In this study, a 10% over-compensation is introduced by the controller to counteract any drops.

7. Results

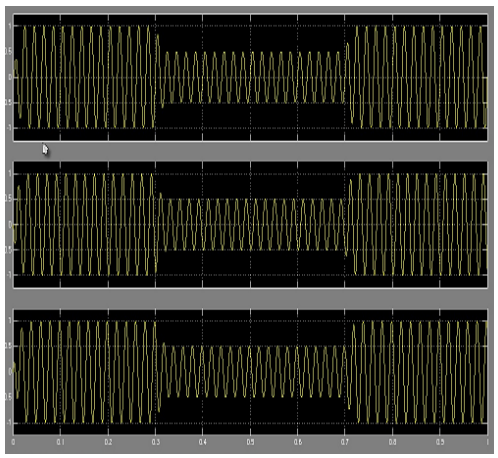
7.1 Voltage sag



7.2 Voltage swell



7.3 Three phase fault of voltage sag



Conclusion

The simulation results clearly showed the performance of the DVR in mitigating the voltage sag due to different fault conditions in distribution system effectively.DVR is one of the fast and effective custom power devices which has higher efficiency on voltage sag compensation .Hence this makes the DVR to be an interesting power quality improvement device.

Future Scope:

In future the multilevel concept of inverters will be a prominent choice for power electronic systems for medium voltage operation.

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