Modeling and Simulation of Dynamic Voltage Restorer (DVR) for Voltage Sag Mitigation (Outline)

By
Syed Khundmir T
Department of Electrical Engineering
University at Buffalo
Email: khundmir@buffalo.edu
Introduction

- Electrical power is one of the most dominant factors in our society.
- One major aspect is its **quality and stability**.
- Optimum power quality results in significant increase in **productivity, efficiency and profitability**.
- Power quality broadly encompasses the study of deviations in current and voltage waveforms from ideal sine waves.
POWER QUALITY PROBLEMS

A power quality problem can be defined as any deviation of magnitude, frequency or purity from the ideal sinusoidal voltage waveform.
There are two major reasons for the increased concern:

1. Newer-generation load equipment, with microprocessor-based controls and power electronic devices, is more sensitive to power quality variations than was equipment used in the past.

2. Many things are now interconnected in a network. Integrated processes mean that the failure of any component has much more important consequences.

   For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc.
Some of the power quality problems are:-

- Voltage sag
- Voltage swell
- Harmonic distortion
- Interruptions
- Transients
- Surges

Among all the problems, voltage sag and swell are most widespread power quality issue affecting distribution systems, especially industries, where involved losses can reach very high values. Short and shallow voltage sag can produce dropout of a whole industry.
**Voltage Sag**

**Definition:**

A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0.5 cycle to 1 minute.

In general, voltage sag is the origin of 10 to 90% power quality problems. The main causes of voltage sag are:-

- Heavy equipment being turned on.
- Starting large electrical motors.
- Switching power mains.
- Overloaded circuits.
VOLTAGE SAG MITIGATION TECHNIQUES

Presently, the most popular techniques to mitigate the effects of voltage sag are:-

- **Dynamic Voltage Restorer (DVR)**
- **Distribution Static Compensator (D-STATCOM)**

Among the two techniques mentioned above, DVR is relatively new technique and provides relatively better voltage regulation capabilities.

- A DVR injects a voltage in series with the system voltage and a D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption. It is observed that the capacity for power compensation and voltage regulation of DVR is better than D-STATCOM.
Dynamic Voltage Restorer (DVR)

- Dynamic Voltage Restorer (DVR) is the most efficient and effective modern custom power device used in power distribution networks.

- It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC).

- DVR is designed to protect sensitive equipments like Programmable Logic Controllers (PLCs), adjustable speed drives etc from voltage sag and swell.
FEATURES OF DVR

The important features of DVR are:

1. Lower cost, smaller size, and its fast dynamic response to the disturbance.
2. Ability to control active power flow.
3. Higher energy capacity and lower costs compared to the SMES device.
4. Less maintenance required.
LOCATION OF DVR

- The DVR is located at the distribution side of the power system and helps in the mitigation of voltage sag.
**PRINCIPLE**

- The basic principle of the DVR is to inject a voltage of required magnitude and frequency, so that it can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted.
A Dynamic Voltage Restorer is basically controlled voltage source converter that is connected in series with the network. It injects a voltage on the system to compensate any disturbance affecting the load voltage.

A basic block diagram for open loop DVR is shown in fig 1:-
Circuit Analysis

Consider the schematic diagram shown in the above fig 2. By using KVL

\[ V_{th} - Z_{th} I_L + V_{DVR} = V_L \]

\[ \Rightarrow V_{DVR} + V_{th} = V_L + Z_{th} I_L \]
MATHEMATICAL EQUATIONS

Therefore, the series injected voltage of the DVR can be written as

\[ V_{DVR} = V_L + Z_{th} I_L - V_{th} \]

Here,

- \( V_{th} \) = system supply voltage (Thevenin voltage)
- \( V_L \) = load bus voltage
- \( Z_{th} \) = system impedance (Thevenin impedance)
- \( I_L \) = load current

The load power factor angle is given by

\[ \phi = \tan^{-1}\left(\frac{Q_L}{P_L}\right). \]
CONFIGURATION OF DVR

The main components of the DVR are the units mentioned below:-

1. An Injection/ Booster transformer
2. A Harmonic filter
3. Storage Devices
4. A Voltage Source Converter (VSC)
5. A Control and Protection system
**INJECTION TRANSFORMER**

The Injection transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are:

1. It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.

2. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).
HARMONIC FILTER

• The nonlinear 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.

• This can cause voltage drop and phase shift in the fundamental component of the inverter output and has to be accounted for in the compensation voltage.
Storage Devices

- The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages.
- The different kinds of energy storage devices are Superconductive Magnetic Energy Storage (SMES), batteries and capacitance.
IMPORTANCE OF ENERGY STORAGE UNITS

During a voltage sag, the DVR injects a voltage to restore the load supply voltages. It needs a source for this energy.

Two types of system are considered; one using stored energy to supply the delivered power as shown in Fig. (i), and the other having no internal energy storage, where energy is taken from the incoming supply through a shunt converter as shown in Fig. (ii).
**Voltage Source Converter**

- A VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle.
- In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing.
- Depending on the method in which DVR takes the input; the Voltage Source Converter works as either inverter or rectifier as well as inverter.
CONTROL AND PROTECTION

- The control mechanism of the general configuration typically consists of hardware with programmable logic.

- All protective functions of the DVR should be implemented in the software.

- The performance of DVR is directly affected by the control strategy of inverter.
OPERATING MODES

The DVR has three modes of operation which are:

1. Protection mode
2. Standby mode
3. Injection/boost mode.

- **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 and supplying another path for current.
Contd....

- **Standby mode**:
  - 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.
**Injection/Boost Mode**:- 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.

- Due to switching ON of heavy equipment, starting large electrical motors, switching power mains or overloaded circuits; voltage sag occurs and reduces the voltage reaching at the load.
- In such case, the DVR is operated in **injection mode** by injecting the voltage difference between source voltage and load voltage at the point of common coupling.
VOLTAGE INJECTION METHODS

There are mainly two different methods of DVR voltage injection which are

- **Pre-sag compensation method:**
  - Compensation of voltage sags in the both phase angle and amplitude sensitive loads would be achieved by pre-sag compensation method.

- **In-phase compensation method:**
  - 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.
Pre-Sag compensation technique

where, \[ V_{DVR} = V_{prefault} - V_{sag} \]
\[ \Theta_{DVR} = \tan^{-1} \left[ \frac{V_L \sin \theta_L}{(V_L \cos \theta_L - V_s \cos \theta_s)} \right] \]
One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies.
REFERENCES


Conclusion
Thank you!