Unit.2-Voltage Sag

D. Maharajan Ph.D
Assistant Professor
Department of Electrical and Electronics Engg.,
SRM University,
Chennai-203
Unit-2: Voltage Sag

Topics:

- Magnitude & duration of sag, phase angle jump
- Effect of sag on computer and consumer electronics
Voltage sag

- According to IEEE 1159 (1995) std., sag magnitude range from 10% to 90% of nominal voltage and sag duration from half-cycle to 1 min.
Classification of Voltage sag

<table>
<thead>
<tr>
<th>Type of Sag</th>
<th>Duration</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous</td>
<td>0.5 - 30 cycles</td>
<td>0.1 - 0.9 pu</td>
</tr>
<tr>
<td>Momentary</td>
<td>30 cycles - 3 s</td>
<td>0.1 - 0.9 pu</td>
</tr>
<tr>
<td>Temporary</td>
<td>3 s - 1 min</td>
<td>0.1 - 0.9 pu</td>
</tr>
</tbody>
</table>
Characteristics of Voltage Sag

- Magnitude of the Sag
- Duration of the Sag
- Balanced or Unbalanced
- Phase-angle Jump
- Missing voltage
- Point at which sag initiated
Estimate the Voltage Sag Magnitude
Voltage Sag Magnitude—one cycle window

- The magnitude of voltage sag determined from rms voltage. The rms voltage calculated over a one cycle sliding window.

\[ V_{\text{rms}}(k) = \sqrt{\frac{1}{N} \sum_{i=k-N+1}^{i=k} v(i)^2} \]

Where
N- is number of samples per cycle,
v(i) - the sampled voltage in time domain.
Voltage Sag Magnitude

• This is due to the finite length of the window used to calculate the rms value.
• rms value during the sag is not completely constant and that the voltage does not immediately recover after the fault.
• There are various ways of obtaining the sag magnitude from the rms voltages.
• Most power quality monitors take the lowest value obtained during the event. As sags normally have a constant rms value during the deep part of the sag, using the lowest value is an acceptable approximation.
Voltage sag Magnitude

• Alternatively, estimate the rms value using only half cycle of instantaneous values. This algorithm is called half cycle window

\[ V_{rms(1/2)}(k) = \sqrt{\frac{2}{N} \sum_{i=k-(N/2)+1}^{k} v_i^2} \]

• It is very sensitive to changes in the voltage and has a faster response to detect an event.
Voltage Sag Duration

• The moment the short circuit fault is cleared by the protection, the voltage starts to return to its original value.

• The duration of a sag is thus determined by the fault-clearing time.

• However, the actual duration of a sag is normally longer than the fault-clearing time.
Voltage Sag Duration

• Measurement of sag duration is less trivial than it might appear.
• From a recording the sag duration may be obvious, but to come up with an automatic way for a power quality monitor to obtain the sag duration is no longer straightforward.
• The commonly used definition of sag duration is the number of cycles during which the rms voltage is below a given threshold.
• This threshold will be somewhat different for each monitor but typical values are around 90% of the nominal voltage.
• A power quality monitor will typically calculate the rms value once every cycle.
Voltage Sag Duration

• The main problem is that the so-called post-fault sag will affect the sag duration.

• When the fault is cleared, the voltage does not recover immediately. This is mainly due to the reenergizing and reacceleration of induction motor load (Bollen, 1995).

• This post-fault sag can last several seconds, much longer than the actual sag. Therefore, the sag duration as defined before, is no longer equal to the fault clearing time.

• More seriously, different power quality monitors will give different values for the sag duration. As the rms voltage recovers slowly, a small difference in threshold setting may already lead to a serious difference in recorded sag duration (Bollen, 1999).
Voltage Sag Duration

• Faults in transmission systems are cleared faster than faults in distribution systems. In transmission systems, the critical fault-clearing time is rather small.

• Thus, fast protection and fast circuit breakers are essential. Also, transmission and sub-transmission systems are normally operated as a grid, requiring distance protection or differential protection, both of which allow for fast clearing of the fault.
Voltage Sag Duration

• The principal form of protection in distribution systems is over current protection. This requires a certain amount of time-grading, which increases the fault-clearing time. An exception is formed by systems in which current-limiting fuses are used.
Voltage Sag Duration

• These have the ability to clear a fault within one half-cycle. In overhead distribution systems, the instantaneous trip of the recloser will lead to a short sag duration, but the clearing of a permanent fault will give a sag of much longer duration.

• The so-called magnitude-duration plot is a common tool used to show the quality of supply at a certain location or the average quality of supply of a number of locations.
Phase angle jump

• A short circuit in a power system not only cause a voltage sag, but also a change in the phase angle of the voltage.

• This sudden change in phase angle is called a “phase-angle jump.” The phase-angle jump is visible in a time-domain plot of the sag as a shift in voltage zero-crossing between the pre-event and the during-event voltage.
Phase angle jump

• If source and feeder impedance have equal X/R ratio, there will be no phase-angle jump in the voltage at the PCC. This is the case for faults in transmission systems, but normally not for faults in distribution systems.

• The distribution systems may have phase-angle jumps up to a few tens of degrees (Bollen, 1999; Bollen et al., 1996).

• For unsymmetrical faults, the analysis becomes much more complicated.

• A consequence of unsymmetrical faults (single-phase, phase-to-phase, two-phase-to-ground) is that single-phase load experiences a phase-angle jump even for equal X= R ratio of feeder and source impedance (Bollen, 1999; Bollen, 1997).
Finding the phase-angle jump

- From the measured voltage wave shape, the phase angle of the voltage during the event must be compared with the phase angle of the voltage before the event.
- The phase angle of the voltage can be obtained from the voltage zero-crossings or from the argument of the fundamental component of the voltage.
- The fundamental component can be obtained by using a discrete Fourier transform algorithm.
Finding the phase-angle jump

• In case there is no change in voltage magnitude or phase angle, the fundamental component as a function of time is found from:

\[ V_1(t) = V_1(0)e^{j\omega t} \]

• The phase-angle jump, as a function of time, is the difference in phase angle between the actual fundamental component and the “synchronous voltage”

\[ \phi(t) = \arg\{V_1(t)\} - \arg\{V_1(0)e^{j\omega t}\} = \arg\left\{\frac{V_1(t)}{V_1(0)}e^{-j\omega t}\right\} \]
Effect of Voltage Sag on Sensitive Equipment

- Reduced equipment operating life.
- Instantaneous equipment malfunction
- Equipment malfunction to data corruption.
- Reduced process quality
- Process stoppage
- Equipment damage
- Economic damage to operators
- Safety issues
Effect of voltage sag on computer

• The power supply to a computer, process-control equipment, consumer electronics, etc. consists of a single-phase (four-pulse) rectifier together with a capacitor and a DC-DC converter.

• During normal operation the capacitor is charged twice a cycle through the diodes. The result is a DC voltage ripple:

\[ \varepsilon = \frac{PT}{2V_0^2C} \]
Power supply of single phase equipment for computer
Effect of voltage sag on computer

• with $P$ the DC bus active-power load, $T$ one cycle of the power frequency, $V_{o_{\text{max}}}$ DC bus voltage, and $C$ size of the capacitor.

• During a voltage sag or interruption, the capacitor continues to discharge until the DC bus voltage has dropped below the peak of the supply voltage. A new steady state is reached, but at a lower DC bus voltage and with a larger ripple.
Effect of voltage sag on computer

• The resulting DC bus voltage for a sag down to 50%, together with the absolute value of the supply voltage. If the new steady state is below the minimum operating voltage of the DC-DC converter, or below a certain protection setting, the equipment will trip.

• During the decaying DC bus voltage, the capacitor voltage $V(t)$ can be obtained from the law of conservation of energy:

$$\frac{1}{2} CV^2 = \frac{1}{2} CV_0^2 - Pt$$
Effect of voltage sag on computer

\[ V(t) = \sqrt{V_0^2 - \frac{2P}{C} t} \]

\[ V(t) = V_0 \sqrt{1 - 4\varepsilon \frac{t}{T}} \]

\[ t_{\text{max}} = \frac{1 - \left( \frac{V_{\text{min}}}{V_0} \right)^2}{4\varepsilon} T \]

The larger the DC ripple in normal operation, the faster the drop in DC bus voltage during a sag. From above equation the maximum duration of zero voltage \( t_{\text{max}} \) is calculated for a minimum operating voltage \( V_{\text{min}} \).
References

• **Understanding Power Quality Problems: Voltage Sags and Interruptions** by Math H. Bollen

• **Effects of Voltage Sags on Loads in a Distribution System** - George G. Karady, Project Leader, Saurabh Saksena, Graduate Student, Arizona State University, Baozhuang Shi, Philips Research Group, China, Nilanjan Senroy, Graduate Student, Arizona State University, PSERC Publication 05-63, Final Project Report