Voltage Dip Immunity of Equipment and Installations

TUTORIAL

Voltage Dip Characteristics

(Part 2)
A Typical Voltage Dip

![Graph showing voltage dip over time](image)

- **Voltage**: [kV]
- **Time**: [Cycles]
Voltage Magnitude (rms) vs Time

![Graph showing voltage magnitude over time with cycles on the x-axis and voltage in kV on the y-axis. The graph displays multiple curves that show variations in voltage.](image)
IEC 61000-4-30

- **Dip threshold** (usually 90% of $U_N$)

- **Duration**

- **Residual voltage**
IEC 61000-4-30

- The voltage waveform should be obtained in three channels (phase-to-ground, phase-to-neutral or phase-to-phase voltages)
- The one-cycle rms voltage is calculated every half-cycle in every channel
- A voltage dip threshold is defined, typically 90% of the nominal voltage
- The *duration* is the time during which the voltage is below the threshold in at least one of the channels
- The *residual voltage* is the lowest rms voltage in any of the channels during the event
A Less Typical, but Not Uncommon Voltage Dip
A Not So Common, but Still Realistic Voltage Dip
Beyond IEC 61000-4-30

- There is more to voltage dips than one voltage magnitude and one duration value
- Main contributions of JWG C4.110
  - Classification of dips into three types in a three-phase system
  - Voltage-dip segmentation for dip description and characterisation
- Additional dip characteristics
  - Point-on-wave
  - Phase-angle jump
  - Voltage recovery
Voltage Dips in Three-phase Systems

![Graphs showing voltage dips over time]
Classification proposed by JWG C4.110

Type I

Type II

Type III
Classification Proposed by JWG C4.110

**Type I**

- **Networks \ Type**
  - MV and HV: 27%
  - LV: 64%

**Type II**

- **Networks \ Type**
  - MV and HV: 53%
  - LV: 25%

**Type III**

- **Networks \ Type**
  - MV and HV: 20%
  - LV: 11%

*Table 6-5 Overall distribution of voltage dips types.*
The Classification in Words

- **Type I**: A major drop in magnitude of one of the three phase-to-ground voltages, and no drop, or a much lesser drop in the other two.
- **Type II**: A major drop in magnitude of two of the three phase-to-ground voltages, and no drop, or a much lesser drop in one.
- **Type III**: An almost identical drop in magnitude in all three phase-to-ground voltages.
Read the Report to Find Out

- How to know the dip type from the voltage waveforms.
- How to know the dip types from the rms voltages.
Dip Segmentation Method

- Pre-event segment
- Event segment
- Recovery segment
- Transition segments
In Words:

- The ”Transition Segment” is where the voltage suddenly changes in magnitude
  - Signal processing: the signal is non-stationary; advanced detection methods use this property.

- The ”Event Segments” are the periods between the transition segments
  - Signal processing: the signal is quasi-stationary
  - Power systems: we can use our normal tools like rms, FFT and symmetrical components
Different Transition Segments

- **Dips with only one transition segment (switching events):**
  - Motor starting
  - Transformer energizing
  - Capacitor switching (very short duration)

- **Dips with two transition segments:**
  - Short-circuit faults with successful clearing

- **Dips with three (more) transition segments:**
  - Developing short-circuit faults or cleared by different circuit breakers
Dips with One Transition Segment: Motor Starting
Dips with One Transition Segment: Transformer Energizing
Dip with Three Transition Segments
Characterization of Voltage Dips

- Number of transition segments
- Time between transition segments
- Pre-event segment: rms voltage, distortion, unbalance
  - Using e.g. IEC 61000-4-30 3-sec values
- During-event segments: dip type, residual voltage, phase angle, etc.
- Recovery segment: unbalance, time to recover, phase shift, etc.
## Characterization of Voltage Dips

**Checklist**

<table>
<thead>
<tr>
<th>Dip Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-event segment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Characteristics of the pre-event segment</strong></td>
<td>The actual or expected values of the pre-event voltage magnitudes, voltage phase angles, harmonics and other waveform distortions, voltage magnitude/phase angle unbalances and frequency variations.</td>
</tr>
<tr>
<td><strong>During-event segment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Dip magnitude</strong></td>
<td>Quantifies the reduction in voltage magnitude below the “dip magnitude threshold”, usually expressed as a root mean square (rms) value of the measured or calculated instantaneous voltage in any of the affected input voltage channels.</td>
</tr>
<tr>
<td><strong>Dip duration</strong></td>
<td>The time for which a reduction in voltage magnitude that is qualified as a voltage dip is present in a single voltage channel (per-phase/per-channel dip duration), or in at least one of the affected voltage channels (the total dip duration).</td>
</tr>
<tr>
<td><strong>Dip shape</strong></td>
<td>Dips with the constant during-event rms voltage magnitudes are rectangular dips, while non-rectangular dips have variable rms voltage magnitude.</td>
</tr>
<tr>
<td><strong>Dip voltage magnitude unbalance</strong></td>
<td>In case of polyphase dip events, voltage magnitudes in different channels are typically different.</td>
</tr>
<tr>
<td><strong>Dip phase shift (phase-angle jump)</strong></td>
<td>Change of during-dip voltage magnitudes is often associated with a change in corresponding voltage phase angles. In case of polyphase dips, voltage channels with different voltage magnitudes will typically have different phase shifts.</td>
</tr>
<tr>
<td><strong>Dip phase angle unbalance</strong></td>
<td>For polyphase dips with different voltage magnitudes and/or different phase shifts in different channels, during-dip voltages will also experience voltage phase angle unbalance.</td>
</tr>
<tr>
<td><strong>Dip waveform distortion and transients</strong></td>
<td>Dips due to transformer energising are associated with a high level of harmonic distortion, while some dips have high-frequency transients imposed to the fundamental component of the during-dip instantaneous voltage.</td>
</tr>
<tr>
<td>Transition segment</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Dip initiation</strong></td>
<td>The first transition segment marks the instant of dip initiation (i.e. the transition from pre-dip voltage to during-dip voltage), manifested as a sudden drop in voltage magnitude at the start of the dip.</td>
</tr>
<tr>
<td><strong>Point-on-wave of dip initiation</strong></td>
<td>Phase angle of the instantaneous pre-dip voltage waveform at which (main) transition from pre-dip voltage to during-dip voltage is initiated.</td>
</tr>
<tr>
<td><strong>Phase shift at the dip initiation</strong></td>
<td>The majority of fault-caused voltage dips are associated with a change in voltage phase angles. Accordingly, sudden drop in voltage at the start of the dip event is usually accompanied by a distinctive shift/jump in corresponding phase angle.</td>
</tr>
<tr>
<td><strong>Multistage dip initiation</strong></td>
<td>At the dip initiation, the drop in voltage magnitude in affected channels may take place in several steps due to e.g. developing faults. The corresponding multiple stages may occur at a sub-cycle time scale, or at a time scale of several seconds.</td>
</tr>
<tr>
<td><strong>Dip ending</strong></td>
<td>The last transition segment marks the instant at which underlying cause of the dip is cleared, manifested as a sudden voltage rise. It is followed by a voltage recovery segment, during which voltage may be still below the dip magnitude threshold.</td>
</tr>
<tr>
<td><strong>Point-on-wave of dip ending</strong></td>
<td>Phase angle of the post-dip instantaneous voltage waveform at which (main) transition from during-dip voltage to post-dip voltage is finished.</td>
</tr>
<tr>
<td><strong>Phase shift at the dip ending</strong></td>
<td>Sudden rise in voltage at the end of the dip event is usually accompanied by a distinctive shift/jump in corresponding phase angle, which usually cancels all the changes in phase angles in affected channels, except for the post-dip phase shift.</td>
</tr>
<tr>
<td><strong>Multistage dip ending</strong></td>
<td>The voltage magnitude rise at the end of fault-caused dips may take place in several steps due to e.g. difference in circuit breaker opening instants in different phases or at different network locations. The corresponding multiple stages may occur at a sub-cycle time scale, or at a time scale of up to one second.</td>
</tr>
<tr>
<td><strong>Rate-of-change of voltage</strong></td>
<td>The transition from one steady state to another steady state (or from one quasi-steady state to another quasi-steady state) takes place with a certain speed. Corresponding temporal change of voltage is denoted as the rate-of-change.</td>
</tr>
<tr>
<td><strong>Damped oscillations</strong></td>
<td>Transition segments are often associated with damped oscillations, whose frequency of oscillation and damping time constant depend on the location/type of the fault and characteristics of system load and generation.</td>
</tr>
</tbody>
</table>
## Characterization of Voltage Dips Checklist

<table>
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<tr>
<th>Voltage recovery (post-event) segment</th>
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<td><strong>Voltage recovery</strong></td>
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<tr>
<td><strong>Post-fault dip (prolonged voltage recovery)</strong></td>
</tr>
<tr>
<td><strong>Post-dip phase shift</strong></td>
</tr>
<tr>
<td><strong>Multiple dip events (dip sequences)</strong></td>
</tr>
<tr>
<td><strong>Composite dip events</strong></td>
</tr>
</tbody>
</table>
Read the Report to

- Find out more about how dip characteristics change when propagating through the power system
- Learn more about characteristics for event segments
- Read a discussion on characteristics for transition segments
Summary of Voltage Dip Characteristics

- A detailed list of voltage dip characteristics, without commenting on their importance
- The aim is to act as a check-list that equipment designers and manufacturers can use in a very early stage of the design of power electronic equipment
- The list is also used as a basis for the discussions on equipment testing
Conclusions

- Voltage dip duration and residual voltage are used in IEC 61000-4-30, but that is not enough.
- Three types of dips are to be distinguished in a three-phase system:
  - To be included in statistics on voltage dips.
- Voltage-dip segmentation
  - As a method to characterize dips in more detail
  - As a basis to define more characteristics
- Checklist of voltage-dip characteristics
  - To help in capturing the complexity of voltage dips
The report can be obtained in electronic format for free from: www.uiie.org;
a hardcopy can be purchased from www.e-cigre.org

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