The Regulatory View on Voltage Dip Immunity

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- Regulators’ focus and concern
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NVE

• The Norwegian Water Resources and Energy Directorate (NVE) is subordinated to the Ministry of Petroleum and Energy, and is responsible for the administration of Norway's water and energy resources.

• One of NVE's main functions is to promote an efficient energy market and cost-effective energy system.
  – The quality of supply in the transmission / distribution networks is an important issue for NVE.
  – NVE has set requirements for quality of supply for all parties connected to the power system and the TSO.
European Energy Regulators

• CEER – Council of European Energy Regulators
  – The overall aim is to facilitate the creation of a single, competitive, efficient and sustainable internal market for gas and electricity in Europe.

• ERGEG – European Regulators’ Group for Electricity and Gas
  – ERGEG is an advisory group of independent national regulatory authorities to assist the European Commission in consolidating the Internal Market for electricity and gas.
Stakeholders’ general view

- What to be defined as satisfactory level of quality of supply may differ between various stakeholders, including:
  - Distribution and transmission system operators
  - End-users
  - Equipment manufacturers
  - Regulator
    - Aims at ensuring a quality that is beneficial for the society as a whole
    - Take into account all public and private interests
Voltage disturbances

- **Voltage frequency**
- **Voltage RMS value**
  - Supply voltage variations
  - Voltage dips
  - Voltage swells
  - Rapid voltage changes
  - Voltage fluctuations (flicker)
- **Voltage wave form**
  - Harmonic voltages
  - Interharmonic voltages, subharmonic voltages
  - Transient overvoltages
  - Signal voltages superimposed on the supply voltage

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Regulation of voltage dips in Europe

<table>
<thead>
<tr>
<th>Voltage characteristics in EN 50160</th>
<th>Countries with a different regulation or standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage variations</td>
<td>ES, FR*, HU, NO (only for LV customers), PT (only for EHV-HV customers)</td>
</tr>
<tr>
<td>Flicker</td>
<td>NO (requirements for both $P_{st}$ and $P_{lt}$), PT (only for EHV-HV customers), NL (maximum limit for $P_{lt}$)</td>
</tr>
<tr>
<td>Voltage dips</td>
<td>NO, FR* (customised engagement on request only for MV and HV customers)</td>
</tr>
<tr>
<td>Voltage swells</td>
<td>NO, FR*</td>
</tr>
<tr>
<td>Transient overvoltages</td>
<td>FR*</td>
</tr>
<tr>
<td>Voltage unbalance</td>
<td>FR*, NO, NL</td>
</tr>
<tr>
<td>Harmonic voltage</td>
<td>FR*, NO, PT (only for EHV-HV customers), NL (maximum limit for THD, 5th and 7th harmonic)</td>
</tr>
<tr>
<td>Interharmonic voltage</td>
<td>None</td>
</tr>
<tr>
<td>Mains signalling voltage</td>
<td>None</td>
</tr>
<tr>
<td>Single rapid voltage changes</td>
<td>NO</td>
</tr>
</tbody>
</table>

(*) In France the voltage quality limits are set in the contracts between the customer and the distribution/transmission operator; the regulator surveys the contracts but does not set standards.
Slow vs fast variations

Source: SINTEF Energy Research, Norway
Costs due to voltage dips

• **Norway, 2002 (inhabitants, ca 4.8 M):**
  – Estimated annual costs due to dips for end-users to be between 170 and 330 MNOK

• **Sweden, 2003 (inhabitants, ca 9 M)**
  – Estimated annual costs for industrial customers due to dips and interruptions at about 157 M€

• **Italy, 2006 (inhabitants, ca 58 M)**
  – Estimated annual costs due to dips and interruptions (< 1 sec) for the whole production system to be between 465 and 780 M€

  – *Ref: CEER 4th Benchmarking Report on Quality of Electricity Supply*
### Monitoring of voltage dips in Europe

<table>
<thead>
<tr>
<th>Voltage disturbance</th>
<th>Belgium</th>
<th>Czech Republic</th>
<th>France</th>
<th>Greece</th>
<th>Hungary</th>
<th>Italy</th>
<th>the Netherlands</th>
<th>Norway</th>
<th>Portugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power frequency (1)</td>
<td>HV</td>
<td>HV</td>
<td>HV, HV</td>
<td>HV, HV</td>
<td>LV</td>
<td>EHV, HV</td>
<td>All</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Supply voltage variations</td>
<td>HV, MV</td>
<td>HV</td>
<td>HV, MV</td>
<td>HV, MV</td>
<td>LV</td>
<td>EHV, HV</td>
<td>All</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Single rapid voltage changes</td>
<td>HV</td>
<td>LV</td>
<td>LV</td>
<td>LV</td>
<td>EHV, HV</td>
<td>All</td>
<td>EHV, HV</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>Flicker</td>
<td>HV, MV</td>
<td>HV</td>
<td>HV, HV</td>
<td>HV, HV</td>
<td>LV</td>
<td>EHV, HV</td>
<td>All</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Voltage unbalance</td>
<td>HV</td>
<td>HV</td>
<td>HV, HV</td>
<td>HV, HV</td>
<td>LV, LV</td>
<td>EHV, HV</td>
<td>All</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Harmonic voltages</td>
<td>HV, MV</td>
<td>HV</td>
<td>HV, HV</td>
<td>HV, HV</td>
<td>LV, LV</td>
<td>EHV, HV</td>
<td>All</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Voltage dips</td>
<td>HV</td>
<td>HV</td>
<td>HV, MV</td>
<td>HV, MV</td>
<td>LV</td>
<td>EHV, HV</td>
<td>All</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Voltage swells</td>
<td>HV</td>
<td>HV</td>
<td>MV</td>
<td>LV</td>
<td>LV</td>
<td>EHV, HV</td>
<td>EHV, HV</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Transient overvoltages</td>
<td>HV</td>
<td>LV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interharmonic voltages</td>
<td>HV</td>
<td>LV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mains signalling voltages</td>
<td>HV</td>
<td>LV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) In all countries the power frequency is monitored and managed by the interconnected European transmission system operators and international system operation agreements. This table only refers to what is monitored by voltage quality instruments in place for continuous monitoring.
CEER/ERGEG view

ERGEG Public Consultation Paper, ref E06-EQS-09-03

Recommendations to CENELEC for improving EN 50160

• Improve definitions and measurement rules
• Limits for voltage variations
  – avoid “95%-of-time” clause
  – avoid long time intervals for averaging measured values
• Enlarge the scope to HV and EHV
• Avoid ambiguous indicative values for voltage events
  – Classification of voltage dip/swell severity
• Consider duties and rights for all parties involved
• Introduce limits for voltage events according to network characteristics
• Develop the concept of power quality contracts
CEER/ERGEG view

ERGEG Conclusions Paper ref E07-EQS-15-03

A “road map” for the revision of EN 50160, inter alia:

• Restates the principles given in the public consultation paper

• ERGEG considers that the structure of the revised EN 50160 should be adaptable to the differences among the European countries. The rationale of the future EN 50160 could be:

  – to give homogeneous “responsibility-sharing curves” (or “indicative compatibility curves”) between network operators and customers, especially for voltage dips and swells, in order to allow a homogenous usage of electrical products all over Europe;

  – more ---
Compatibility curve - principal

Equipment is immune to voltage dips

Number of events is regulated

Hypothetical curve for responsibility sharing.
Source: Prof. Math Bollen, CEER workshop on Voltage quality standards, Milan September 29th 2006
Revised CENELEC standard EN 50160

Table 2 - Classification of dips according to residual voltage and duration

<table>
<thead>
<tr>
<th>Residual voltage $u$ [%]</th>
<th>Duration $t$ [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$10 \leq t \leq 200$</td>
</tr>
<tr>
<td>$90 &gt; u \geq 80$</td>
<td>CELL A1</td>
</tr>
<tr>
<td>$80 &gt; u \geq 70$</td>
<td>CELL B1</td>
</tr>
<tr>
<td>$70 &gt; u \geq 40$</td>
<td>CELL C1</td>
</tr>
<tr>
<td>$40 &gt; u \geq 5$</td>
<td>CELL D1</td>
</tr>
<tr>
<td>$5 &gt; u$</td>
<td>CELL X1</td>
</tr>
</tbody>
</table>

Green – Class 2 test, c.f. revised EN 50160 Annex B (IEC 61000-4-11)

Yellow – Class 3 test, c.f. revised EN 50160 Annex B (IEC 61000-4-11)

Red – Non equipment tested for?

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Regulatory aspects

- Should limits be differentiated on:
  - Voltage levels
  - Network characteristics
  - Load density
  - Classification of events
  - Causes
  - ???

- Cost-efficient solutions,
  - i.e. what causes can be handled
  - When introduce measures in the grid and in the customer’s installation, respectively
Regulatory aspects

- Should dips and swells be limited (to zero) when due to the use of end-use equipment?
  - Given that a satisfactory minimum level of short circuit power is ensured by the network company?
- Short circuits can never be eliminated completely
- Global, European or National limits?
Reduce the scope of voltage dips

• Focus on causes
  – End use equipment including motors
  – Transformer inrush currents
  – Short circuits or earth faults
  – Short circuit power
How to reduce voltage dips

1 Temporary earth faults that self-quench before disconnection of the faulty component and automatic re-closing.
2 Temporary earth faults quenched by disconnection of the faulty component and automatic re-closing (ARC).
3 Sustained earth faults.
5 Peterson coil in operation in Frosta from ultimo August 1996.

<table>
<thead>
<tr>
<th>Year</th>
<th>Skogn (name of the place)</th>
<th>Frosta (name of the place)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>1990</td>
<td>91</td>
<td>40</td>
</tr>
<tr>
<td>1991</td>
<td>145</td>
<td>39</td>
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<td>1992</td>
<td>106</td>
<td>84</td>
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<tr>
<td>1993</td>
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<td>1994</td>
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<tr>
<td>1995</td>
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<td>1997</td>
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<td>1998</td>
<td>156</td>
<td>1</td>
</tr>
<tr>
<td>1999</td>
<td>114</td>
<td>0</td>
</tr>
</tbody>
</table>

1 Temporary earth faults that self-quench before disconnection of the faulty component and automatic re-closing.
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Conclusions

• Regulators are concerned with voltage dips due to high costs involved - scope and consequences can be reduced
• A two dimensional aspect (depth and duration) is probably adequate for regulatory purposes
• Important to focus on causes
• Cost estimates should be improved and include more countries
• Compatibility curves (i.e. limits) should be developed taking into account, *inter alia*, various equipments’ tolerances (i.e. immunity voltage tests)
• Equipment should be tested for realistic supply situations

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Thank you all for your attention!

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