A report submitted to the research team relating to the PSerc project


on

Basic Impulse Level (BIL, Lightning Impulse Withstand Level)

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What I hope to cover

• What is BIL?

• Why is compliance with BIL important?

• How is compliance with BIL perhaps the most important issue related to power electronic components deployed in power systems?

• What are the BIL requirements?

• How is compliance assured?

• Beyond BIL, are there other requirements (e.g., safety)?
What is BIL?

• Insulation is required in power systems to avoid short circuit, component failure, safety hazards.
• Examples of insulation failure: dielectric failure (e.g., caps, transformers, reactors, voltage regulators, insulators)
• The main causes of insulation failure in bare conductor overhead transmission and distribution primaries are: switching surge voltages and lightning
• Some IEC documents now refer to BIL as “Lightning Impulse Withstand Level (LIWL)”. 

The BIL is the established minimum impulse voltage withstand of a component appropriate for a given application. The ‘impulse’ used for BIL compliance is usually not an impulse, but a specified waveshape of high voltage that has been established to capture the vulnerabilities of electric power components in a given application.
Why is compliance with BIL important?

Failure of insulation in a power system will generally result in an outage and possibly failure of an asset.

All components in the transmission and distribution system need to pass BIL requirements – otherwise failure is probable after the first switching event or lightning storm.

Components are 100% tested.

Records of the test are retained.

Safety is also a very important issue.
How is compliance with BIL perhaps the most important issue related to power electronic components deployed in power systems?

If a component cannot pass the BIL tests for a given application, it cannot be used in a commercial application.
What are the BIL requirements?

• There is no single document or standard applicable to all components in all circumstances

• There are isolated requirements in IEEE, CIGRE, DoE, IEC, Underwriters Laboratories, and others

• For transmission and distribution primaries, most classes and shapes of overvoltages, standard voltage shapes, and standard withstand voltage tests appear in IEC 60071

• This is the standard presently used for SVCs and DSTATCOMs
### IEC 60071

<table>
<thead>
<tr>
<th>Class</th>
<th>Low frequency</th>
<th>Transient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous</td>
<td>Slow-front</td>
</tr>
<tr>
<td>Voltage or over-voltage shapes</td>
<td><img src="image1" alt="Waveform" /> $T_1$</td>
<td><img src="image2" alt="Waveform" /> $T_p$</td>
</tr>
<tr>
<td>Range of voltage or over-voltage shapes</td>
<td>$f = 50$ Hz or $60$ Hz</td>
<td>$10$ Hz &lt; $f$ &lt; $500$ Hz</td>
</tr>
<tr>
<td></td>
<td>$T_t$ ≥ $3$ 600s</td>
<td>$0,02$ s ≤ $T_t$ ≤ $3$ 600 s</td>
</tr>
<tr>
<td>Standard voltage shapes</td>
<td><img src="image5" alt="Waveform" /> $T_1$</td>
<td><img src="image6" alt="Waveform" /> $T_p$</td>
</tr>
<tr>
<td></td>
<td>$f = 50$ Hz or $60$ Hz</td>
<td>$48$ Hz &lt; $f$ ≤ $62$ Hz</td>
</tr>
<tr>
<td></td>
<td>$T_t$ ≤ $60$ s</td>
<td>$T_2 = 2500$ μs</td>
</tr>
</tbody>
</table>

**NOTE:** In the last case additional characteristics of the overvoltage shapes may have to be considered.

The representative voltages and overvoltages may be characterized either by:

- an assumed maximum, or
- a set of peak values, or
- a complete statistical distribution of peak values.

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*To be specified by the relevant apparatus committees.*
The class of the component is shown in the IEC 60071 table as an rms voltage at 60 Hz phase – neutral. For example, a 13.8 kV distribution primary is 7967 V rms and this appears in the table with the red arrow. The BIL in this case is (for the lowest case considered) 60 kV zero-peak.

<table>
<thead>
<tr>
<th>Highest voltage for equipment ($U_{\text{m}}$) (kV (r.m.s. value))</th>
<th>Standard rated short-duration power-frequency withstand voltage (kV (r.m.s. value))</th>
<th>Standard rated lightning impulse withstand voltage (kV (peak value))</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>7.2</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td>17.5</td>
<td>38</td>
<td>75</td>
</tr>
<tr>
<td>24</td>
<td>50</td>
<td>95</td>
</tr>
<tr>
<td>36</td>
<td>70</td>
<td>145</td>
</tr>
<tr>
<td>52</td>
<td>95</td>
<td>250</td>
</tr>
<tr>
<td>72.5</td>
<td>140</td>
<td>325</td>
</tr>
<tr>
<td>100</td>
<td>(150)</td>
<td>(380)</td>
</tr>
<tr>
<td>123</td>
<td>(185)</td>
<td>(450)</td>
</tr>
<tr>
<td>145</td>
<td>(185)</td>
<td>(450)</td>
</tr>
<tr>
<td>170</td>
<td>(230)</td>
<td>(550)</td>
</tr>
<tr>
<td>245</td>
<td>(275)</td>
<td>(550)</td>
</tr>
</tbody>
</table>

NOTE: If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltages are met, additional phase-to-phase withstand voltage tests are needed.

* These $U_{\text{m}}$ are non preferred values in IEC 60038 and thus no most frequently combinations standardized in apparatus standards are given.

* This $U_{\text{m}}$ value is not mentioned in IEC 60038 but it has been introduced in range 1 in some apparatus standards.
### IEC 60071
Zoomed view of the table

<table>
<thead>
<tr>
<th>Highest voltage for equipment ((U_m)) (kV) ((r.m.s.\ value))</th>
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<td>12</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td>17.5 (a)</td>
<td>38</td>
<td>95</td>
</tr>
</tbody>
</table>
For distribution primary applications, perhaps the most stringent requirement is the lightning impulse test, 60 kV 0-peak, 1.2 / 50 μs

**An example:** an electronic converter with PWM switching energized by a 14.8 kV distribution primary. Modelled as a simple rectifier in one phase with a resistive load, a 60 kV 1.2 / 50 μs impulse is applied in simulation. A 10 kHz filter is used in the front end.
How to harden the electronic device to comply with the BIL requirements

- MOVs
- Other lightning arresters – possibly of new design
- All underground circuits
- Change BIL requirements
- Utilize components that can withstand these voltages
- Series connections / grading high voltage across components
- Use a magnetic transformer as an interface
- Oil immersion
- Redundant MOVs or similar measures

All of these methods have problems including:

- **Cost**
- Poor or ‘no’ commercial availability
- Requirements exceed design capabilities
- Loss of some / most of the advantages of the power electronic device
- Losses – especially in the steady state
- Reduction in safety
- Loss of galvanic (ohmic) isolation
This could be a ‘deal breaker’
Possible solutions

Limit applications to lower voltages where the BIL requirements are lowest and easiest to satisfy, e.g., 20 kV BIL in 3.5 kV circuits.

Applications in which safety is not really an issue, e.g., an HVDC application in which a lightning surge is passed to high voltage and lower voltage circuits which do comply with BIL requirements.

Reduced BIL requirements for temporary applications – especially where impulses are passed to circuits that comply with BIL requirements, e.g., a temporary substation transformer. Is this legal?

Research into high speed surge arresters – especially those that can withstand very high energy dissipation (including sustained dissipation after the 60 Hz voltage is applied to a conducting arrester)
Possible solutions

Insertion of BIL compliant inductors ahead of all power electronic devices – to effectively attenuate impulses

Semiconductor switches with really high voltage piv

Research into innovative methods of BIL coordination, e.g., highest BIL at the substation, lower along a feeder (including underground circuits), still lower at distribution transformer.

Mitigate switching transients