GE Power: Transient Recovery Voltage (TRV)

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11/27/2017 – CIGRE CHILE

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CIGRE Chile: Transient Recovery Voltage (TRV)

Agenda

1) **General considerations**
2) TRVs with higher values than the standard
3) Performances already demonstrated
4) Increase the performances
5) Future developments
6) Experiences and other markets
The **Transient Recovery Voltage** (TRV) is the voltage which appears across the terminals of a pole of circuit breaker after current interruption.
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General considerations

During the first microseconds after current zero, the TRV withstand is function of the energy balance in the arc: it is the **thermal phase of interruption**

Later, the voltage withstand is function of the dielectric withstand between contacts: it is the **dielectric phase of interruption**

The breaking operation is successful if the circuit breaker is able to withstand the TRV and the power frequency recovery voltage
Short-line faults occur from a few hundred meters up to several kilometers down the line.

After current interruption, the line-side voltage exhibits a characteristic triangular wave shape in addition of the voltage on the source side.

TRV, neglecting the contribution from the supply-side
General considerations

Short line fault: Thermal capability

Impact of the line

$U_r = 245$kV
$I_{sc} = 40$kA
$f_r = 50$Hz
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General considerations

Due to the impedance of the line (Z), the time delay for the rise of the voltage on the line side is $<0.1\mu s$ for AIS and $<0.5\mu s$ for GIS.

In comparison, for SLF, the time delay for the source side is $2\mu s$.

Diagram:
- Source side voltage (point B)
- Line-side voltage (point C)
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General considerations

Short line fault: Thermal capability

Zoom at the current 0

Voltage from the line side

Voltage from the source side

Ut = 36.4kV  \rightarrow\ RRRV (slope) = \frac{36.4}{4.45} = 8.2kV/\mu s

Td = 2\mu s

TI = 4.45\mu s

Slope: 1.8kV/\mu s

Slope: 7.2kV/\mu s

-12kV

36.4kV

32kV

-15

-10

-5

0

5

10

15

20

25

30

0

0.5

1

1.5

2

2.5

3

3.5

4

4.5

5

Time (\mu s)

Voltage (kV)

Voltages from the line side

Voltages from the source side
## General considerations

### Short line fault: Thermal capability

**Challenge for the CB**

<table>
<thead>
<tr>
<th>Current (% of Icc)</th>
<th>Current (kA)</th>
<th>Tdl (µs)</th>
<th>RRRV (kV/µs)</th>
<th>Time for the first peak of the line (µs)</th>
<th>Voltage at the first peak of the TRV (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L60 (60% of Icc)</td>
<td>24</td>
<td>&lt;0.1</td>
<td>5.9</td>
<td>26.7</td>
<td>157.6</td>
</tr>
<tr>
<td>L75 (75% of Icc)</td>
<td>30</td>
<td>&lt;0.1</td>
<td>7.3</td>
<td>13.3</td>
<td>97</td>
</tr>
<tr>
<td>L90 (90% of Icc)</td>
<td>36</td>
<td>&lt;0.1</td>
<td>8.2</td>
<td>4.45</td>
<td>36.4</td>
</tr>
</tbody>
</table>

**Main challenges**

The **thermal capability** of the circuit-breaker is demonstrated during **short line fault** tests (L60 only needed with critical current)
Terminal faults occur at the terminals of the circuit-breaker, in the sub-station.

After current interruption, the standards considers a three phases defaults to the ground.
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General considerations

Terminal fault: Dielectric capability

The time delay for the rise of the TRV is longer for the terminal fault.

<table>
<thead>
<tr>
<th>Time delay</th>
<th>AIS</th>
<th>GIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short line fault</td>
<td>&lt;0.1µs</td>
<td>&lt;0.5µs</td>
</tr>
<tr>
<td>Terminal fault</td>
<td>≥2µs</td>
<td></td>
</tr>
</tbody>
</table>

The needed shorts circuits current to test defined by the standard are 10%, 30%, 60% and 100% of the Icc with the TRV above.
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### General considerations

**Terminal fault: Dielectric capability**

<table>
<thead>
<tr>
<th></th>
<th>Current (kA)</th>
<th>Td (µs)</th>
<th>du/dt (kV/µs)</th>
<th>TRV peak (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T10</strong> (10% of Icc)</td>
<td>4</td>
<td>10</td>
<td>7</td>
<td>459</td>
</tr>
<tr>
<td><strong>T30</strong> (30% of Icc)</td>
<td>12</td>
<td>12</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td><strong>T60</strong> (60% of Icc)</td>
<td>24</td>
<td>2-20</td>
<td>3</td>
<td>390</td>
</tr>
<tr>
<td><strong>T100</strong> (100% of Icc)</td>
<td>40</td>
<td>2</td>
<td>2</td>
<td>364</td>
</tr>
</tbody>
</table>

The **dielectric capability** of the circuit-breaker is demonstrated during terminal fault tests.

Examples for 245kV, Kpp=1.3
Out of phase: Dielectric capability

Out-of-phase occur at the terminal of the circuit-breaker, in the sub-station.

After current interruption, the TRVs appeared in both terminals and in reversed polarity each others.
General considerations

Out of phase: Dielectric capability

![Graph showing Transient Recovery Voltage (TRV)](image-url)
### General considerations

#### Out of phase: Dielectric capability

Challenge for the CB

<table>
<thead>
<tr>
<th>OP2 (25% of the Icc)</th>
<th>Current (kA)</th>
<th>( T_d ) (µs)</th>
<th>( \frac{du}{dt} ) (kV/µs)</th>
<th>TRV peak (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>2-20</td>
<td>1.54</td>
<td>500</td>
</tr>
</tbody>
</table>

Main challenge

The **dielectric capability** of the circuit-breaker is demonstrated during **out of phase** tests.
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General considerations

Capacitor switching: Dielectric capability

[Graph showing recovery voltage, supply voltage, and load voltage over time]
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General considerations

Capacitor switching: Dielectric capability

Challenge for the CB

<table>
<thead>
<tr>
<th></th>
<th>Current (A)</th>
<th>Time of the first peak (ms)</th>
<th>RV Peak (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cap-switching</td>
<td>Around 500</td>
<td>10</td>
<td>560</td>
</tr>
</tbody>
</table>

Due to the very small current compared to the Icc (500A), the minimum arcing time will be very short (smaller than 1ms)

The main difficulty is to withstand the rise of the voltage after the clearance despite a small distance between the contacts

An efficient speed and insulating coordination must be defined for this application

The dielectric capability of the circuit-breaker is demonstrated during capacitor switching tests.
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6) Experiences and other markets
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TRVs with higher values than the standard

Chilean request (example at 245kV)

TRV with smaller RRRV but higher peak of voltage

<table>
<thead>
<tr>
<th></th>
<th>RRRV (kV/µs)</th>
<th>Uc (kVp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (IEC)</td>
<td>1.54</td>
<td>500</td>
</tr>
<tr>
<td>Request</td>
<td>0.36</td>
<td>641</td>
</tr>
</tbody>
</table>
TRVs with higher values than the standard

Chilean request (example at 550kV)

Once again, a TRV with smaller RRRV but higher peak of voltage

<table>
<thead>
<tr>
<th></th>
<th>RRRV (kV/µs)</th>
<th>Uc (kVp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (IEC)</td>
<td>7</td>
<td>1031</td>
</tr>
<tr>
<td>Request</td>
<td>1.13</td>
<td>1225</td>
</tr>
</tbody>
</table>

Values from the standard

Performance reach following customer request
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Today chambers

With the today circuit-breakers, **performances** up to **800kV** and **63kA** according the standard are reached

The **performances limitations** are **not necessarily** the values of the standards

**Higher performances** can in general be **reached** with the today design by performing **new tests** with specific requirements **beyond** the standards values
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Performances already demonstrated

Values from the standard and performances

Example: 245kV, 40kA, 50Hz

Some « extra » performances are already demonstrated
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Performances already demonstrated

Other market (550kV chamber)

<table>
<thead>
<tr>
<th></th>
<th>RRRV (kV/µs)</th>
<th>Uc (kVp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (IEC)</td>
<td>5</td>
<td>899</td>
</tr>
<tr>
<td>Request</td>
<td>4.4</td>
<td>1592</td>
</tr>
</tbody>
</table>

Values from the standard
Performance reach following customer request
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Performances already demonstrated

Other market (245kV chamber)

All the performances were demonstrated at 300kV with a 245kV chamber

The peak voltage was increased by more 22%

Values from the standard
Performance reach following customer request
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Performances already demonstrated

Chilean request (245kV chamber)

During the test, the applied TRV was higher than the standard but not covering the request.
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Performances already demonstrated

Chilean request

To cover the TRV, a test was done according the request and based on the IEC standard. Despite a higher peak of voltage, the performance was demonstrated with the same chamber.
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4) **Increase the performances**
5) Future developments
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Increase the performances

How we proceed with a special request?

The performance is already demonstrated?

Yes
Quotation from tendering will be done

No

Analysis of the performance
Dielectric and breaking calculations to estimate the capability of an existing chamber
Risk analysis and selection of the chamber to perform a test and validate the performance
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Increase the performances

- Dedicated chamber
- Perform extra tests on the today design
- Increase the pressure
- Add capacitor(s)
- Surge arrestors
- Add or increase the number of chamber(s) in series

Not an efficient solution

Really expensive solution (one chamber for one market) due to small volume

Perform extra tests on the today design

No new development, only tests to be done

The today requests seems only higher peak of voltage (Uc) and smaller rise of voltage (RRRV) are requested

On these conditions, reach the requests seems possible (already done for Transelec and other markets)
Another solution, is to do small adjustments on the existing chambers for the Chilean market.

As example, the dielectric withstand is link to the filling pressure of the circuit-breaker.

Increase the filling pressure will increase the dielectric withstand.

Increase the filling pressure will also increase the thermal capability of the chamber.
Possible adjustment: Increase the pressure

The filling pressure is linked to the minimum temperature to avoid liquefaction. As example, increase the filling pressure from 3barA to 5barA, the voltage can be increase from 50kV to 75kV (service pressure vessel are designed up to -15°C).
Increase the performances

Possible adjustment: Add capacitors on the chambers

Influence of the capacitor on the L90

- Rise of the voltage from the line without capacitor
- Rise of the voltage from the line with the influence of a parallel capacitor (2nF)

Add capacitors will delay the rise of the line for short line fault

With capacitors, the repartition of the voltage on one chamber of a two phases circuit-breaker is closed to 70% without grading capacitors and close to 50% with grading capacitors

Once again, add capacitors on the chamber(s) will increase the price of the circuit-breaker
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Increase the performances

Possible adjustment: Add capacitors on the chambers

The **today chamber** with capacitors may be sufficient to reach the peak of the voltage
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Increase the performances

Possible adjustment: Add surge arrestors

The surge arrestors will limit the peak of the voltage

Example of calibration for the surge arrestors
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Increase the performances

Possible adjustment: Add surge arrestors and/or capacitors

One drawback of these solutions is the weight of the total chamber(s) for the seismic issue.

New developments are in progress to solve this issue.
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Increase the performances

Possible adjustment: Add chamber(s)

The 245kV is a one chamber circuit-breaker

Add a second chamber in series helps to increase the performance

The natural repartition of the voltage is 70-30%

Add a second chamber will increase the price of the global circuit breaker
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Increase the performances

Possible adjustment: Add chamber(s)

Add chambers can be also done for the 550kV

2 chambers (today design)

2 other chambers can be added in series

On this architecture, the voltage on one chamber is around 30% of the full voltage (with capacitors)

Once again, this will increase the price of the global circuit breaker
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Futures developments

The today performances are following the market and the standard to have volume. Keep the same chamber will also increase the reliability of the circuit-breaker.

<table>
<thead>
<tr>
<th>Voltage (Ur – kV)</th>
<th>Rated short circuit current (Icc – kA)</th>
<th>Frequency (Hz)</th>
<th>First pole to clear factor</th>
<th>Minimam temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>245</td>
<td>40/50</td>
<td>50/60</td>
<td>1.3</td>
<td>-30/-25</td>
</tr>
<tr>
<td>550</td>
<td>40/50</td>
<td>50/60</td>
<td>1.3</td>
<td>-30/-25</td>
</tr>
</tbody>
</table>

The demonstrations of the TRVs were based on these parameters.

Reach higher performances is possible with extra tests following the requests of costumers. Adjustments (minimum temperature for example) according Chilean market can be done to increase the performances.

The main requests are with a reduction of the rise of the voltage and a higher peak. These conditions were demonstrated for the Chilean market and for other markets.
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Futures developments

New developments is possible (some are in progress), but following the values from the standard and large markets

For special requests, the best option is to do a risks analyses with an existing design and perform the test with the same design or with adjustments (filling pressure/capacitors/surge arrestors/more chambers)

Chart of estimated over cost from an existing solution per chamber

Increase the filling pressure

Add surge arrestor

Add capacitor

Add chamber

Dedicated development

>1.5M€
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Experiences and other markets

On the other markets, the requests are following the standard (IEC & IEEE mainly)

The are special requests from the customers, but following the values from the standard

For example, the kpp was increased from 1.3 to 1.5 on a dedicated market with the existing chamber
Conclusion

The today **performances** demonstrated are **following** the standards (IEC and IEEE)

Reach **higher TRVs** is **possible** with the **today** circuit-breaker **range**
For that, **studies** can be done to select the **best design** and, if needed, adjust our **common chamber** (increase the minimum pressure for example)

In any case, we need to know your requests **as soon as possible** to analyze the request and **propose** the **best option**
An efficient **communication** should be set up to select the best design for **customer/application**
Conclusion

Thank you for your attention

Do you have any question?
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General considerations

Terminal fault: Dielectric capability

Example of TRV with two parameters
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General considerations

Terminal fault: Dielectric capability

Example of TRV with four parameters