Exploring the Arrester Jungle

Author: Bengt Johnnerfelt

Presenter: Bengt Johnnerfelt

April 28th, 2016

Arrester Selection: Why use Surge Arresters?

- Protection of other substation equipment from harmful overvoltages
  - Well defined overvoltage requirements for substation equipment
  - Lower cost of substation equipment
- Increasing the reliability of the power system
  - Reducing outage time due to equipment failures and/or transmission line trippings
- Being the weakest link for unexpected overvoltage incidents
  - No system can be designed for all unlikely eventualities
    - Like e. g. some resonance phenomena

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Arrester Selection: What could possibly go Wrong?

- Misleading the customer
  - Information used to snare the customer
- Traps in catalogues and manufacturers data
  - How are data presented?
- Exploring test weaknesses in standards
  - Which tests have crucial test parameters and/or set up?
    - HV arresters most complicated testing of all substation apparatus.
- General guidance for best specification and selection
  - What to think about

Misleading the Customer

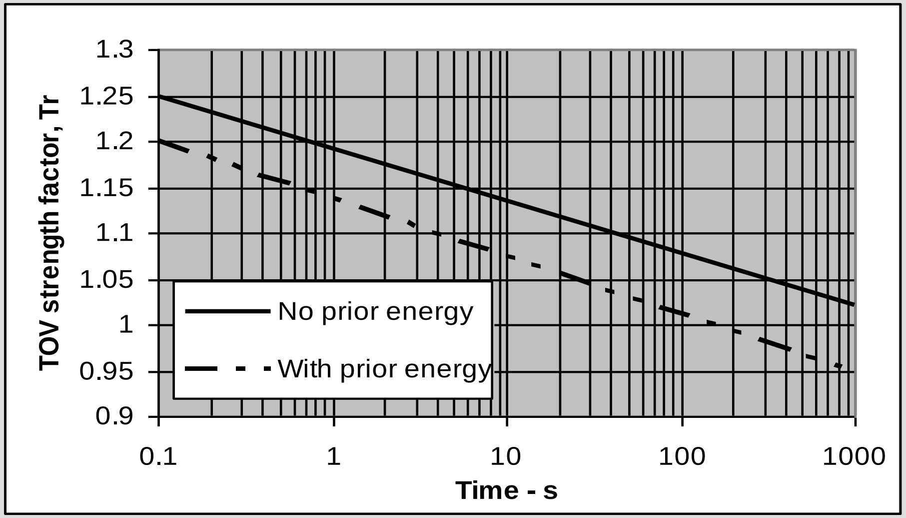
Misused Information to Confuse the Customer

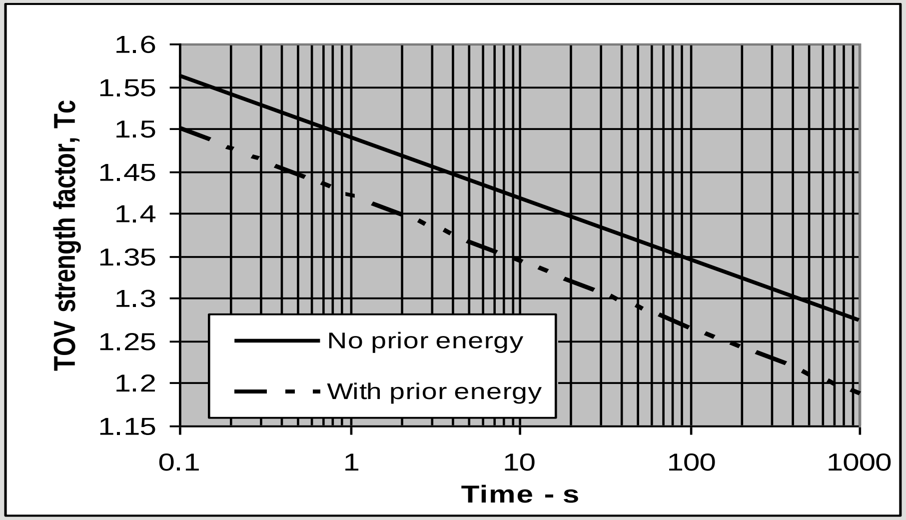
- Mixed classification data
  - 10kA distribution class arresters but with 65 kA 4/10µs high current.
    - Such 10kA arrester have never existed in IEC nor IEEE
    - As soon as it is only 65 kA 4/10µs it is a 5 kA distribution class arrester
  - Old LDC 4 arresters but with a nominal current of 10 kA
    - LDC 4 always need nominal current 20 kA.
    - Station arrester class SH always need nominal current 20kA
    - Nominal current 10 kA is always class SM (old LDC 3)

Traps in Manufacturers Catalogues and Data

How are Data Presented?

- Which base is used for TOV calculations, U_r or U_c/MCOV?
  - TOV curves automatically 25% higher values by using U_c/MCOV as the base for the curves.





- Which base is used for energy values, U_r or U_c/MCOV?
  - Energy values given as kJ/kV U_c/MCOV becomes automatically 25% higher.
    - 5.0 kJ/kV U_c is less than 4.2 kJ/kV U_r

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How are Data Presented?

- Which nominal current is used?
  - 10 or 20kA: Residual voltage around 10% higher for 20kA
  - 1 or 2kA switching around 4% higher for 2kA
    - Old LDC 3 (10kA & 1kA) and 4 (20kA & 2kA)
    - New IEC, SM 10kA & 1kA and SH 20kA & 2kA
      - SM typically around 2.4 p.u. of U_r at 10kA
      - SH typically around 2.55 p.u. of U_r at 20kA, but around 2.3 p.u. at 10kA
      - Asking for protective level at nominal current will give you 6.3% higher voltage for SH or old LDC 4 class arresters compared to SM or old LDC 3 class arresters.

    - Always ask for protective levels for a specific current amplitude, not at nominal currents

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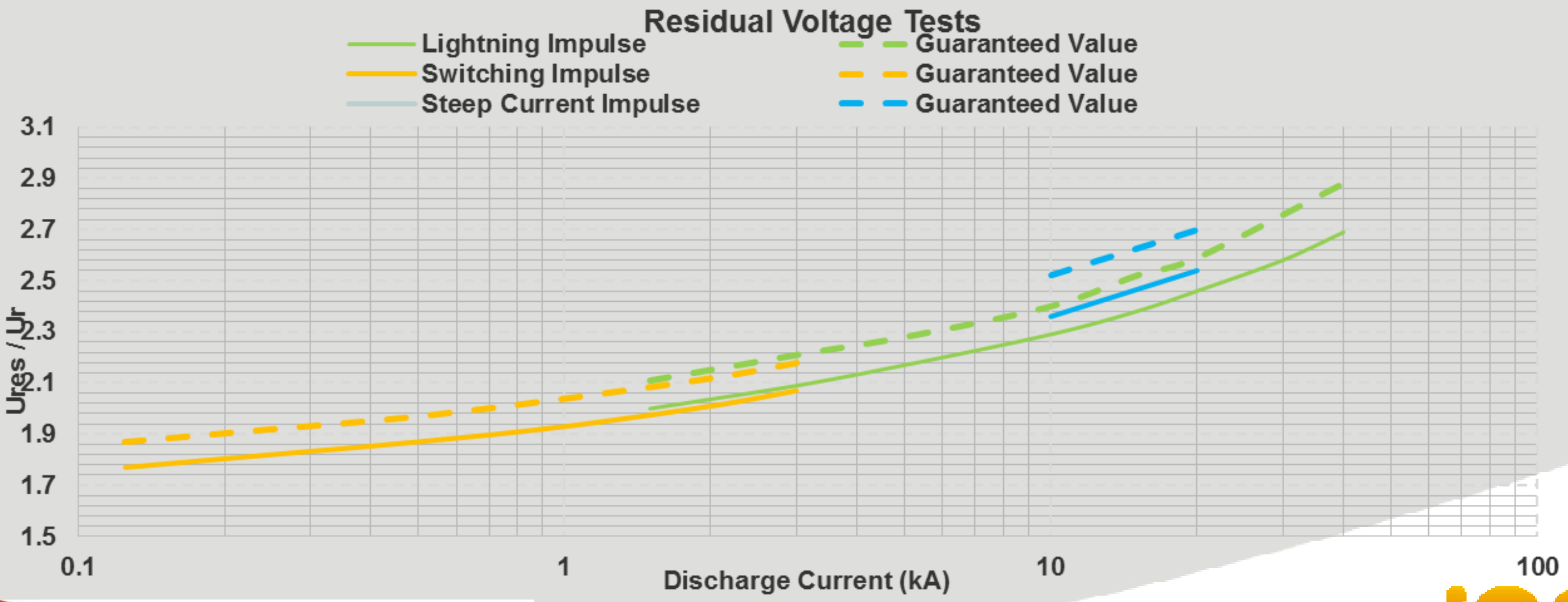
Exploring Test Weaknesses in Standards

Which Tests have Crucial Test Parameters?

- Short-circuit tests for polymeric arresters Type B in IEC/IEEE. Typically directly molded or arresters with separate sleeves pulled on.
  - These arresters must first be overheated close to failure by either constant current or constant voltage. When the arrester resistance is close to zero, the short-circuit current shall be applied as soon as possible.
  - In real life the short-circuit current follows immediately after the arrester is getting close to short-circuit.
  - Due to test limitations most labs need to use two separate voltage sources for this test and switching between them cannot occur directly.
  - However, if the preheating goes on for too long you may puncture the arrester housing or even fail the arrester before the short-circuit current is applied.
    - This of course means that the arc already has an opening and the “explosive“ effect on the arrester design from the first short-circuit peak is not verified.
    - On the other hand if the time between the two voltage sources is long enough the arrester will recover parts of its resistance due to cooling down and the lab do not have enough power to short-circuit the tested arrester.
    - The more powerful generators the labs has the more realistic is the test. This is true even for distribution arresters.

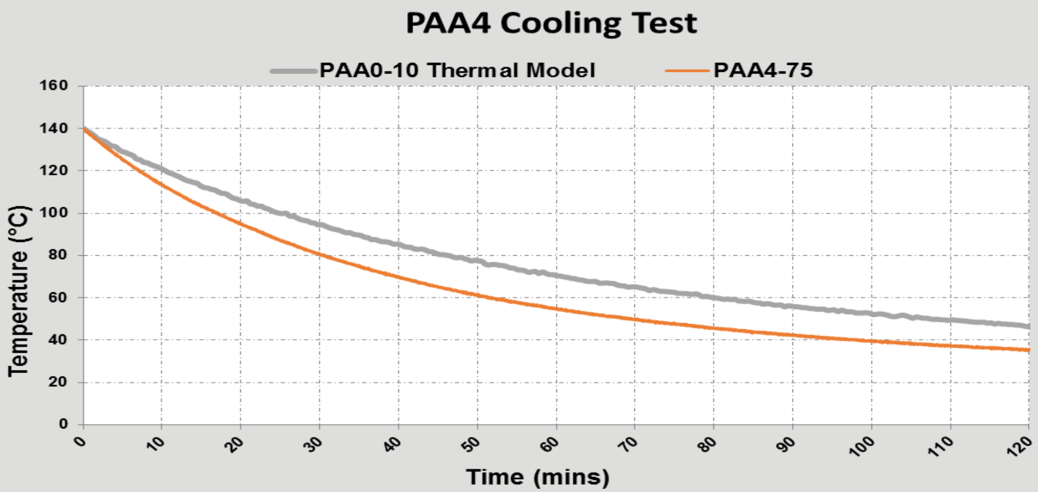
Which Tests have Crucial Test Parameters?

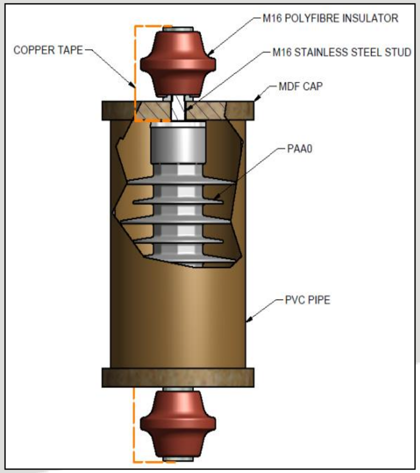
- Residual voltage tests
  - The test is performed on three block samples for different wave shapes and current amplitudes.
  - These measurements do not represent the protective characteristics of an actual arrester itself. Instead the measurements should verify the given data sheets for all ratings.
  - Protective levels should be given in factors to the 100% routine test current residual voltage on each block or arrester unit, or reference voltage for distribution arresters.



Which Tests have Crucial Test Parameters?

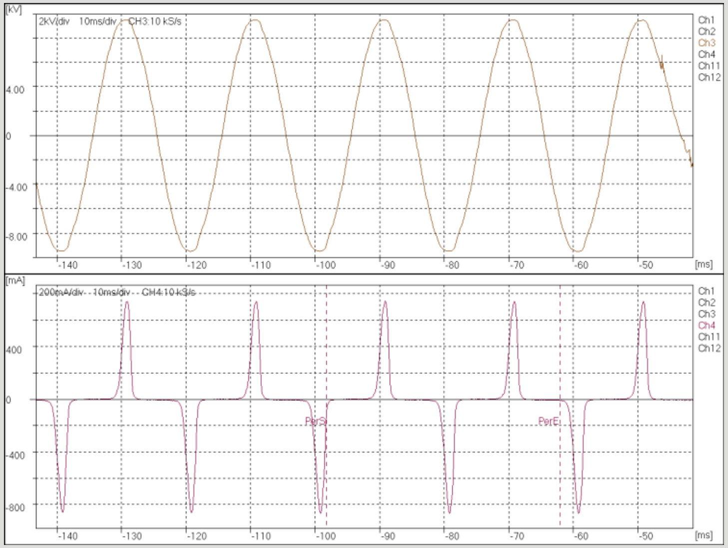
- Thermal model of arresters
  - Thermal models are to represent the longest most stressed arrester unit of the verified arrester designs.
  - This will never be a short standard arrester of rating, say 6 or 10kV, unless this is the highest rating you manufacture for this design.
  - Independent of porcelain or polymeric arresters most cooling comes from the end flanges, due to that both air (or other gases) as well as rubber are poor heat conductors.
  - The first minutes are the most critical and shall match the complete arrester.

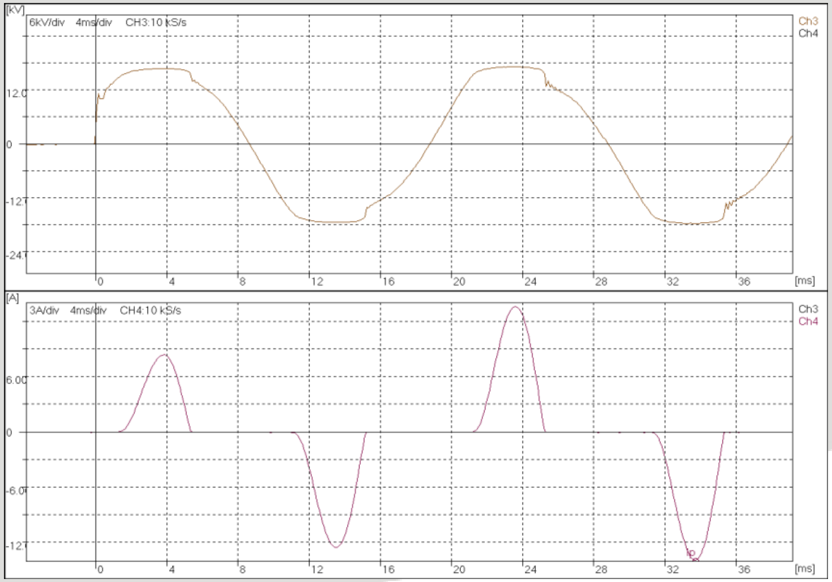




Which Tests have Crucial Test Parameters?

- TOV tests
  - Two parameters are extremely important.
    - Apply TOV voltages in direct relation to actually measured reference voltage of test samples.
      - Average rating for the blocks is not okay to use.
    - The transformer/generator must be strong enough to not "flatten" out the voltage peak.





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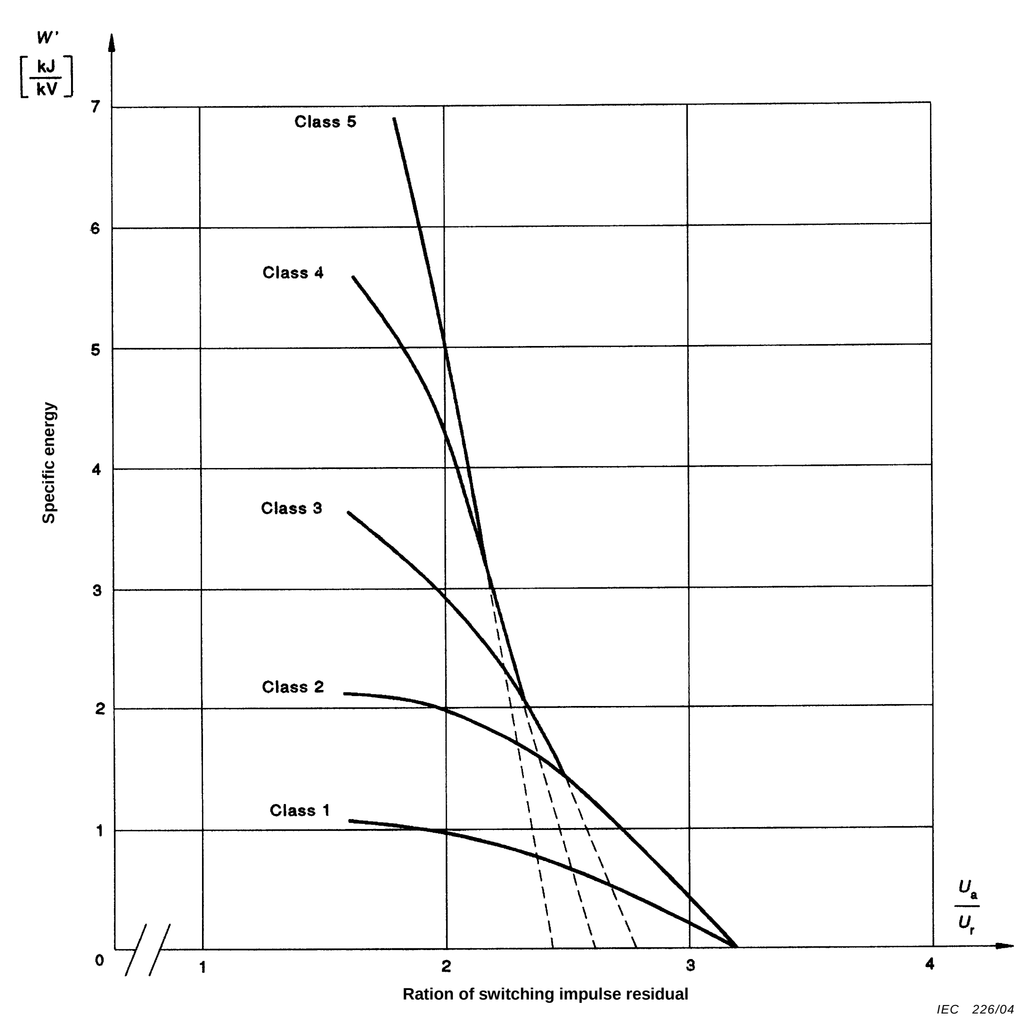
Which Tests have Crucial Test Parameters?

- Old LDC tests

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

<u>LDC 4</u>

Where $U_L = 2.6U_r = 15.6$ kV
$Z = 0.8U_r = 4.8\ \Omega$; $T = 2.8$ ms
$U_r = 6$ kV
U_{res1} @2kA = 12.0 kV
U_{res2} @2kA = 14.4 kV
$W_1 = 25.2$ kJ; 4.2 kJ/kV
$W_2 = 10.1$ kJ; 1.68 kJ/kV



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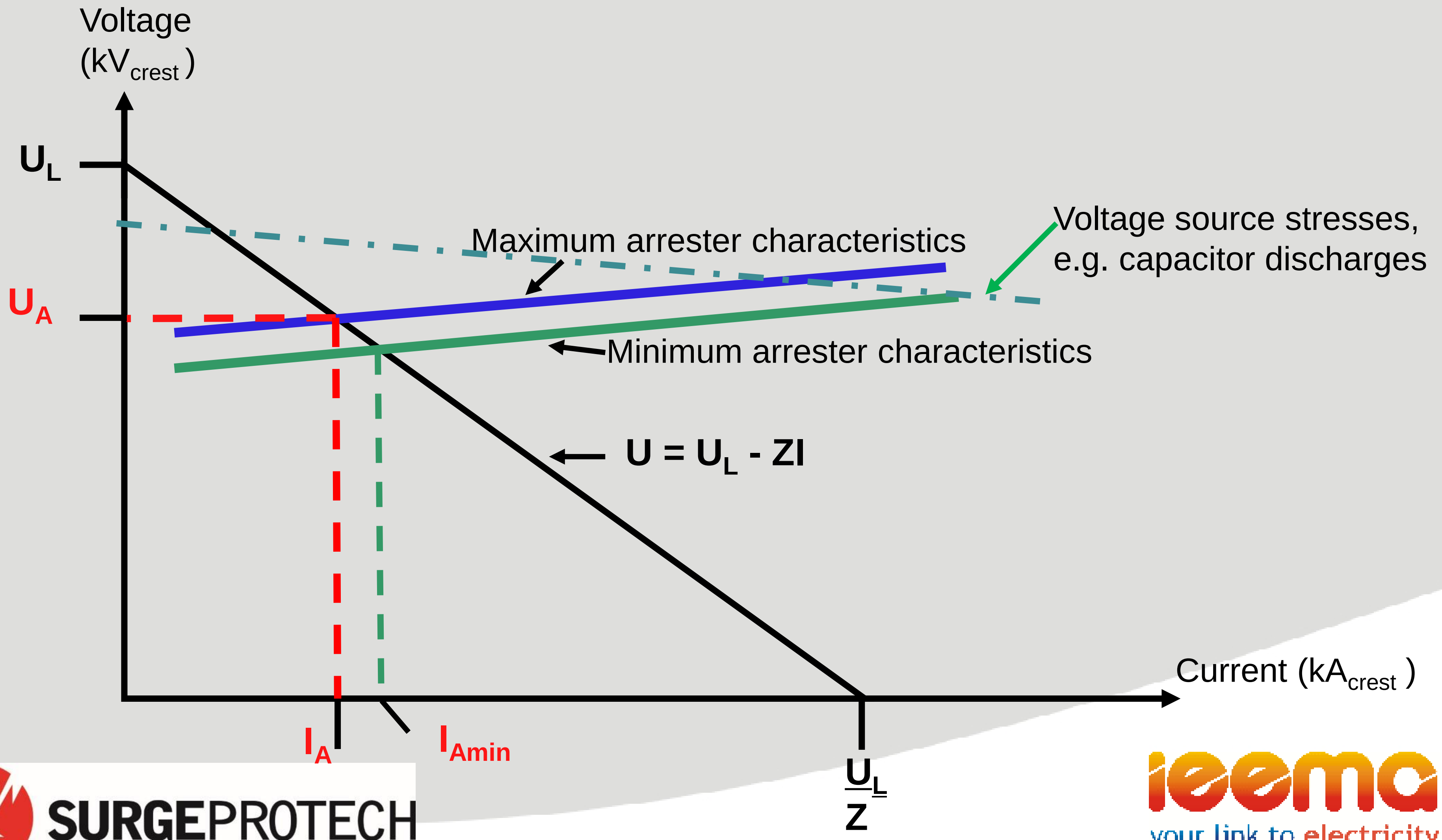
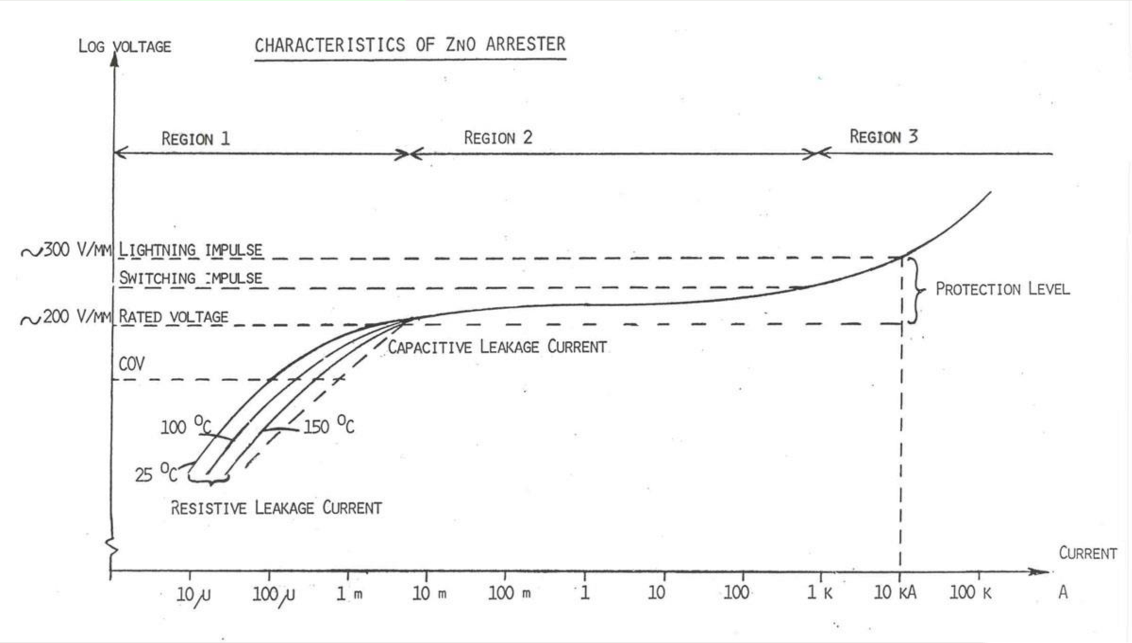


General Guidance for best Selection

Arrester Selection: What could possibly go Wrong?

- Usage of U_c/MCOV as base for selection
  - Reference/rated voltage has a better relation to system conditions and stresses.
  - The true U_c/MCOV is in most cases the maximum system voltage divided √3.
    - All higher voltages are TOV stresses even if they last for hours.
      - Exception not directly earthed systems where the system runs with an earth fault for days.
    - Low current characteristics below the “knee” point are strongly temperature dependent.

$\alpha \leq 5$	$I = k \cdot U^{\alpha}$ α values up to 50	$\alpha \leq 8$



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Arrester Selection: What could possibly go Wrong?

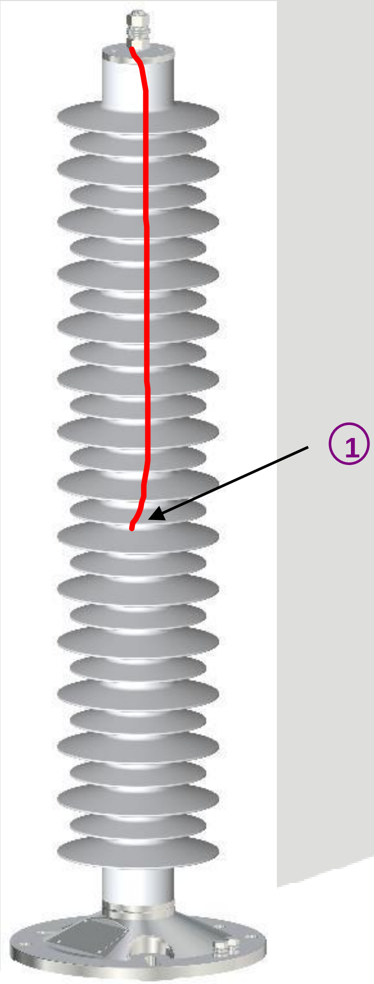
- Cases where selection of arresters based on a higher rated voltage at actual COV is beneficial.
  - High TOV stresses
    - Higher rated voltage with actual COV means easier cooling down after TOV stresses.
  - Heating due to pollution effects
    - Higher rated voltage with actual COV means better cooling (more mass and better margin between COV and rated voltage).
  - Capacitor discharges
    - Voltage sourced stresses means that the energy stress stops when the capacitor discharge reaches the rated (reference) voltage.
    - The minimum reference voltage gives the highest energy stress.

Arrester Selection: What could possibly go Wrong?

- 1000H salt fog test.
- Longest polymeric arrester unit tested.
    - Performance under pollution conditions
    - Testing of 800mm long unit or shorter

1 Measures against internal PD

- Maximum 60% of the maximum insulator length before flashover occurs
- Say 2.2mm long arrester 198 kV rated voltage
- Tested 0.8m insulator 63 kV rated voltage
- Test stresses 0.8x72x0.5 = 28.8x√2=40.7 kV
- In service stresses 0.8x198x0.5 = 79.2x√2=112.0 kV



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Arrester Selection: What could possibly go Wrong?

- Insulation withstand requirements of the arrester housings
  - Arresters are unique in that they are self-protecting devices which means that the internal nonlinear resistors of the arrester will inherently limit the voltage across the terminals. Due to this self-protecting nature, the arrester housing can have lower withstand voltages than the rest of the system without any negative impact on the system withstand level. Also, for this reason, arresters do not have a standardized insulation withstand rating.
- Never require system standard insulation withstand levels for surge arresters.
  - Will only make arrester longer and may need larger grading rings than necessary.
  - Standard withstand levels can even be impossible to reach across the arrester terminals due to it would need a current amplitude of some hundred kA!
    - 850 BIL for 245 kV system. SM arrester U_r =192 kV, 10 kA 461kV; 1,3x 461=599kV
      - 850kV > 200kA impulse (100kA 4/10µs gives around 610 kV)

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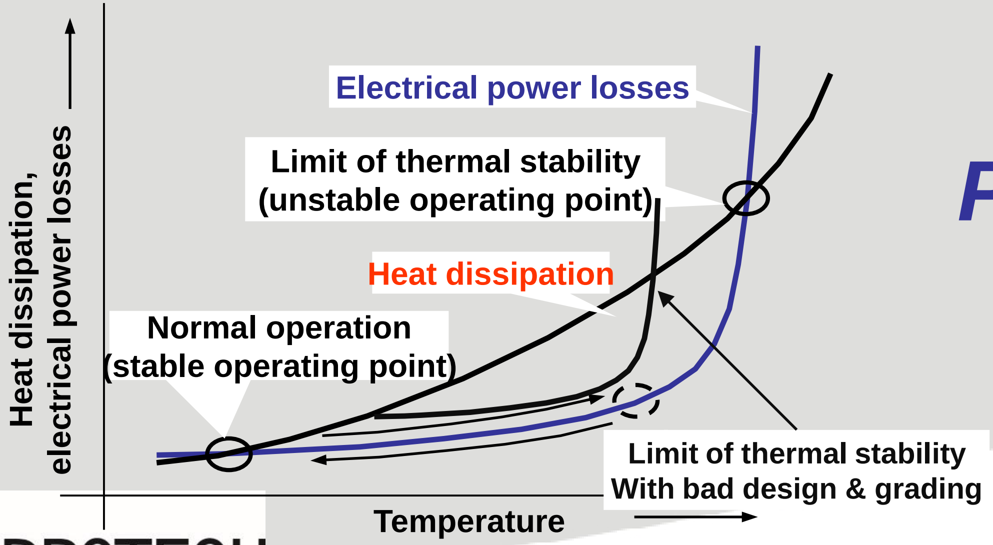
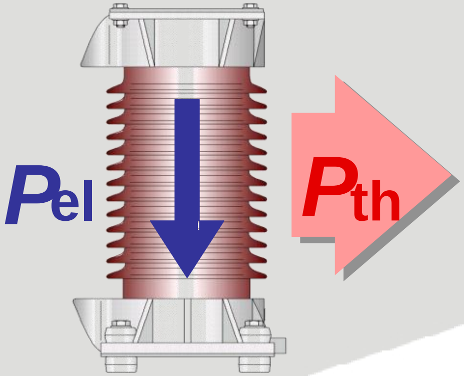
Arrester Selection: What could possibly go Wrong?

- Grading rings
  - Bad UHV arrester grading will reduce energy capability and/or overstress the blocks, due to self heating.
  - Accelerated ageing tests should be preformed at the highest block stresses in the arrester considering grading rings.
- Corona rings
  - Use corona rings for 300 kV systems and above.

Thermal energy absorption capability





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Arrester selection: What could possibly go Wrong?

- Parallel columns or arresters
  - Lowering the residual voltages
    - Nothing need to be done as they all see the same current. If from same block type, actual residual voltage will be at half the current amplitude for two parallel columns and for one third for three parallel columns and so on.
  - Sharing energy
    - For lower current amplitudes where Need to consider spread between minimum and maximum protective levels.

$I = U^{\alpha} \times C$, Where C = Constant, α = Non-linear coefficient

a = 30 → $\Delta U = 0.1\%$ → $I = 3\%$

$\Delta U = 1.0\%$ → $I = 34.8\%$

Spares for many parallel columns should be installed from the beginning.

Thanks for you time

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