Understanding the Arrester Energy Handling Issue

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Introduction
Over the past two to three years, the arresters standards writers around the world have been actively trying to resolve the basic misunderstandings of surge arrester energy handling capacities. The most progressive resolution has come out of research at Darmstadt Technical University that is sponsored by CIGRE working group A3.17. At Darmstadt TU, Prof Volker Hinrichsen is leading a team that continues to produce results that are clarifying the issue. Members of A3.17 as well as members of IEC TC37 MT4 and IEEE SPD working group 3.3.11 are examining the research results and attempting to resolve the issue. Their plan is to publish guidance on the subject as well as a test standard that will resolve the issue once and for all. The following dissertation is my attempt to clarify and outline the issue after attending meetings from all the above mentioned expert groups.

The Issue
Engineers responsible for specifying arresters used on power systems often need to know how much energy an arrester can handle during normal operation. Unfortunately, no unified measurement of this characteristic has been set forth by the industry so it is not possible for users to compare arresters from various manufacturers.

The Many Dimensions of the Problem
Surge Types
The fundamental function of an arrester is to transfer accumulated charge on a power system to earth and at the same time limit the voltage stress on the protected insulation. During the process of the charge transfer, the arresters react to the charge and associated energy content based on the voltage and current waveshape and duration. Very fast charge transfers such as lightning affect the arrester differently than slow front, longer duration switching events.

Energy Limits
There are two types of energy overload limits and no accepted definition that differentiates them. The first limit is related to the temperature of the arrester where it cannot stably operate while energized. The second limit is related to the thermo-mechanical impulse withstand of the arrester. All electro-ceramic material has a limit where thermal mechanical failure or serious degradation may occur when exceeded.

Voice of the Specifiers
Those who specify arresters, typically specify energy handling capabilities in joules. Seldom is the duration of the surge specified making a realistic response to the specification impossible. See Table 1 for a summary of this issue.

Measurement Methods
Manufacturers have devised many ways to define and test energy handling capability. Some measure the energy in one pulse,
some in three pulses; others do not define their method at all.

**Unit of Measurement**

There is little agreement in the industry as to whether charge (amp seconds), current (amps), or energy absorption (joules) should be the unit of measurement for durability. Each unit of measure has positive and negative attributes to consider.

**Standards**

Neither the IEC nor IEEE standards effectively address the subject of energy handling capability. High current tests, transmission line discharge tests, operating duty test, and the latest lightning discharge test all attempt to address the energy handling measurement, but fall short.

**Conflicting Characteristics**

If energy absorption is measured in joules, an arrester with a higher discharge voltage will have a higher energy rating, and this is in contradiction to seeking the better arrester. For a gapped MOV arrester that has significantly better (lower) discharge voltage, a joule energy rating is altogether inadequate.

**Recent Progress**

CIGRE working group A3.17 met two times in 2008 and reviewed recent progress on work being done at Darmstadt Technical University to resolve the issue. It appears that the Klaus Ringler Energy Handling Equation as published in a 1997 IEEE Transaction was reconfirmed however, with new surprising findings using the 200 µs lightning discharge impulse. Also for the first time publicly, impulse degradation was quantified using a change \( V_{ref} \) before and after energy input. From the discussion, clear definitions of the two well-known energy-handling characteristics began to emerge. Both of these definitions were described in a CIGRE paper presented in Brazil in September 2007. The two types of energy ratings discussed were **Thermal Energy Absorption Limit** and **Single Impulse Energy Absorption Limit**.

The **Thermal Energy Absorption Limit** is defined as the maximum level of energy injected into an arrester at which it can still cool back to its normal operating temperature while energized. This limit can be reached over the entire disk, or locally along preferential current paths inherent in MOV material. This characteristic is due to the negative thermal coefficient of ZnO.
material in general. In other words, as the temperature of MOV material increases, so does its leakage current, this in turn generates more heat. At some point the ability of the material to create heat exceeds its ability to shed it off through conduction and radiation. Figure 1 shows this graphically.

**The Single Impulse Energy Absorption Limit** is the energy in joules (current density, or amp seconds) and duration of energy injection, required to damage an arrester permanently. The damage can be at a macroscopic level or a microscopic level. In either case it is measurable using Vref and/or physical fracture.

**The Solution**
These two characteristics discussed above need clear definitions and both need to be used to describe arrester energy handling capability, not just one or the other. Once the two-part definition is accepted, then the tests to measure these characteristics need to be developed. Along with the test to measure these characteristics, the unit of measure needs to be agreed upon. The industry needs to eradicate the joule rating from the solution of this energy handling issue.

**Specifiers and Manufacturers Responsibility**
To resolve the energy handling issue, specifiers will need to adopt new specification methods that provide more information about the energy handling needs and in particular it will need a new section that describes the energy injection duration. Manufacturers also need to adopt new specification procedures and not continue to respond to the joule-rating question when it is not correct. See Table 1 for more on this.

**Looking Ahead**
We will have two new definitions of energy handling, new test procedures (or modified old procedures) that relate to both types of energy ratings, and new specification procedures.

We will learn that a distribution arrester (Class 1 10kA arrester in the IEC world) needs to handle both types of energy input when it functions to clamp lightning surges. Not only must it not exceed its Single Impulse Energy Absorption Limit, but it must also not exceed its Thermal Energy Absorption Limit. The high current short duration test of the IEEE standard first stresses the Impulse Energy Absorption Limit of the arrester, then the Thermal Energy Absorption Limit. See Figure 2

We will learn that the energy handling capability of a transmission line arrester may need to be different than that of a station or distribution arrester. Currently in the IEC, there is a different test for each,
and perhaps it should be that way in the IEEE standards too. We will also learn that the proper way to quantify these two new limits of arrester energy handling limits, are with means that do not discriminate between equally good arrester designs as the joule rating does.

Table 1  
Arrester Energy Handling Requirement  Overview

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical Arrester for this application</th>
<th>Energy Handling Req.</th>
<th>Test to Verify</th>
<th>Issues</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution System Equipment</td>
<td>IEC - Class 1 (2.5, 5, 10kA)</td>
<td>Lightning (No Switching)</td>
<td>IEC- Operating Duty Test</td>
<td>There is no defined energy capability measurement.</td>
<td>Cap banks and Reactors should be checked more closely</td>
</tr>
<tr>
<td></td>
<td>IEEE- Dist Class (Light, Normal, Heavy Duty)</td>
<td></td>
<td>IEEE - High Current Short Duration Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution and Transmission Lines &lt;230kV</td>
<td>IEC Class 1, 2, 3</td>
<td>Lightning</td>
<td>IEC- Operating Duty Test</td>
<td>Since the switching surge energy level is so low, lightning duty is all that may be necessary.</td>
<td>Cap banks and Reactors should be checked more closely</td>
</tr>
<tr>
<td></td>
<td>IEEE - Dist, Inter and Station</td>
<td></td>
<td>IEEE - High Current Short Duration Test and TLD Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Externally Gapped Line Arrester (EGLA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission Line &gt;230kV</td>
<td>IEC- Class 2, 3, 4</td>
<td>Lightning and Switching</td>
<td>IEC- Operating Duty Test</td>
<td>No defined energy capability measurement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IEEE- Station</td>
<td></td>
<td>IEEE - High Current Short Duration Test and TLD Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Externally Gapped Line Arrester (EGLA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution Feeders from Substations</td>
<td>IEC - Class 1 (2.5, 5, 10kA)</td>
<td>Lightning (No Switching)</td>
<td>IEC- Operating Duty Test</td>
<td>There is no defined energy capability measurement.</td>
<td>Cap banks and Reactors should be checked more closely</td>
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<tr>
<td></td>
<td>IEEE- Dist Class (Light, Normal, Heavy Duty)</td>
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<td>IEEE - High Current Short Duration Test</td>
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<tr>
<td>Substation &lt;230kV</td>
<td>IEC- Class 2, 3, 4</td>
<td>Lightning (No Switching)</td>
<td>IEC- Operating Duty Test</td>
<td>No defined energy capability measurement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IEEE - High Current Short Duration Test and TLD Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substations &gt;230kV</td>
<td>IEC – Class 3, 4, 5</td>
<td>Lightning and Switching</td>
<td>IEC- Operating Duty Test</td>
<td>No defined energy capability measurement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IEEE - High Current Short Duration Test and TLD Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riser Pole or Terminal Poles &lt;230kV</td>
<td>IEC- Class 1, 2, 3, 4</td>
<td>Lightning (No Switching)</td>
<td>IEC- Operating Duty Test</td>
<td>No defined energy capability measurement.</td>
<td></td>
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<tr>
<td></td>
<td>IEEE- Dist, Inter, Station</td>
<td></td>
<td>IEEE - High Current Short Duration Test and TLD Test</td>
<td></td>
<td></td>
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<tr>
<td>FACTS Equipment</td>
<td>IEC- Class 2-5</td>
<td>Lightning, Switching and Fault Current</td>
<td>IEC- Operating Duty Test</td>
<td>No Issues</td>
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<tr>
<td></td>
<td>IEEE – Station</td>
<td></td>
<td>plus 60143-2</td>
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<td></td>
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<tr>
<td></td>
<td>Plus Special Parallel column High Energy Devices</td>
<td></td>
<td>IEEE - High Current Short Duration Test and TLD Test</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td>Plus IEEE 824</td>
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</table>
Other ArresterFacts Available

- Arrester Lead Length
- Field Testing Arresters
- Infrared Thermometer
- Guide for Selecting an Arrester Field Test Method
- VI Characteristics
- The Externally Gapped Arrester (EGLA)
- The Disconnector
- Understanding Mechanical Tests of Arresters
- What is a Lightning Arrester?
- The Switching Surge and Arresters
- The Lightning Surge and Arresters

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