Standards:
What Now, What's Next?

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Standards are in the background of any industry but often the dynamics of standardization are ignored by most users except those who are either directly involved in their design or those who need to use them directly such as engineers at the design stage or manufacturers of goods. As far as overhead line insulation is concerned, standards are perceived as "slow moving entities", and this is perhaps a good thing given the nature of the utility world which is conservative and usually resistant to adopt new materials, new designs, new habits. Given the size and strategic importance of the assets at stake it can simply be called prudence.

In the world of overhead line insulators IEC is the dominant actor and numbers of national standardization committees adopt in one way or another the content of the work produced by IEC expert groups.

It appears that the global evolution of our climates wherever we are on the globe will quickly require another approach to make the grid more resilient and capable to cope with elevated temperatures or new stress conditions. New tests certainly need to be crafted and existing test procedures modified to adjust with the changes we see now more often every year…and perhaps it is urgent.

1. What Do We See ?

There is abundant information on the news channels showing heat waves with record breaking temperatures, longer dry seasons, tornadoes in areas which did not have such events so far, more brutal and stronger wind events, floods and unexpected rains in desertic areas, wildfires, mud slides, unexpected snowfalls, ice and more….nothing which does not exist, but it becomes more intense and sometimes hits countries and areas which had moderate climates and unprepared for such events.

As an example figure 1 [1] shows the latest highest records of air temperature worldwide and it is stunning to see how may places have now reached temperatures at or above 50°C. The change in temperature is certainly the most visible direct phenomenon for the populations and linked to longer and harsher dry periods it also affects the risk of having more frequent and larger wildfires.

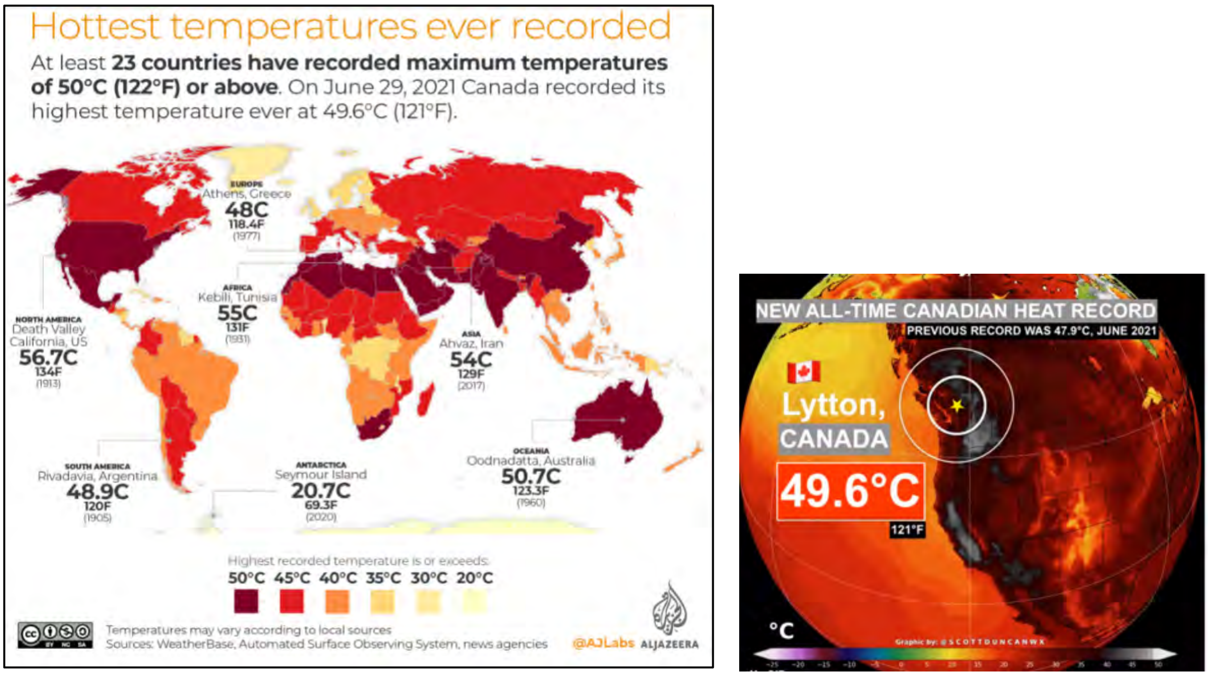

Figure 1 : Hottest temperature ever recorded worldwide [3] and focus on Canada

2. Impact on Overhead Line Insulator Standards

Most utilities have engaged into resiliency and grid hardening programs, looking at all the components of transmission lines and how to best run the grid under such constraints. When concentrating on insulators there are new issues which need to be addressed and probably with an impact on most standards.

To illustrate this point, figure 1 shows the case of the town of Lytton, Canada where a temperature of 49.6°C was measured in June 2021. Canada being a relatively cold country, it is interesting to note that the insulator standard CSA 411.1-16 [1] nevertheless calls for some tests to be performed at a maximum temperature of +50°C.

One would consider that Lytton was at the limit of the standards, but this is misleading since air temperature is different from the contact temperature measured on objects under the sun. In the case of insulators all the tests are performed with air temperatures set at the required value the standard is asking for. A maximum temperature of +50°C is therefore an air temperature and does not take into consideration what really happens in the field. This was probably not a major concern as long as temperatures do not hit the values shown in figure 1 and which may be exceeded in the coming years.

Figure 2 shows the difference between air temperature and contact surface temperature measured in the yard of our Research Center this summer where air temperature was around 37°C. the temperature on the fittings of several insulators was measured and established around 53°C and 55°C. it is expected to see fitting and insulator temperatures under the sun in extreme summer time conditions reach 70°C, even 80°C or more. This is far above the +40°C stipulated in IEC 60383-1 [2].

Figure 2 : Temperature gap between air temperature and contact on insulator fittings

Another illustration of this is visible in figure 3 with actual temperature readings air and land in Spain July 11th, 2023, where the difference exceeds 20°C. Having this in mind insulators are no longer tested at the correct temperatures.

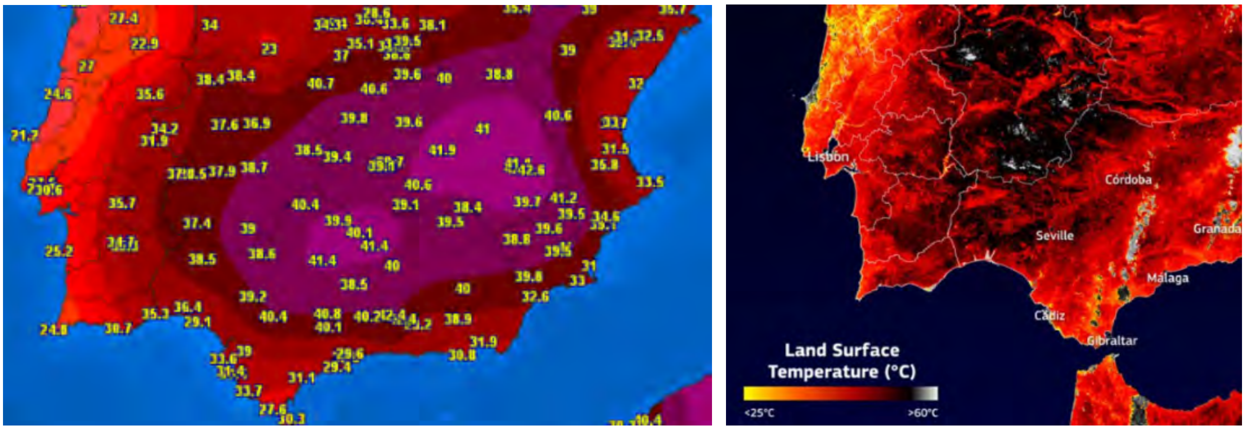

Figure 3 : Difference between air temperature and land temperature in Spain July 11th, 2023

This shows a need to probably review all the standards, mainly those involving temperatures such as thermo-mechanical test to reach out to higher temperatures. As a reference today Saudi Arabia standards call for a hot temperature of 65°C while IEC 60383 [2] is limited to +35°C and CSA 411.1-16 [1] to +50°C.

3. Temperature Stability of Overhead Line Insulators

Depending upon which insulator technology is involved there are some basic parameters to consider when dealing with high temperatures. The most common parameter is the relative linear expansion of the various components of an insulator especially for glass and porcelain as shown in figure 4. The biggest challenge is for porcelain which faces a mismatch of coefficients between the porcelain body and the metal parts. This can lead to unexpected structural degradation of the porcelain body leading to potential punctures or an acceleration of the aging of porcelain.

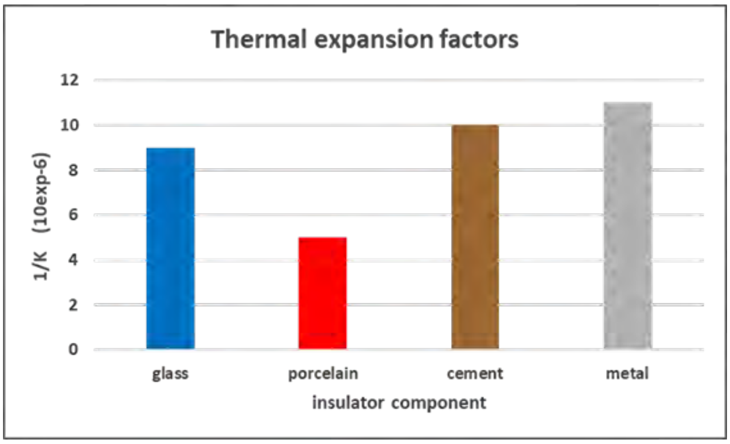

Figure 4 : Linear thermal expansion factors of components used for glass and porcelain insulators

For polymer insulators the biggest challenge at high temperatures is the mechanical stability of the combination between the fiberglass rod and the crimping of the end fitting on the rod. Compression crimping requires a balance between applied force and pressure on the rod avoiding breaking the rod while putting enough grip between the fitting and the fiberglass rod. This operation when done correctly is under the supervision of acoustic or other types of sensors detecting a possible damage in the rod. One of the real questions when considering high temperatures is the upper limit of the tests recommended in IEC or other standards. The upcoming IEC 62217 [4] clearly mention that the maximum operating conditions should be +40°C and no continuous exposure above +35°C which is consistent with all polymer standards such as IEC 61109 [5], ANSI C29 11 [6] and others .

A real question here is the evaluation of the risk of relaxation of the compressive strength of the fitting to rod connection. An important parameter is the Tg, which can be described as the softening temperature of the resin system of the fiberglass rod which is not described at all in any standard.

Figure 5 shows the evolution of this parameter with temperature on several commercially available rods used in polymer insulators with a reduction of stiffness starting around 80°C for some of them which could become a problem considering actual and future contact temperatures of end fittings in some hot countries.

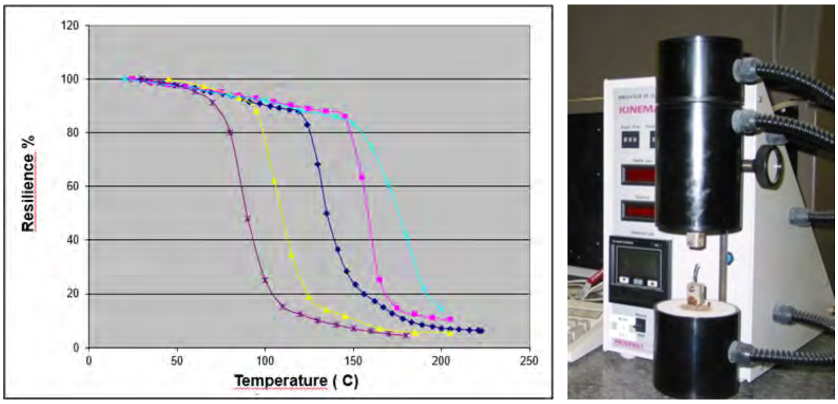

Figure 5 : drop of stiffness in a flexural test using a Trombomat (slice of rod placed between two clamps tested in torsion while the temperature is being increased.

4. Wildfire & Extreme Heat Conditions

Power lines can be seriously deteriorated when directly facing a fire. Distribution lines are more impacted than transmission lines, but the latter is also a risk depending on the fire size. Bush fires might not have the same consequences on the lines than forest fires which may generate high temperatures far beyond the direct location of the fire, with possible extreme heat around lines which after the fact do not appear to be damaged at least from a visual inspection level.

The question of resiliency of insulators under extreme heat is therefore essential and is raising interest by numbers of utilities who suffered destruction and casualties in the surrounding communities during wildfire events.

The study described hereafter is aimed at determining the evolution of mechanical strength of porcelain, glass and polymer insulators under extreme heat, and a large spectrum of insulator brands and designs was used for this program as shown in figure 6.

Figure 6 : Diversity of brands and designs used in in the test program

For porcelain and glass insulators the main factor of influence is the compatibility of linear expansion factors as shown in figure 4.

The test protocol was concentrating at the M&E strength of various porcelain insulators after being subjected to high temperatures for a duration of 3h. Figure 7 show the results as a function of temperature and it must be noted that none of the samples failed mechanically but all the tested units showed a consistent pattern of puncture inside the head, which materialize in a failure during the ANSI C29 2B [7] M&E test.

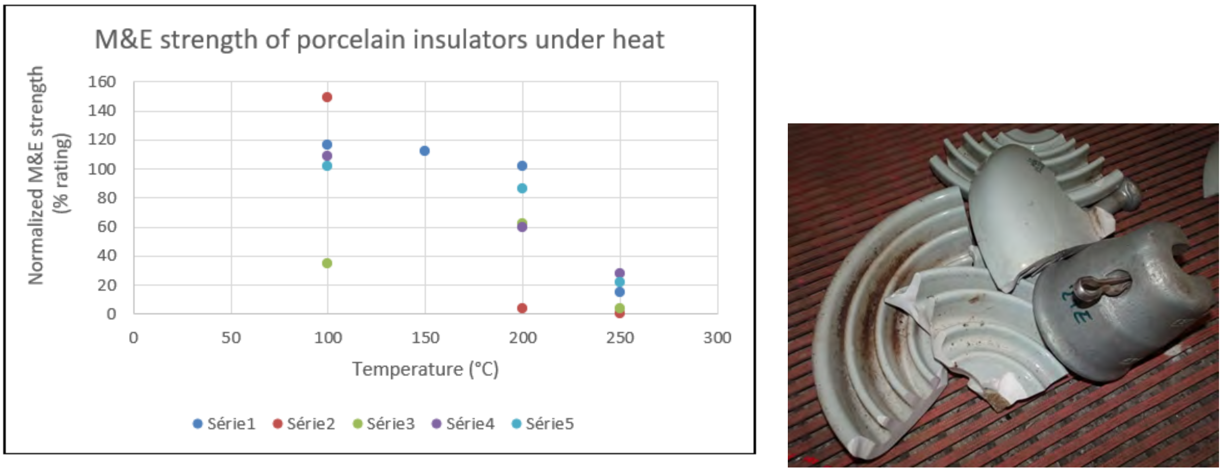

Figure 7 : M&E test results of porcelain insulators subjected to extreme temperatures for 3h

The same exercise was applied to toughened glass insulators with the results shown in figure 8 producing results in line with normal insulators performances . it can be noted that for some brands the use of Portland cement has led to slightly lower results than those using hot cured alumina cement.

(Given the immunity of toughened glass in the temperature range for which porcelain was tested the program was expanding to higher temperatures).

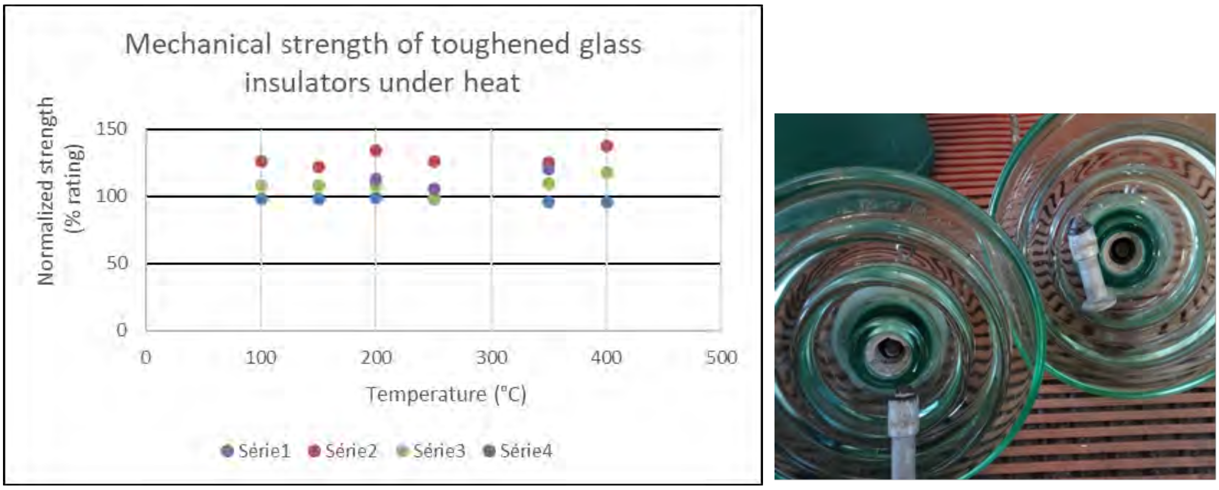

Figure 8 : Mechanical test results on toughened glass insulators and failure mode. (According to IEC and ANSI toughened glass insulators are only tested in mechanical mode and not M&E like porcelain since no internal puncture can take place)

The possibility for having the glass shell shattered during such strong heat events has led to an additional test where stubs (broken glass discs) were tested under similar conditions with the results shown in figure 9. These results need to be compared to the requirements of the residual strength tests in ANSI and IEC where a minimum of 65% of the rating is required. All the test samples pass this test with one manufacturer still above 80% of the initial rating.

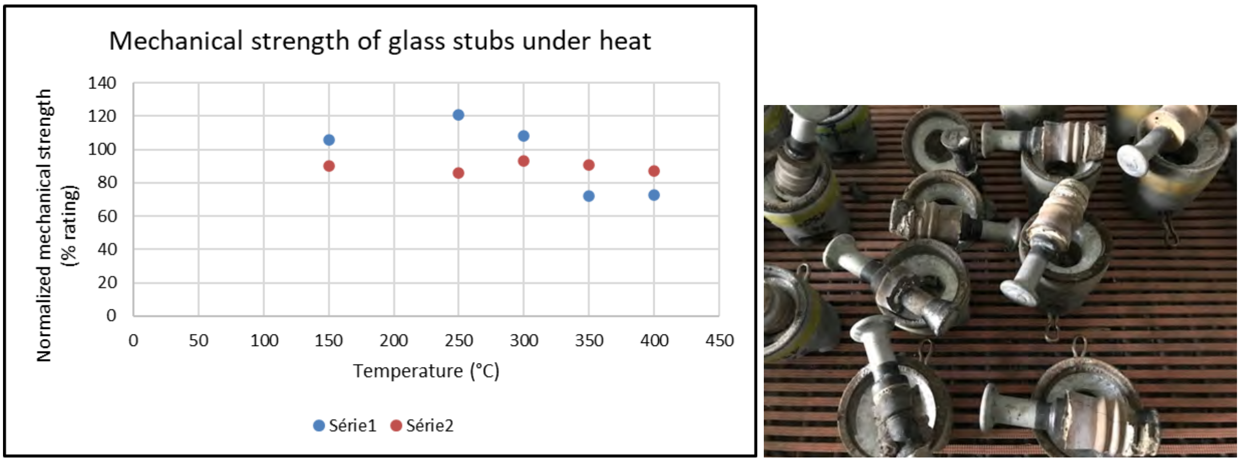

Figure 9: Residual strength test of toughened glass insulators under extreme heat and failure mode

When testing polymer insulators, the results were very different (figure 10) and the failure modes which were very consistent across the brands and designs show that the main contributing factor was a relaxation of the crimping stress associated to the softening of the fiberglass rods leading to a decrease of mechanical strength.

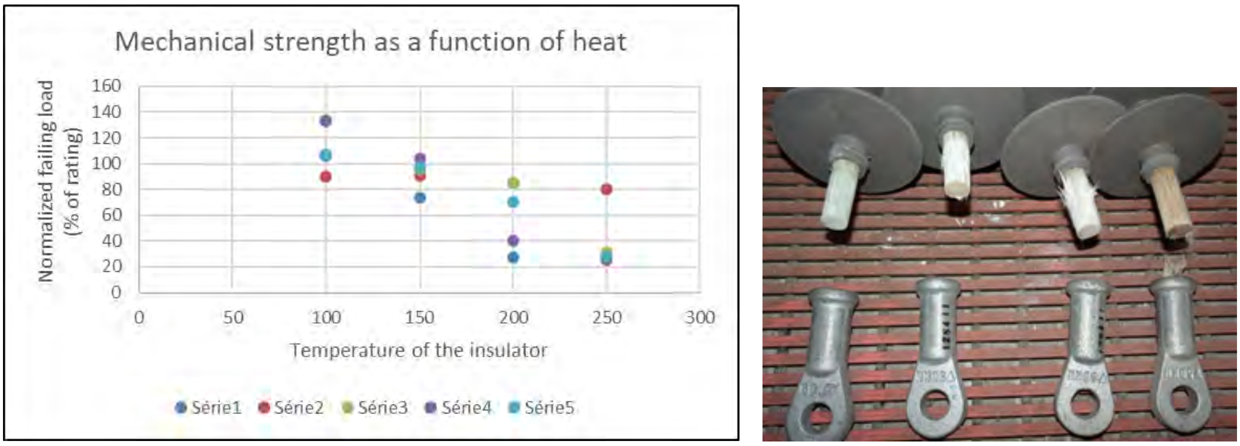

Figure 10 : Strong reduction of the mechanical strength of polymer insulators and typical failure modes

Given the results obtained in this test, an additional test was performed to establish the time needed to lose strength. The results are shown in figure 11 with evidence that the phenomenon takes place rapidly for most cases.

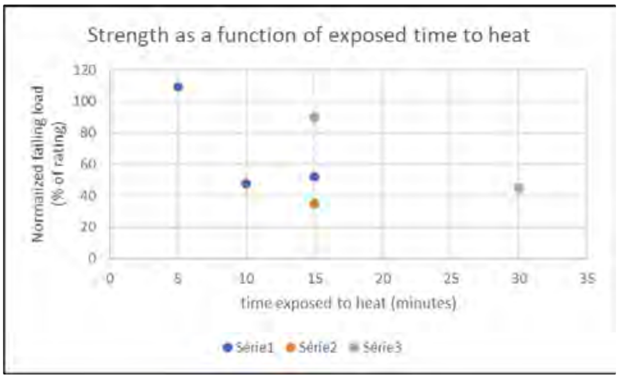

Figure 11 : Drop of strength of polymer insulators as a function of exposure time to heat (300°C)

Conclusions & Future Directions for Standards

The evolution of the environmental and climatic conditions worldwide is already imposing temperatures on insulators which are beyond what they are tested for. New tests and new test parameters should be drafted to better cover the ability of insulators to cope with elevated thermal stresses we start to see in the field. Likewise, the resiliency of insulators in extreme temperatures such as those encountered near wildfire should be considered.
Among these changes in standards :

- Modification of the hot temperature value of thermo-mechanical tests
- Description of the Tg of polymer insulators fiberglass rods
- High temperature tests on all three technologies to determine and characterize the upper temperature limits before there is a strength reduction as well as time limit before a reduction of the mechanical strength (or M&E) appears.

References:

[1]: CSA 411.1-16. AC suspension insulators
[2]: IEC60383-1 Insulators for overhead lines with a nominal voltage above 1000V Part 1. Edition 5.0 2023
[3]: AL Jazira news
[4]: IEC 62217, “Polymeric HV insulators for indoor and outdoor use - General definitions, test methods and acceptance criteria”
[5]: IEC 61109, “Insulators for overhead lines - Composite suspension and tension insulators for a.c. systems with a nominal voltage greater than 1 000 V - Definitions, test methods and acceptance criteria”, Edition 2.0, 2008.
[6]: ANSI C29 11 Composite insulators. Test methods
[7]: ANSI/NEMA C29 2B wet process porcelain and toughened glass transmission suspension type