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Design and Testing of a 230-kV MICA

Molded insulator
cross-arm assembly
for the Brazilian
transmission system



Introduction

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Abstract

This paper presents some results on the development and testing of a molded composite insulator cross-arm assembly (MICA) for the 230 kV system voltage level resulting from a Eletrobras R&D program developed in Brazil.

It's a part of the worldwide efforts to develop this new tower design technic that has on continuous growth on last years.

Although composite insulator use is now spread everywhere on all HV, EHV and UHV applications, with huge knowledge and consistent design & testing standards, the use of such insulators on tower cross-arm constructions still be a challenging, imposing the need for a better understanding on their behavior as a mechanical tower component together with their initial insulating purposes.

At the time of this publication, working groups in IEC and CIGRE [1, 2] are conducting a major worldwide study to stablish suitable design and testing procedures applicable to this new appliance on polymer insulators for TL projects – this work intend to be a part on this challenging effort, just another drop of water on this endless sea that are been opening in front of all of us.

Key words: Line compaction, Line uprating, Tower design, Insulated cross-arm, Molded Insulator Cross-arm Assembly, composite insulator cross-arm

Background

Insulated cross-arm assemblies with composite insulators have been used on the HV transmission systems worldwide for decades. We consider on this affirmation mainly the use of Line post insulators as per IEC 61952 std. [3] and braced post solutions based in line-post supported by tension insulators; both used as per application guides like IEEE 1572 [4].

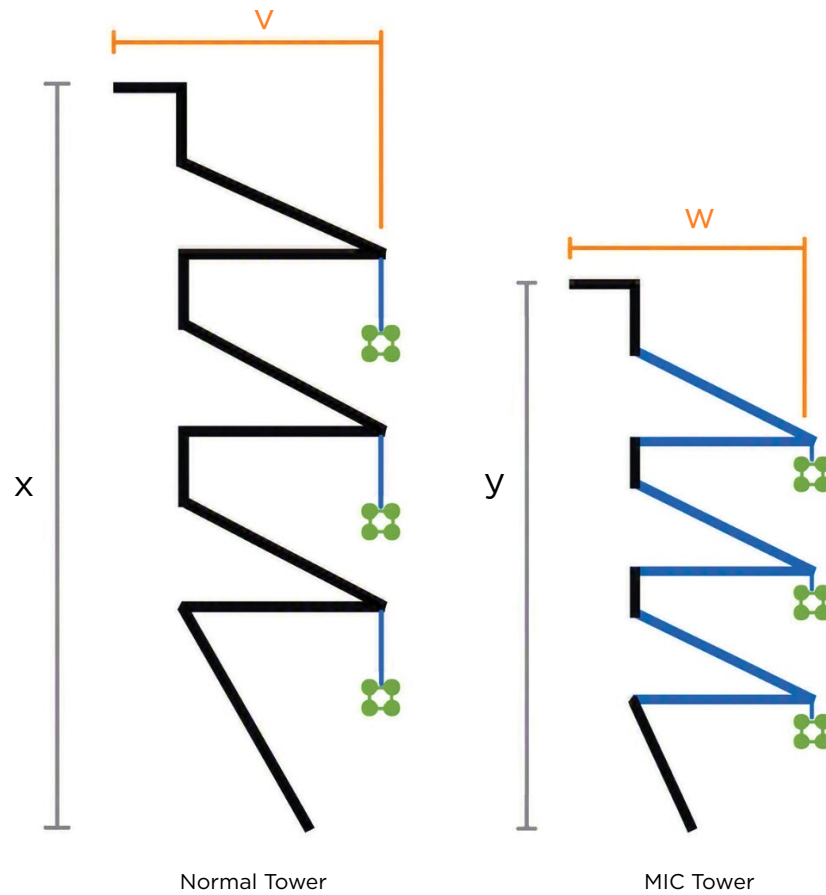
The application of line-post and braced post solutions has limitations related to the low longitudinal forces withstand capabilities, and such applications are dominant on dense urban areas, where the establishment of ROW paths became challenging for the growth on the power supply needs at large cities.

Due to these mechanical limitations, it's more usual to find such applications at voltage levels up to 230 kV, with a few exceptions.

The use of three or more composite insulators to design an insulating cross-arm able to withstand longitudinal forces like the metallic ones present on the regular lattice towers is a more recent development that is now becoming a disruption on the tower and lines design, with a clear impact on the line compaction and uprating possibilities to existing towers on TL [5].

This renewed interest in this old idea [6] is related to the growth on experience and knowledge of composite insulators.

The resultant insulated cross-arm on this design can withstand the tri-axis forces on lines above 230 kV up to UHV appliances [20].



Where:

- Grounded Part
- Insulated Part
- Phase
- Tower Height
- Tower projection

$$x > y$$

$$v > w$$

Figure 1 - Comparison between standard double-circuit suspension type tower and a MICA design for the same voltage level - adapted from [5]

This insulating cross-arm application is now starting to be studied on the power community [1,2,7] to generate deeper knowledge on the design concept, relevant electro/mechanical considerations, and adequate testing procedures that cover all new exigencies from such technology and their impact on TL design.

In this paper will be presented some development, construction and testing conducted in Brazil on a 230 kV tower and their 230 kV MICA.

Construction

For this project, based on a design of a typical 230 kV single circuit line established by Eletrobras [8], Balesbro Hubbell have designed a double V MICA able to withstand both electrical and mechanical requirements assigned for the line structures, and the tower manufacturer SAE Towers have designed a 230 kV single circuit lattice tower in triangular configuration to be fitted with the 230 kV MICA and withstand the worst case conditions mechanical performance on the line project, as per the applicable standards [9,10].



(a)



(b)

Figure 02 – First 230 kV MICA prototype (a) and a 3D render of the 230 kV tower (b)

Eletrobras CEPEL have conducted characterization testing on the line-post insulator rods to verify elastic properties and compression at an eccentric loaded rod, one of the key features related to the assessment of Euler buckling load for a MICA design related to the combined loads and to their increase on the longitudinal force withstand when compared to the braced-post solution.

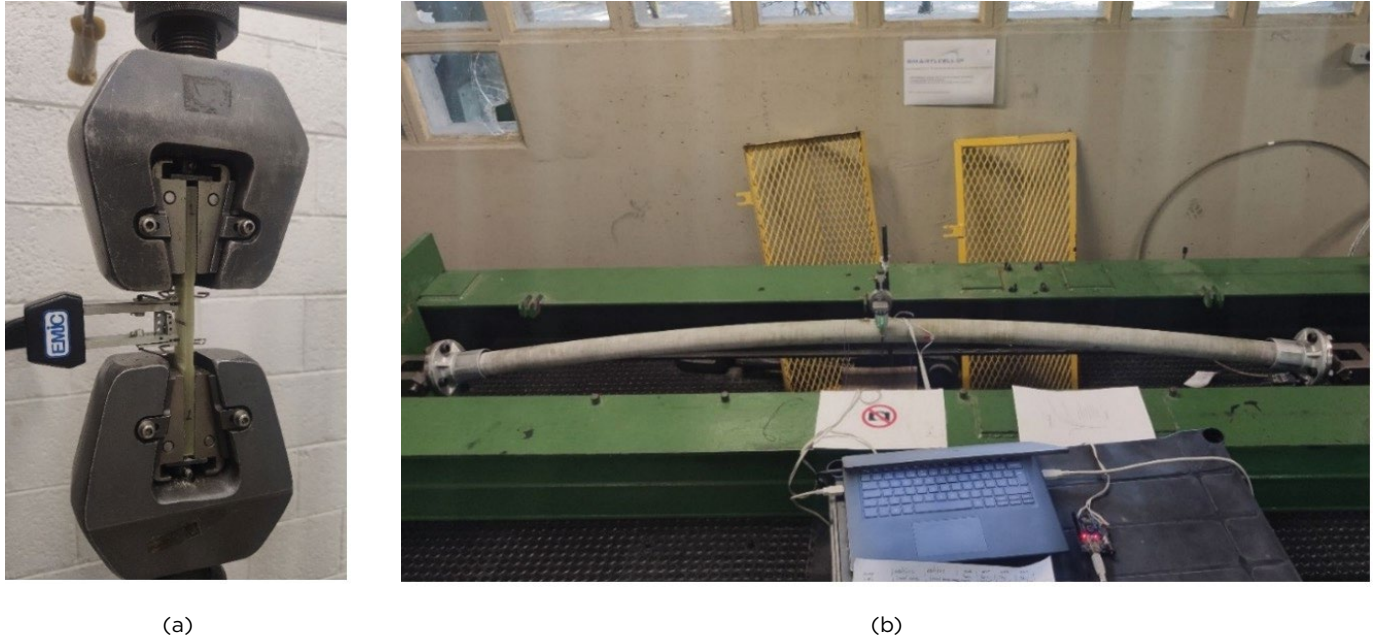


Figure 03 – Mechanical characterization – Measuring elastic properties at coupon test (a) and the eccentrically axially loaded behavior on a full-length rod (b)

The most relevant element on MICA design related to the growth on the longitudinal mechanical behavior is the line-post insulator in the base triangle working at compression forces. Due to the orthotropic nature of the FRP rods, the mechanic and elastic response of such insulator is related to the force direction, and according to Euler's critical buckling load expression [11], the buckling capacity are related to the axis symmetry of this force and the kind of freedom in the movement at the end points of the compressed rod, basically by:

$$P_{cr} = \frac{\pi^2 E I}{(K L)^2} \quad (1)$$

Where:

PCR = Critical axial force for flexural buckling of the rod, N,

E = Elasticity modulus, MPa,

I = Inertia moment of the rod cross-section area, $I = \frac{(\pi d^4)}{64}$, d is the rod diameter, mm,

K = Effective length factor, that is related to the rod end degree of freedom (can vary between 0.5 and 2.0, from none to full freedom – for this case their value is 1.0),

L = The effective length (unsupported) of the rod, mm.

Mechanical Testing

This expression only applies to high slenderness ratio, as in case of long rod line-post insulator.

The conducted testing presents a good agreement on theoretical to practical behavior, as shown in figure 04 below. The results according to a geometrically non-linear spatial beam finite element analysis [12] are compared to the experimental data for the long rod.

A good correlation was found for small displacements, scattering gradually for greater displacements, leading to conservative elastic properties for Euler buckling load calculation in MICA design, which leads to a safe approach.

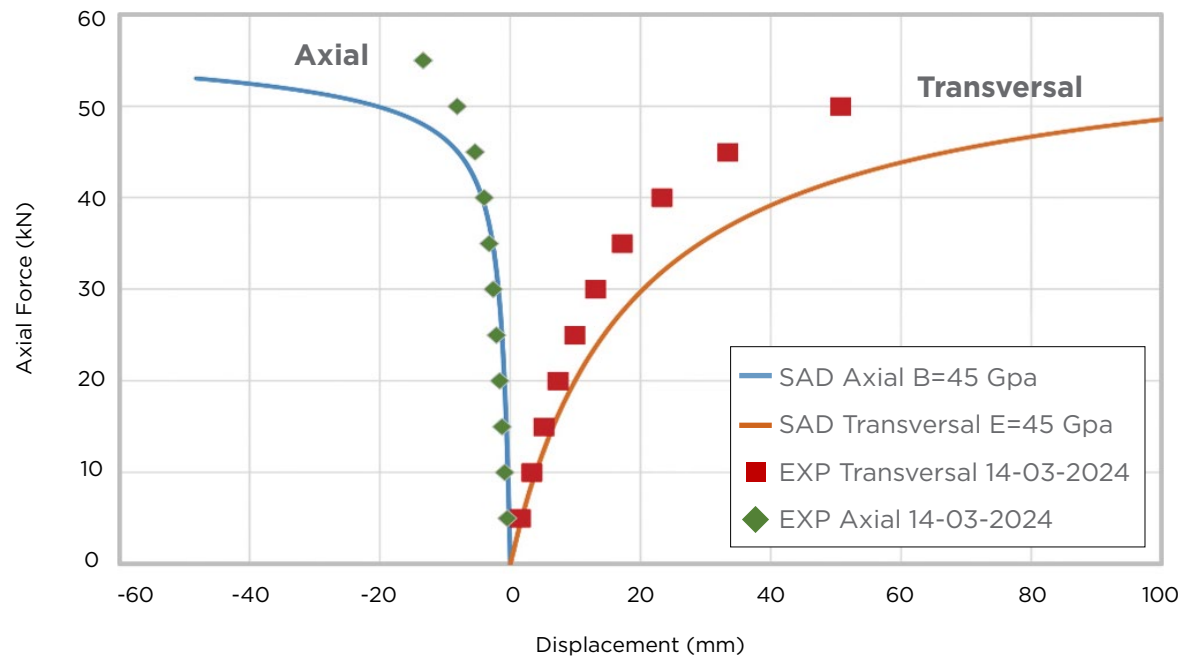


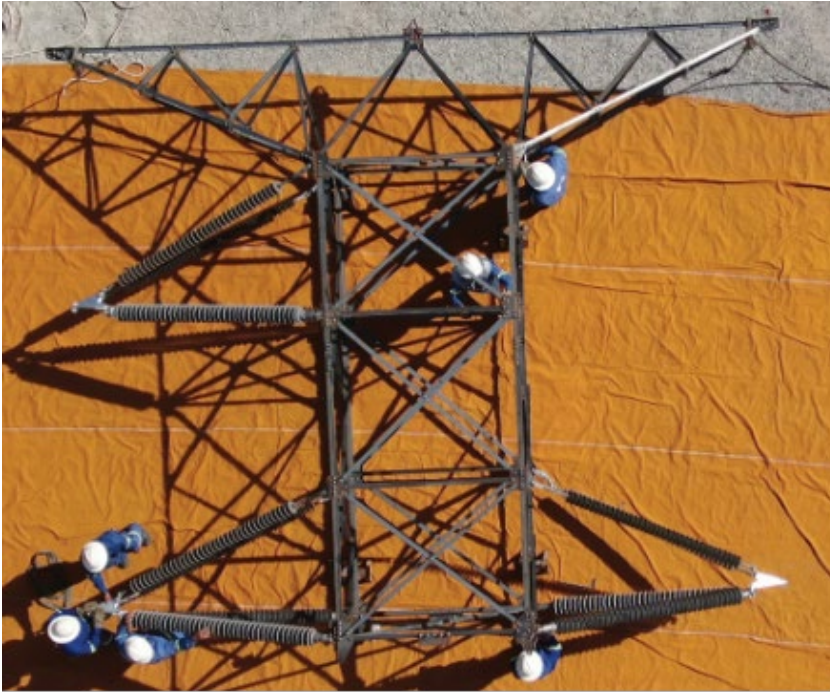
Figure 04 – Compression axial force x displacement on both axial and transversal directions – Calculated (SAD) x measured (EXP) for a 2.5” rod with 2.48m long, applied force eccentric 15mm on both sides from rod axis (intentional)

The full tower for this project was mechanically tested at SAE Towers test station for the worst-case scenarios [8] for the mechanical 3 axis forces expected on the field [13]. From the MICA point of view, the most relevant mechanical loads were applied on the cases at table 01.

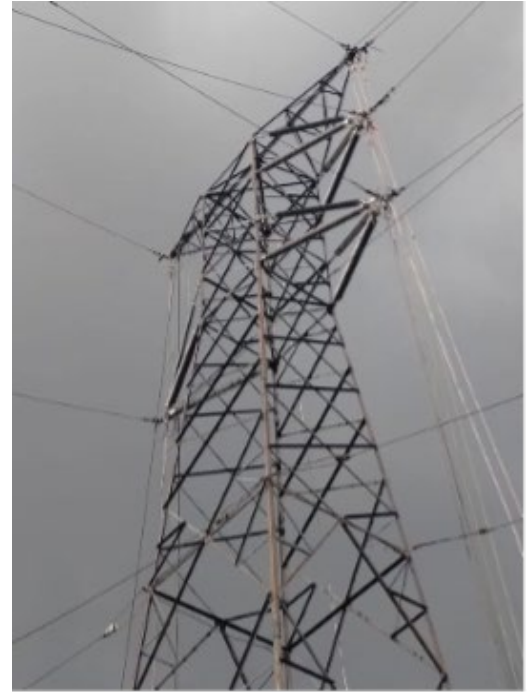
Table 01 – Applied loads to the MICA 230 kV at tower testing
Applied forces on the most stressed MICA 230 kV
One #AAAC 1120 838 kcmil conductor, mid span 500m, max span 600 m

Case:	Vertical Load (kN)	Transverse Load (kN)	Longitudinal Load (kN)
Extreme Wind @ 15°	8,07	21,32	1,96
Extreme Crosswind	8,07	22,29	0,00
Cable laying	25,00	1,87	1,88
Broken phase conductor	3,03	1,02	13,70
Cascade restraint	8,07	0,30	6,85

For this project in those cases the applied forces had shown to be below the expected maximum combined loading for the MICA itself, and a large trial test on a reaction wall is already planned to find the ultimate strength on this design.



(a)



(b)

Figure 05 - Tower erection (a) and mechanical testing at SAE Towers test station (b)

The full-tower tests, although mandatory, showed a result influenced by the tower movement, and no visible buckling in the MICA line-posts insulators at compression conditions. The future work on the CIGRE and IEC WG [1,2] and the recent publication of IEEE [7] should address some more specific mechanical testing for the insulating cross-arm and both designers and users will be involved in their improvement.

Electrical Testing

Electrical Testing

All electrical testing was performed at CEPEL Labs, in Rio de Janeiro [14, 15]. It's important to point out that this lab is almost at sea level, what means that in some testing the correction factors at applied voltages can move to lower than applied voltages, and of course all shown results are corrected ones according to [16,17], with correct factor k in some cases higher than 1.0.

This design of a MICA that is adequate to 230 kV system voltage level requires the below withstand voltages according to IEC standards [17-18]

- Dry and wet power frequency withstand voltage level: 460 kV_{RMS}
- Lightning impulse withstand voltage (BIL): 1050 kV_{PK} both polarities
- RIV measurement @ 1Mhz [19] and 156 kVRMS: maximum 500 uV
- Minimum positive corona extinction voltage: 156 kVRMS
- Power arcs withstand capability: 30 kARMS

Additionally, as a research program, some other testing was performed:

- Critical lightning impulse flashover voltage determination (up-and-down method)
- Critical wet switching impulse flashover voltage determination (same method)
- Withstand impulse voltages by statistics approach ($V_{10\%}$)

High Voltage Power Frequency Testing

For the electric tests in this case a section of the real tower with two 230 kV MICA and the ground wire metallic cross-arm were mounted in the HV Lab, with tubes simulating all the wires of the real tower (including the ground wire). The bottom phase tube was erected to 6.0 m above the HV lab ground.

We can see in table O2 that the upper phase has a small reduction on the minimum arc distance due to the metallic ground wire cross-arm, and this plays a hole on the testing numbers.



Figure O6 - Tower mounted at HV LAB for impulse (a) and power frequency (b) voltage tests [14]

This is an innovative way to test this tower, as the differences in height to the ground from both MICA and the presence of all wiring reflect some differences in test results. The phase tube that is not being tested was kept grounded as well as the tower and ground wire.

Table O2 - Electrical Testing Results on MICA 230 kV Setup

Test:	Bottom MICA	Upper MICA
RIV, step cycles between 56 and 160 kV (μV)	8 to 10	8 to 10
Corona with Daycor UV camera (kV_{RMS})		
Positive corona inception voltage	214 to 218	198 to 200
Positive corona extinction voltage	194 to 206	186 to 199
Lightning impulse withstand voltage (kV_{PK})		
Positive polarity, 15 impulses, no flashover	1090	1079
Negative polarity, 15 impulses, no flashover	1090	1079
Critical Lightning impulse flashover voltage (kV_{PK})		
• $V_{50\%}$ positive polarity	1250	1169
• $V_{50\%}$ negative polarity	1515	1463
• $V_{10\%}$ positive polarity	1172	1069
• $V_{10\%}$ negative polarity	1438	1365
Critical wet switching impulse flashover voltage (kV_{PK})		
• $V_{50\%}$ positive polarity	-	861
• $V_{50\%}$ negative polarity	-	1080
• $V_{10\%}$ positive polarity	-	794
• $V_{10\%}$ negative polarity	-	995
Dry and wet power frequency withstand voltage, 60s (kV_{RMS})	-	460

Note: measured minimum arc distance on the setup structure results:

Upper MICA = 1,870 mm, bottom MICA = 2,060 mm

High Voltage Power Frequency Testing

For RIV and corona effects the design approach was conservative, considering the complex geometry on the “live” nose of the MICA and the design rings shown an efficiency above than needed, as per the measured RIV values near to background noise.

The corona inception and extinction voltages also surpass the values established for the MICA voltage class ($UM = 245 \text{ kV}$ – Test voltage = $245/\sqrt{3} * 1.1 = 156 \text{ kV}$). In fact, it's possible to see by the figure 07 below that the nose and insulator rings have no ionized point on a higher than established test voltage, with the corona inception starting at 214/198 kV (bottom/top cross-arm values) from the cable protecting armature.

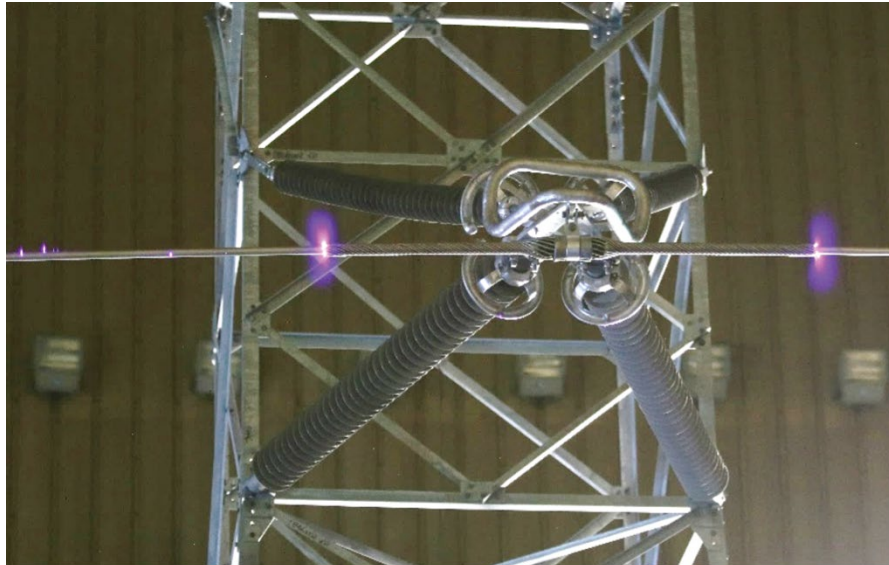


Figure 07 – Positive corona at inception voltage starts in the borders of the cable protection armature hardware.



Figure 08 – Generalized corona effect forced by much higher voltage – Only the most extreme parts on the insulator rings and the external point on the nose protection ring shows ionized activity in this extreme condition above voltage class level.

The wet power frequency withstand voltage was also performed using this same circuit arrangement (as per figure 06 (b)) and have no remarks (see table 2). CEPEL doesn't perform the power frequency disruptive testing for safety reasons on the testing transformers.

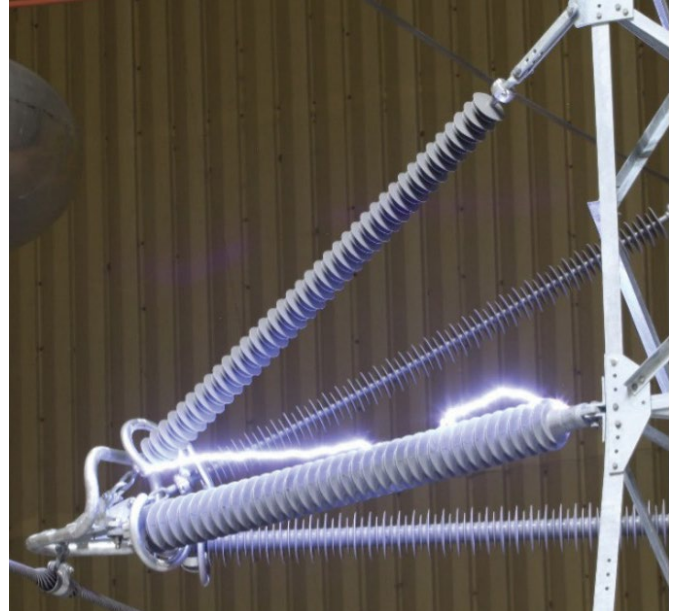
High Voltage Impulse Testing

Moving to impulse voltage testing, the effects on tower position, impacts on actual arc distances of the MICA assembly and the complex geometry produces expected deviations on the voltage numbers (see table 2), the influence on the design of the MICA components can play a role on such behavior and must be considered by both MICA and tower manufacturers.

On this testing campaign, the balance found in different disruptive points showed that both MICA and tower manufacturers had taken care to avoid “hot spot” weak points, and the expected withstand voltages were fully met.



(a)



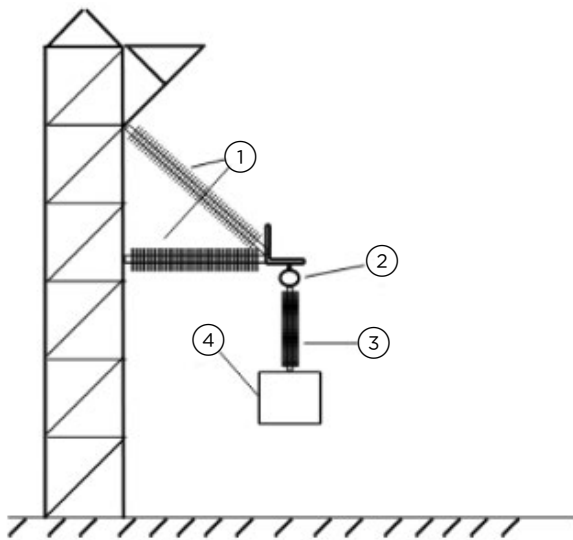
(b)

Figure 09 – Impulse flashover behavior on bottom 230 kV MICA – The balance between the disruptive discharges on different points of the MICA showed a well distributed design. Dry switching surge (a) and lightning surge (b)

Power Arc Testing

One 230 MICA was assembled on a fraction of the tower in the HP laboratory of CEPEL to be tested for power arcs. The arrangement on the test circuit was agreed by the research team to be equivalent to the real case tower and fulfill as many as possible with the power arc test standard [23].

The constructed testing circuit is like the design C on this standard, with a balanced supply of the SC current by the line cables and unbalanced return on the tower section. A vertical mechanical load was applied on the connecting point on the MICA nose.



(a)



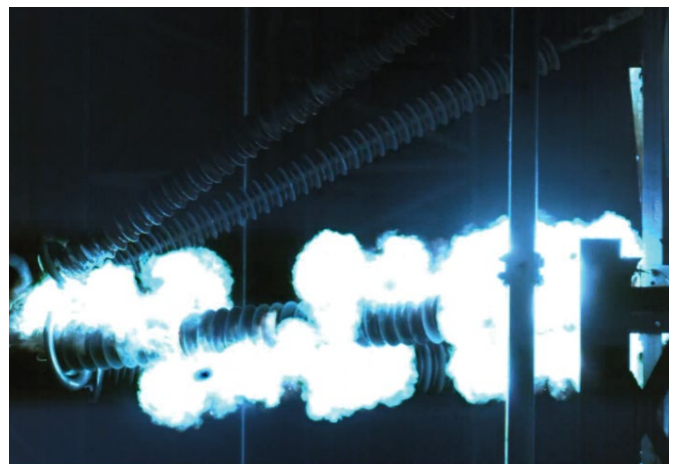
(b)

Figure 10 - Power arc setup diagram and mounted test circuit picture [15]

The testing was performed with effective current of 30 kA by 0.1 s, as defined as minimum requirement for a 230 kV insulator on the Brazilian power system [24], the arc current applied twice on tension and line-post insulators, with good result and no remarkable damage. The final mechanical verification was applied only to tension insulators with no remarks.



(a)



(b)

Figure 11 - Power arc pictures on HS camera images at tension insulator (a) and line-post insulator (b) [15]

It's important to notice that the insulators used on this project (long rod tension insulator and line-post) have already been tested to power arc withstand up to 50 kARMS on individual applications.

Discussion and Conclusions

It was verified by other authors [20] that the complex geometry of the MICA design plays a role in the discharge paths on the impulse up-and-down and disruptive discharge in power frequency voltage testing, as we also can observe when testing line-post installations, that have a different behavior than the usual insulating chain for standard tower construction.



Figure 12 - Wet power frequency flashover voltage on a 230 kV 12° angle upside tilted line-post insulator - The arc voltage path is different than a suspension chain

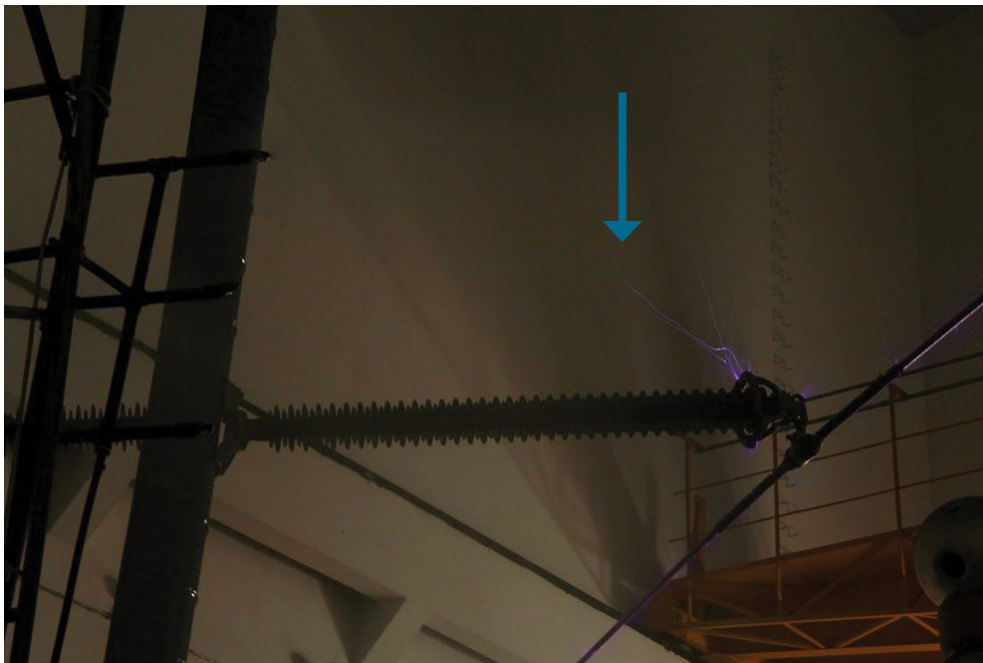


Figure 13 - Same condition of previous picture a few moments before disruption - note that the voltage streamers seem to be going up, attracted by the tower body more than from the insulator base

Discussion and Conclusions

For the MICA manufacturer a deep understanding of the effects of geometry on electrical behavior of insulating cross-arm assemblies are a mandatory requirement.

In case of line upgrading/uprating on existing towers, this is a very sensitive parameter to the MICA designer to take care of, the face elements at the tower on the MICA position must be evaluated to consider their impact on to the disruption phenomena.

The confluency of the four insulators in the live point of the MICA at the nose demands careful design of insulators protection rings for their proximity, and an EF simulation shown to be a useful tool to visualize and adjust their design to prevent electric damage to the insulating material due to concentrated electric fields on this confluency point.

In this work CEPEL have handled such EF simulating using COMSOL® software.

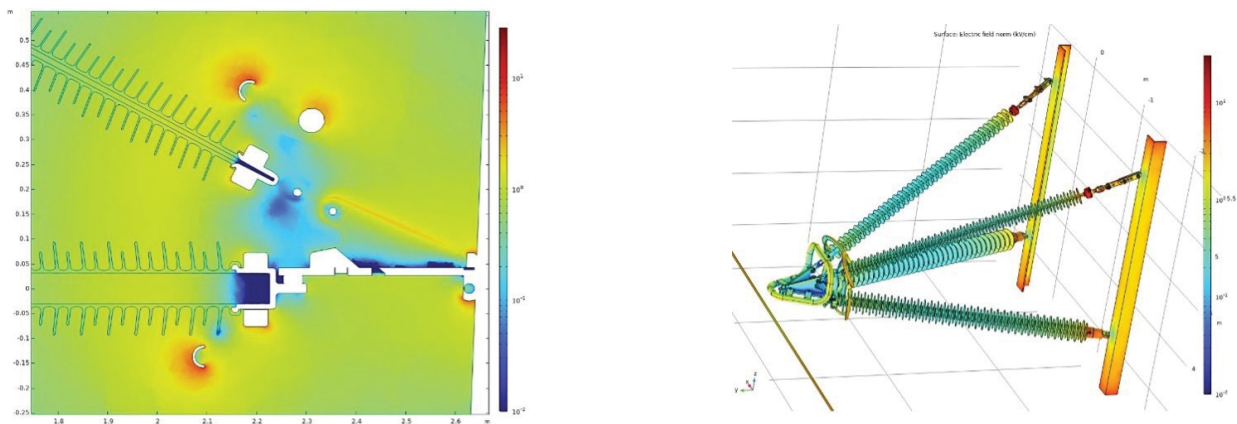


Figure 14 – Preliminary EF simulation on the 230 kV MICA using COMSOL® software

The simulating results show a very protected HV live parts and the highest concentrated fields at outer ring parts, with a stable and well distributed EF on the insulating surface, as required in the state-of-the-art on the use of polymer insulators [21, 22], the field concentration at the hardware agrees with figure 08 on corona effect.

On power arc testing the applied peak current shown that the actual power arc capability on this MICA 230 kV design can be higher than tested. The IEC standard test method [23] may need to be reconsidered for the insulated cross-arm testing.

The appliance on some combined loading during the test can be considered by the WG's on research and standard boards. This can demand on the HP labs to have a proper reacting wall to support the testing setup and involved mechanical charges and can be carefully discussed – and can be very costly.

The current return circuit will always be the unbalanced one.

The arc current application can be distributed in between both tension and line-post insulators, as they reacts in different ways to the power arc, but the number of applications can reach up to 6 times, and the effects of this total number of power arc applications must to be considered for all elements and need to be researched, together with the combined loading that the authors propose.

The last published IEEE document on MICA application and testing [7] is proposing some promising testing, especially in both static and dynamic mechanical testing that will promote further discussions and research activities worldwide. This document where being written at the time this research work was being done.

The authors would like to point out that the mechanical behavior of the MICA during the time must be also evaluated. The ageing on mechanical performance can consider that such devices must stand huge enough within 30 years of life, as per from the Brazilian utility's expectancy. Proper design predictions must take care of this, and some additional mechanical testing on both new and pre-aged/stressed MICA will be useful, and still to be studied/developed.

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References:

- [1] – IEC TS 63594 ED1 – Work in progress by JWG 25 of TC 36 and TC 11 – Composite insulated cross-arms with voltage greater than 1000 V and DC voltage greater than 1500 V – Definitions, design criteria, test methods and acceptance criteria – Planned to be published in 2027
- [2] – CIGRE WG B2.96 – Composite insulated cross-arms for new-build and retrofitted transmission line supports – WG started in 2025, planned to finish 2028
- [3] – IEC 61952:2008 – Insulators for overhead lines – Composite line post insulators for A.C. systems with a nominal voltage greater than 1 000 V – Definitions, test methods and acceptance criteria
- [4] – IEEE 1572-2004 – Guide for Application of Composite Line Post Insulators
- [5] – R. Junior, C. K. C. Arruda, R. W. Garcia, J. C. Salari Filho, A. Dellalibera, The technological Disruption Caused by the Composite Insulator Crossarm in the High Voltage Transmission System, in IEEE 7th International Conference on Electrical Engineering and Green Energy – CEEGE, Los Angeles, USA, 2024 – Paper G3303
- [6] – I. Kimoto, K. Kito, K. Ueno, Insulator Crossarms for 345 kV EHV Transmission Line, IEEE Transactions on Power Apparatus and Systems, vol. PAS-90, nr. 2, March/April 1971 – Paper 70 TP 628-PWR
- [7] – IEEE Std. 2833-2024 – Guide for Overhead Transmission Lines with Composite Insulated Crossarm Supports
- [8] – Eletrobras – Research project PD-00394-2113/2021– Reference term for a 230 kV MICA tower, 2023
- [9] – IEC 60826:2017 – Design criteria of overhead transmission lines
- [10] – IEC 60652:2021 – Overhead line structures – Loading tests
- [11] – J.-P. Marais, Understanding Load Capacity of Post and Braced Post Insulators, EPRI PLS-CADD Advanced Training and User Group, Power Line Systems, 2019
- [12] – Estrella, L. F. – SAD/TLT program – Installation, register and data base – CEPEL report 7624, 2018
- [13] – SAE Towers - Tower test report BL-R8240-CEP-114-23-001, April 2024
- [14] – CEPEL test report DEE – 549/2025 – MICA 230 kV – High Voltage tests
- [15] – CEPEL test report DEE – 1279/2025 – MICA 230 kV – Power arc tests
- [16] – IEC 60060-1:2025 – High voltage test techniques – Part 1: General terminology and test requirements
- [17] – IEC 60071-2:2023 – Insulation coordination – Part 2: Application guidelines
- [18] – IEC 60071-1:2019 – Insulation coordination – Part 1: Definitions, principles and rules
- [19] – NEMA 107:2016 – Methods of Measurement of Radio Influence Voltage
- [20] – Q. Wang, X. Liang, Y. Shen, S. Liu, Z. Zuo, Y. Gao, Lightning flashover characteristics of a full-scale AC 500 kV transmission tower with composite cross arms, Engineering (2022), doi: <https://doi.org/10.1016/j.eng.2021.09.021>
- [21] – CIGRÉ brochure 284 – Use of corona ring to control the electrical field along line composite insulators, December 2005
- [22] – CIGRÉ brochure 794 – Field grading in electrical insulation systems, March 2020
- [23] – IEC 61467:2008 – Insulators for overhead lines – Insulator strings and sets for lines with a nominal voltage greater than 1 000 V – AC power arc tests
- [24] – ONS – “Operador Nacional do Sistema Elétrico” – Brazilian National Power Grid Operator, subchapter 2.7 – Minimum requirements for transmission lines, Rio de Janeiro, release 2022.08, 2022

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