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DEVELOPMENT OF METHODOLOGY FOR INSULATOR REPLACEMENT IN ±800 KVDC STRINGS USING LIVE LINE PROCEDURES

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SUMMARY

In the traditional procedure of replacing broken glass insulators in HV and EHV transmission lines, after releasing the full mechanical load due to the weight of the conductors, using a set of tools composed of tension sticks and two supporting metal parts fixed one to the crossarm and the other on the yoke, the insulator string is removed using a cradle or a trolley pole. In the case of UHV lines, the weight and the length of the insulator strings makes this task extremely difficult or even impossible. In this work, the application of a kind of clamp to be used in a small part of the insulator string to eliminate the necessity of moving the entire string was confirmed. Electrical and mechanical tests were performed to evaluate the safety of the linemen who act with live line procedures to change damaged insulators locally in the string. The minimum approach distance and the minimum number of perfect units in the insulator string were defined experimentally. Several arrangements were proposed to evaluate the movement of the lineman wearing conductive suit with face mask towards the insulator string and the position of the damaged units. The results obtained, considering the risk factor of -3σ, presented values of withstand voltage higher than the maximum overvoltage expected for the lines in an event of fault. At the end, the proposed methodology was tested at the laboratory with the aim of checking step by step all the procedures to change damaged units along the insulator string in different positions.

Although this procedure has been earlier proposed to be applied in UHVDC lines, the concentration and spatial distribution of space charge generated by a steady-state corona present along the insulator string were not considered, nor the superposition of the switching impulses on the DC voltage.

KEYWORDS

UHVDC - Transmission line - Live line maintenance - Tool – Glass insulator - Test - Laboratory

1. Introduction

The UHVDC technology is one of the most advanced and efficient power transmission technology. The most prominent characteristic thereof is the high voltage, large-capacity, long-distance, and low-loss power transmission. Ultra-high voltage results in more complicated requirement in operation and maintenance compared with the ±600 kV DC transmission system.

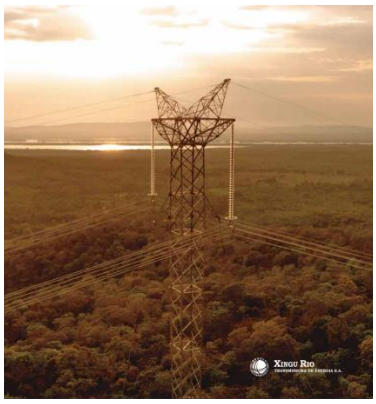
Only a few countries have UHVDC transmission systems. The highlight is China with more than 15 lines in operation. In Brazil, two ±800 kV bipoles were recently built to transport the energy generated at the Belo Monte hydroelectric plant, on the Xingu River, in the Amazon region, to Southeast. Its installed capacity of more than 11,000 MW makes it the fourth largest hydroelectric plant in the world.

The first bipole, operated and maintained by Belo Monte Transmissora de Energia (BMTE), includes a converter station in Anapu (PA) and another in Estreito (MG) with a transmission capacity of 4,000 MW, 2076 km of transmission lines, 3088 towers that crosses 65 municipalities in the states of Pará, Tocantins, Goiás and Minas Gerais.

The second one, operated and maintained by Xingu Rio Transmissora de Energia (XRTE) is composed by two converter stations, one in Anapu (PA) and the other in Paracambi (RJ) crossing the states of Pará, Tocantins, Goiás, Minas Gerais and Rio de Janeiro, with a transmission capacity of 4,000 MW, and extension of 2539 km, using 4448 towers, the longest ±800 kVDC bipole in the world.

Figure 1 shows towers of both bipoles and the schematic routes of the two transmission lines.

(a)



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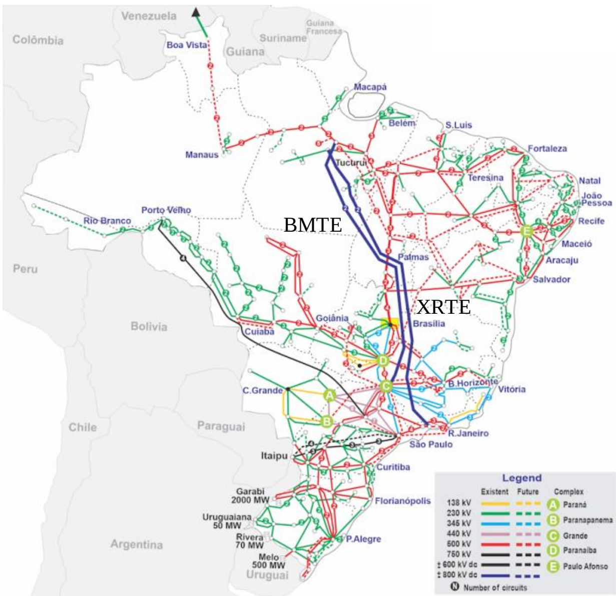


(c)

Figure 1 – (a) BMTE's ±800 kVDC TL [1], (b) XRTE's ±800 kVDC TL [2], (c) schematic routes of the two bipoles (in blue, adopted from [3])

As one can see, both bipoles have a single suspension I-type arrangement of insulator strings. They are composed by two types of large-tonnage cap and pin glass insulators, as established in the basic project [4]. Figure 2 and Table I present their characteristics. Suspension insulator strings of 39 units (320 kN) and 40 units (420 kN) are used. The tension insulator strings are composed of four parallel strings with 41 units (420 kN) in each.

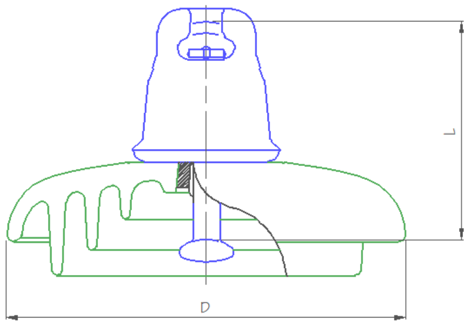


Figure 2 - Insulator profile

Table I - Characteristics of the UHVDC glass insulators

Characteristics	320 kN	420 kN
Diameter (D)	360 mm	360 mm
Length (L)	195 mm	205 mm
Creepage distance	645 mm	635 mm
Weight (approx.)	13.5 kg	15.5 kg

In accordance with Brazilian regulatory rules and procedures, the transmission concession owner will be subject to penalties for unavailability, whether for scheduled or unscheduled interruptions. Therefore, the live line maintenance scheme is extremely necessary to minimize the risk of system shutdown and consequent collection of fines.

In the traditional methodology of replacing broken ceramic insulators in transmission lines, it is necessary to release the full mechanical load due to the weight of the conductors, using a set of tools composed by tension sticks and two supporting metal parts fixed one to the crossarm and the other on the yoke. Then the insulator string is removed using a cradle or a trolley pole for promoting the change in other condition as shown in Figure 3. In the case of UHV lines, the weight and the length of the insulator strings make this task extremely difficult or even impossible.

(a) (b)

Figure 3 - Methodologies applied to replace damaged cap and pin insulators using (a) trolley pole and (b) cradle

Based on the Chinese experience a different methodology of changing broken insulators without removing the entire string was evaluated as a research project developed by CEPEL to be applied in the Belo Monte’s bipoles whose results are presented in this paper. The important difference is related to the insulator string type: while in China it is V-type, in Brazil all of them are I-type, indicating an additional issue to be considered for the safety of the lineman.

To apply this procedure, the presence of a lineman wearing conductive clothes with face mask is required at different locations along the insulator string, which means that it is subject to different electric fields, depending on where the damaged insulator is located.

The proposed live line methodology was based on electrical tests performed in different simulated configurations in a real ±800 kV DC suspension tower assembled in CEPEL´s UHV Laboratory, since there are still no UHVDC live line working international standards or national specifications available in Brazil even with the two systems already in operation.

Transient overvoltages that can occur on bipolar DC transmission lines are generated by electrostatic and electromagnetic couplings on one pole when ground faults occur on the other pole. Live line maintenance on this type of line should consider the possibility of failure that could generate such surges. Considering the results of the studies for the Brazilian ± 800kV DC transmission lines, the value of the maximum switching overvoltage of 1.76 pu was used, which is equal to 1408 kV. This value was obtained during the electromagnetic simulation of the transmission line when a ground fault occurs at the middle point of the line and is measured at the same point on the opposite pole [4].

As live line work is only allowed in good weather (no wind and relative humidity below 70%), lightning overvoltage was not considered and in the event that lightning strikes the line, far from the maintenance location, the traveling wave voltage surge is dampened to safe levels in about 5 km.

Additionally, the mechanical characteristics of the equipment + insulators assembly were evaluated at CEPEL's Mechanics Laboratory to ensure that specified mechanical load of the assembly was greater than the maximum line operating load.

2. Electrical Tests

To ensure the safety of the linemen involved in the activity, it is initially necessary to evaluate two fundamental parameters: the minimum approach distance and the minimum number of good units in the insulator string.

After that, different configurations were simulated with live line tools and a mannequin wearing conductive suit with face mask performing the change of damaged insulator with the equipment.

2.1. Test Setup

CEPEL’s UHV Laboratory comprises three 70 m high supporting structures, spaced by 110 m, which allow great flexibility in the assembling and testing of innovative line arrangements. Figure 4 presents its infrastructure.

(a)

(b)

Figure 4 - (a) UHV Laboratory and (b) 6.4 MV impulse voltage generator and voltage divider

To carry out the electrical tests, the upper part of a real guyed tower of ± 800 kVDC was assembled in the laboratory, as shown in Figure 5. A true arrangement was included with a bundle of six conductors in each pole, forming two spans.

Figure 5 – Upper part of ±800 kV DC guyed tower assembled in the UHV laboratory

2.2. Minimum approach distance and minimum number of good insulators

To determine the minimum approach distance, a metallic panel was placed between tower leg and the conductor cables in different distances. Based on the tests performed whose results are presented in detail in [5], the minimum approach distance was defined as 6.70m, including 0.50m of ergonomic distance, as defined in IEC Standard 61472:2013 [6].

To determine minimum number of good insulators in the string, many configurations using short-circuited insulators to simulate broken units were tested considering different quantities (up to 12 units) and positions of them along the suspension insulator string.

From the results obtained in the tests and presented in [5], the minimum number of good insulators in the 39-insulator string was found to be 31 units. This means that the maximum number of damaged insulators is eight. Assuming the lineman in a conductive suit, when sat in the insulated chair in contact with the insulator string, has an equivalent length of 1.20m, it is important to keep six units at the same electric potential for his safety. So, this means that the maximum number of damaged units in the entire string when performing a local replacement must be three.

2.3. Arrangements for live line maintenance

After the previous definitions, in order to evaluate the proposed methodology, tests were carried out to verify whether the presence of the lineman wearing conductive suit with face mask and located in different positions under a floating electric potential is capable of withstanding a possible fault overvoltage during live line work.

The proposed procedure for replacing damaged insulators locally includes the application of a type of equipment shown in Figure 6. Its main function is to promote local traction in part of the insulator string in order to facilitate the replacement of the damaged unit without moving the entire string.

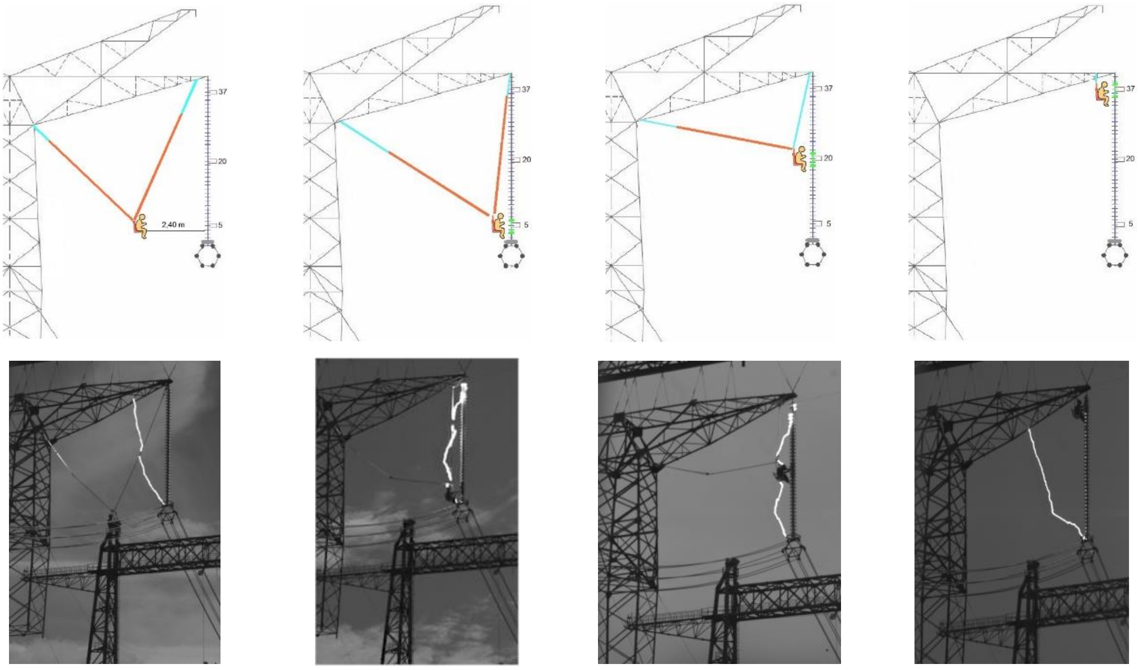
Figure 6 – Equipment applied for replace damaged insulators locally

During the tests, the lineman was simulated by a dummy wearing a conductive suit with face mask sat on an insulating chair, as shown in Figure 7, and being supported by insulating sticks and blocks, to simulate the replacement of damage insulator using the equipment as presented in Figure 8.

Figure 7 – Simulation of lineman wearing conductive suit and sat on an insulating chair

Figure 8 - Simulation of lineman using the equipment to replace damaged insulator locally

Many arrangements were tested related to the position of the lineman considering his displacement from the tower to the insulator string and the replacement of the damaged insulator in different positions along the string. Figure 9 presents some examples of the tested arrangements and pictures from a high speed camera showing flashover during tests, including the calculated values of U_W (withstand voltage) that consider a risk factor of -3σ.



U_W = 1572 kV U_W = 1746 kV U_W = 1596 kV U_W = 1583 kV

Figure 9 – Examples of different arrangements tested for evaluating lineman safety

The test results described in [7] and [8] have confirmed that all arrangements tested to assess the safety of the lineman who does the live line procedures have indicated that withstand voltage values are far greater than the maximum value expected to occur on the line under the maximum calculated fault overvoltage condition (1408 kV), ensuring the feasibility of the proposed methodology.

3. Mechanical tests

Some mechanical tests were carried out at CEPEL’s Laboratory of Mechanics to assess the mechanical resistance of the set formed by the equipment and insulators. The tensile testing machine used has a limit load of 300 kN. Figure 10 presents the test arrangement.

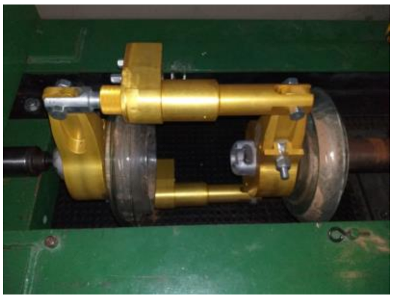


Figure 10 - Arrangement for testing the set of 320 kN equipment and insulators

Different equipment related to each type of insulator (320 kN and 420 kN) were tested. Considering that the maximum tensile load during live line maintenance is about 95 kN, the results of the dynamic load tests performed with both set of equipment and insulators have shown that this equipment can be applied in the lines to replace damaged insulators locally without the necessity of applying tension sticks [9, 10].

4. Evaluation of live line procedures

Based on the different arrangements tested in the laboratory that have indicated the feasibility of the methodology, four procedures were established taking into account the position of the damaged insulator in the string [11].

Real simulations of these procedures were performed at the laboratory to allow linemen to practice all the steps in safety conditions, without the presence of voltage.

Although the mechanical analysis has indicated that the equipment withstands operational line loads the application of the set of tools composed of tension sticks and two supporting metal parts fixed one to the crossarm and the other on the yoke was adopted for increasing the lineman's safety and the line reliability. Figures 11 and 12 show this step which is done before replacing damaged units.

Figure 11 - Moment when lineman touches the conductor with the proper stick

Figure 12 – Linemen performing the conection between tension sticks and the metal component for supporting the conductors

Depending on the position of damaged insulator, the lineman must access the insulator string in different ways using insulating tools.

4.1. Damaged insulator in the upper middle of string

In the case of the damaged insulator between the 21th and 36st positions, the insulating chair sustained by one eyed-type insulating stick and two triple blocks connected at the tower must be used as seen in Figure 13.

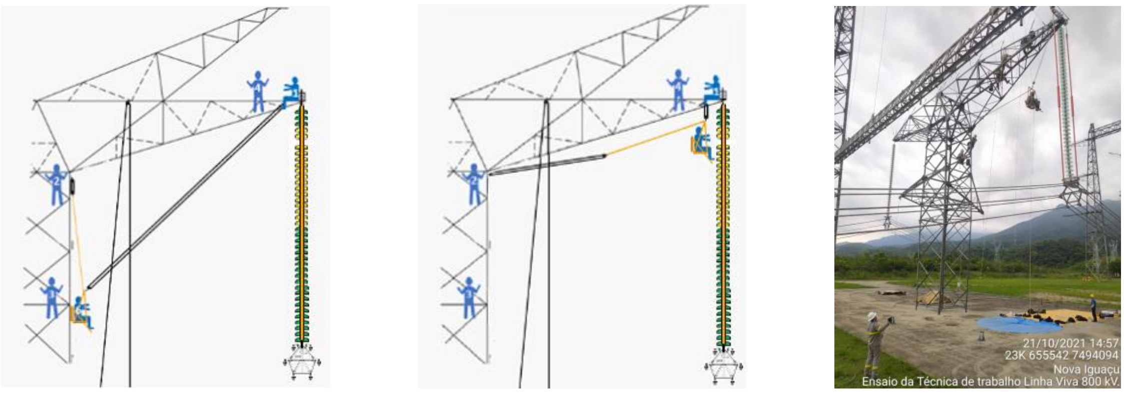
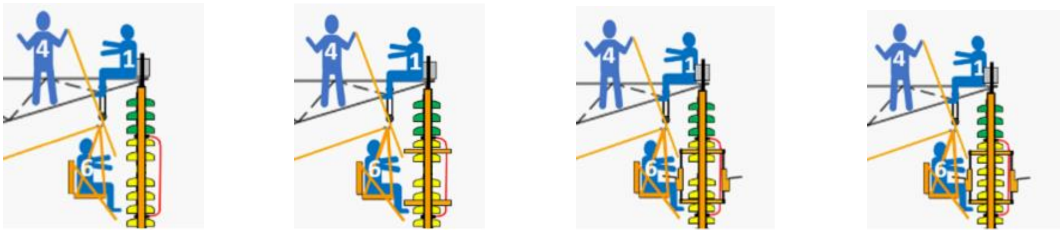


Figure 13 – Displacement of lineman from tower to insulator string

It is very important that the lineman reaches the insulator string as near as possible to the place where the damaged unit is. For this, the lineman must be moved from the tower to the insulator string with simultaneous support of the persons positioned in the tower and in the crossarm.

Figure 14 shows the sequence to replace damaged insulator. After the lineman wearing conductive suit with face mask is correctly positioned near the damaged insulator, the personnel on the crossarm, using an insulating stick, gives him the stick for static grounding which must be placed between the second insulator above the damaged one and the fourth insulator below it, in this sequence, to equalize the potential in the region of work (Figure 14(a)). After connecting stick for equalizing the potential, the team on the crossarm gives the lineman the upper and lower parts of the equipment to be installed respectively on the first insulator above the damaged one and on the third insulator below the damaged one (Figure 14(b)). After that, the team on the crossarm gives the lineman the set of tightening screw that connects upper and lower parts to pull this section of insulator string to allow to removal the damaged insulator (Figure 14(c)). Finally, the team on the crossarm gives the lineman a good insulator which is placed in the insulator string (Figure 14(d)). Then some procedures are repeated in reverse to finish the job. Figure 15 shows a picture of this job at the laboratory.



(a) (b) (c) (d)

Figure 14 - Steps to change the insulator

Figure 15 – Lineman changing damaged insulator in the upper middle of the string

4.2. Damaged insulator in the lower middle of string

In the case of the damaged insulator between the 5th and 20th positions, the insulating chair sustained by two eyed-type insulating sticks and two triple blocks connected at the tower must be used (see Figure 16). All the procedures described above must be applied in the same sequence also in this case.

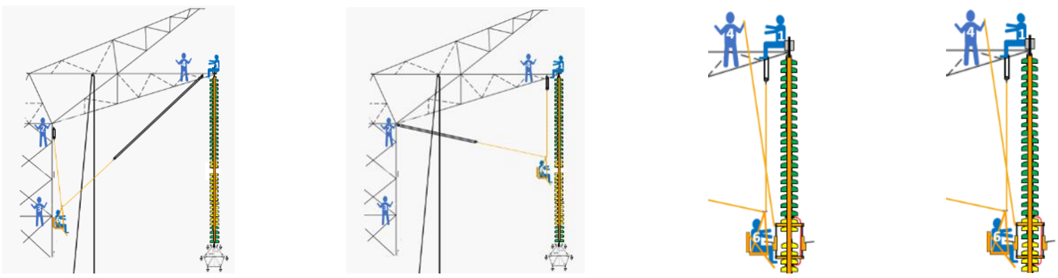


Figure 16 - Steps to change damaged insulator in the lower middle of the string

4.3. Damaged insulator near ground side

When the damaged insulator is one of the last four units near crossarm, the insulating chair is attached directly on it (Figure 17). All the procedure can be applied with the equipment except if the damaged insulator is the last one. In this specific case, it is necessary to adapt another upper part of the equipment to be attached on the metal part of the set of tension sticks. Alternatively, the insulator on the ground side can be changed by tying a rope to the third insulator bellow to support the string. Figure 18 presents a picture related to the change of a damaged insulator near ground side.

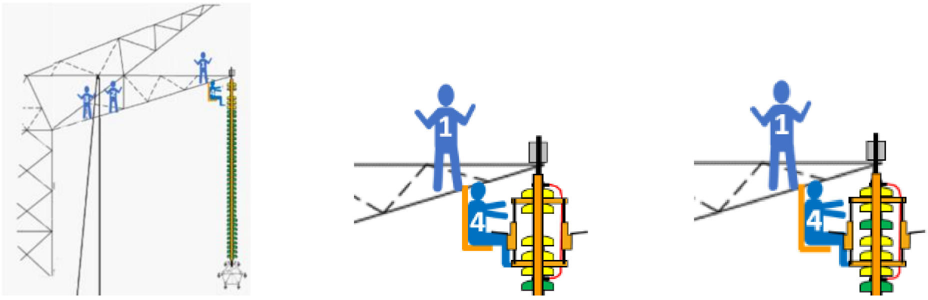


Figure 17 - Steps to change damaged insulator near ground side

Figure 18 – Lineman changing damaged insulator near the ground side

4.4. Damaged insulator near pole side

When the damaged insulator is one of the first four units near yoke, the linemen who are placed on the potential, after connecting the tension sticks can change the damaged insulator. The equipment must be used if the damaged unit is the third or the fourth one and the procedure is the same as described before in 4.3. Figure 19 shows some of the steps. In the case of the damaged insulator is the first or the second one, the equipment is not necessary. Figure 20 shows pictures of these two situations.

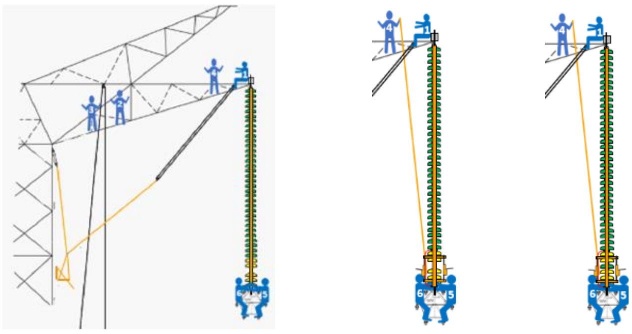


Figure 19 - Steps to change damaged insulator near pole side using the equipment

(a) (b)

Figure 20 - (a) Application of the equipment for changing damaged insulator and (b) changing damaged insulator without equipment near pole side

5. Conclusions

If there are two broken units in sequence in the insulator string, it is possible to consider the maximum number of broken insulators as four.

When the damaged insulator is in the jumper string, it is not necessary to apply the set of tension sticks to transfer the weight of the conductors. The equipment alone can be used.

The established procedures can also be applied to tension strings. As walking on the insulator string is prohibited in Brazil, the lineman wearing conductive suit with face mask must be moved from the crossarm to the damaged insulator position using a ladder with a swivel mechanism and triple blocks. The application of the set of tension sticks is not necessary.

Due to delay in the homologation of using of the conductive suit in UHV lines by the Brazilian authorities, a real application of the methodology proposed was not possible yet.

The information obtained by this research project can be used to produce guides and standards for live line maintenance in UHV transmission lines.

The advantages of this methodology are: smaller teams, less tools, time and cost-consuming per activity.

Finally, the procedure of displacement of the lineman with conductive suit can be considered as an alternative to allow collecting pollution samples from the surfaces of insulators without the need of removing the insulator string from service.

Acknowledgement

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