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Analysis of critical field procedures for power HV overhead transmission line splices installed after restructuring of Brazilian electrical sector

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ABSTRACT

The electricity transmission system lines in the Brazilian re-structured market is the subject on this work. Also are studied transmission lines field procedures considering economy and reliability of ACSR (Aluminum Core Steel Reinforced) cables and compression splices. The work describes compression splices field surveys with suppliers and users concessionaires and also suggest some procedures and inspections routines to improve system reliability.

1. Introduction

Brazil is an enormous country of over 8 million km^2, in which the demand for electric power is constantly increasing as the population grows and the industrial park expands. Issues of economy, reliability and supply security are assuming ever greater relevance as the pressure to transport more electricity over greater distances increases. Overhead transmission lines in the Brazilian electricity system extend for vast distances (some 176,000 km) with voltages of up to 700 kV. Moreover, the restructuring of the Brazilian electric sector after its privatization in 1999 has resulted in a more competitive environment in which various companies are attempting to obtain greater financial returns over shorter time horizons. They thus try to cut the costs of implantation and operation or deliver, as well as delivering higher electrical loads than initially planned. With increasing levels of electrical current, however, every day stress (EDS) must increase to compensate for the increased sag resulting from the higher temperatures involved. Moreover, these changes in the standards adopted and the consequent reduction in the margin of safety of the lines are being implemented without adequate engineering studies to provide the technical support necessary.

2. Economic and system aspects in the Brazil competitive electricity sector

Most of the power generation in Brazil utilizes hydro plants, with thermal sources installed largely as a backup to mitigate the risk of a shortage during dry seasons. The actual generation is controlled by a tight centralized pool regulated by price merit order auctions held periodically in four sub-markets around the country. The country is, however, supplied by interconnected transmission lines, as this permits the maximization of overall power output, especially since the rainy seasons are complementary in the north and south. This system, however, means that most of the hydro potential and actual

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generation is installed at some distance from the consumers and their demands, and the transmission system is critical for the electricity sector of the country. Moreover, the high voltages in the overhead lines make field installation, monitoring and maintenance quite difficult, whereas the harsh environmental conditions often complicate the situation, such as when the lines must pass over the tops of entire forests.

This new economic environment is accompanied by changes in the ecological awareness of the population and the effects of this awareness on governmental policies. No longer is it possible to just build more dams or install new cables to meet increasing demands. Even when new dams are authorized, they must be smaller to limit the social and environmental impacts caused by large reservoirs, but this means that a system of long-term planning horizons (as is traditional in the country) is no longer feasible. These smaller reservoirs mean that fluctuations in demand will lead to fluctuations in electric current transmitted, with all of the wear and tear and other problems which this entails. Moreover, the effects of the fluctuation are heightened by the pricing policies adopted in the four sub-markets. When the price for generation on the local market is higher, it is cheaper to transmit the power from another practicing lower prices, thus increasing even more the pressures on the transmission system and the vulnerability of supply.

These environmental restrictions also limit the traditional solution of installing additional cables to meet increasing demands or provide redundancy. The complications faced in order to install new cables lead to constant adaptations in new projects and consequent delays in launching time, so the overload on the existing cables continues for longer periods.

The end result of these delays and fluctuations is an increase in the number of multiple failure events. The long distances traversed by the transmission lines, in conjunction with the harsh environmental conditions inherent in Brazil, mean that repair of a failure requires relatively long periods of time, yet the extended duration of a failure event and the consequent overload generated for the rest of the system tend to lead to further failures before the initial one has been fixed, especially when the margins of safety have been reduced.

Failures of transmission lines generally take place at splices [1]. Almost all of the splices on Brazilian high voltage transmission lines are of the compression type (Figs. 1 and 2).

These splices have a long history of reliable service [2] under reasonable safety margins, but they do require care in installation. They are, however, vulnerable.

One reason for this is that they are assembled at the very end of the installation process. For economic reasons, the time allotted for installation of cables is limited, and the splices are the last thing to be assembled in these cables. When time is running out, there is a tendency to ignore the safety standards in order to finish more quickly.

3. Failures and causes

Given the difficulty in controlling the quality of the mounting of splices, it seemed prudent to investigate exactly what was responsible for the failures which occurred. The first step was the identification of failure events in the Brazilian transmission network. Such failure events are relatively rare and, to avoid legal problems, companies tend to conceal the fact that they have actually occurred, trying to link power breakdowns to purported anomalies of the weather or mechanical failures in the generators. However, four of them were identified and studied in detail, as it is assumed they are typical of what happens. Three of them seem to have been linked to problems in the mounting of a splice.

The first was a case of the rupture of a cable due to the displacement of a splice (Figs. 3 and 4). The resultant power failure affected hundreds of thousands of consumers, and it took nearly 48 h to restore normal power. The limited surface contact of the cable with the sleeve led to overheating and the consequent melting of the aluminum and steel wires (Fig. 5).

This conclusion is confirmed by the metallurgical analysis presented in Fig. 6, which shows the molecular alterations and deformation of the melted aluminum.

The second was due to the presence of a bend in a replacement of a splice in one of the major transmission lines of the country directly supplying some 8% of the power used, although a failure could have led to an avalanche and a blackout in some 50–60% of the country. Luckily the problem was identified before this happened. Once the bend was identified, political

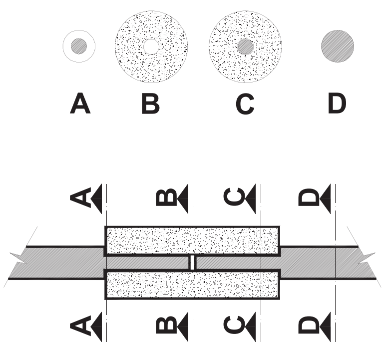

Fig. 1. Aluminum Core Steel Reinforced (ACSR) splice showing cross sections of splice.

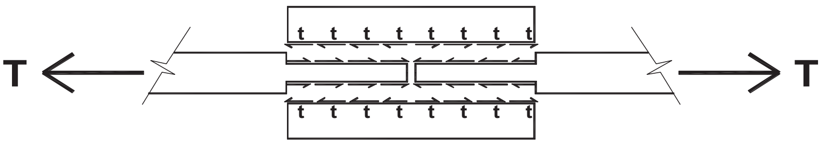

Fig. 2. Traction in steel glove state.

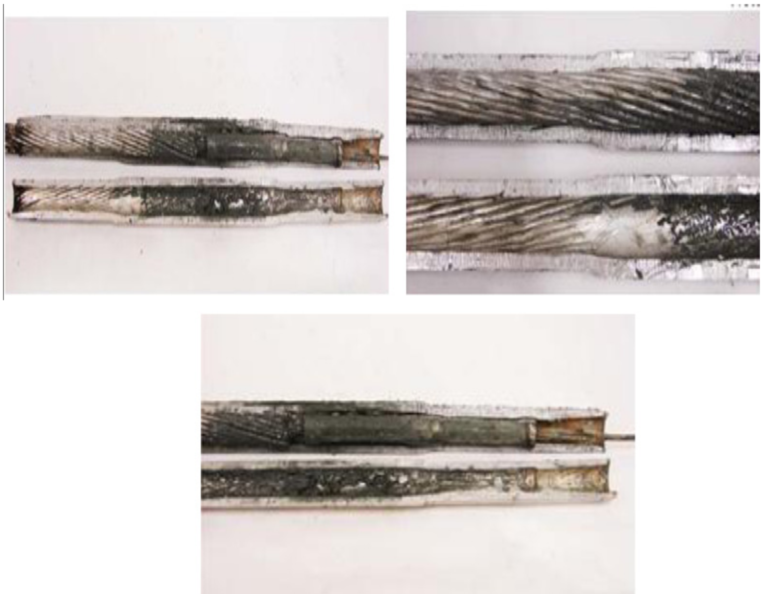

Fig. 3. (a) Overall view cut horizontally through aluminum sleeve of splice, (b) non-ruptured extremity and (c) ruptured extremity.

Fig. 4. Details of ruptured extremity.

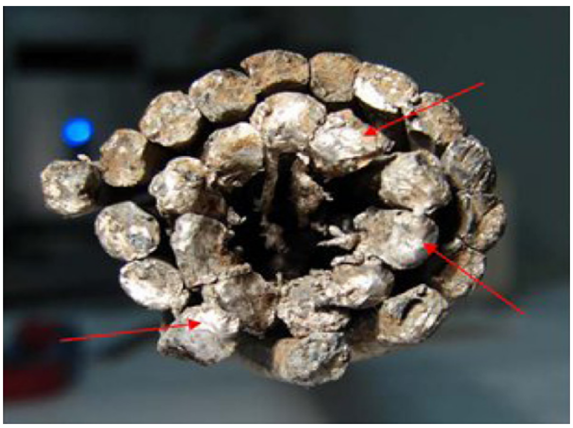

Fig. 5. Ends of aluminum strands, with arrows indicating local fusions.

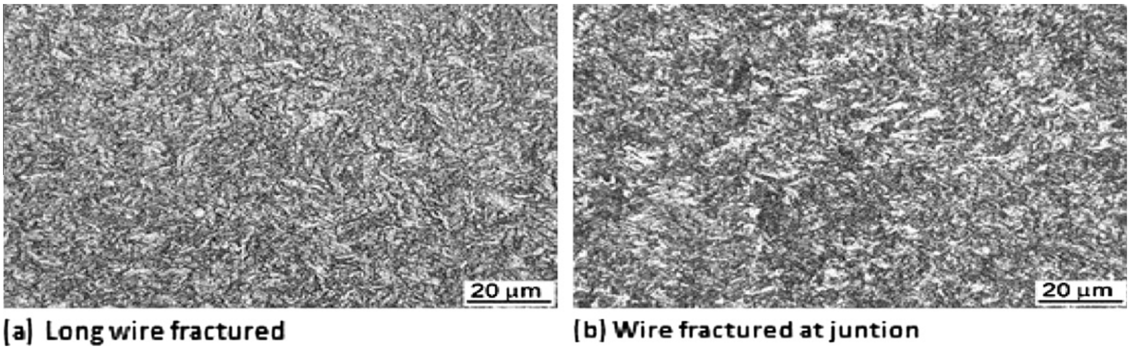

Fig. 6. Optical metallurgical of ruptured wires.

pressure was brought to bear to simply straighten it out, but Brazilian acceptance standards recommended replacement. Simulation studies of this bend in the laboratory showed that replacement was indeed the only safe solution, since the concentration of forces in the center of the splice (Figs. 7 and 8) had indeed compromised it safety.

This was to be expected if one considers the data presented in Figs. 1 and 2, which show that this bend was likely to result in the reduction of the cross section of the sleeve upon sloppy compression, probably due to time pressure.

The third was also probably the indirect result of time pressure. It is well known that aluminum sleeves applied in firm contact with clean aluminum cables protected by sikronil guarantee good connection and transmission (with splices being even better transmitters than the cables themselves). However, a lack of simple hygiene in their installation can have disastrous results. Not only can greasy hands or the dirt in the air compromise the connection, but a failure to clean the cables adequately or apply sikronil evenly can have a similar effect. Such problems of cleanliness, however, are clearly preventable if adequate time and care in installation are taken. The third failure identified apparently involved no more than a failure in the original acid cleaning of cable, as is suggested by the data in Fig. 9, which shows the presence of a layer of oxidation between the cable and the sleeve. Luckily, the problem occurred on a relatively minor line, but its location near a large population center meant that the ensuing power loss affected between ten and one hundred thousand consumers, who spent 24 h without power.

To a certain extent, all three of these failures were the result of a lack of care under excessive pressure, both temporal and economic.

The fourth incident was the direct result of transmission overload. The resultant failure left nearly a million consumers without power for 4 days. The underlying causes of this overload involve the new government policies regulating the payment for the generation and transmission of energy. As mentioned above, the companies producing energy offer long-term contracts for that energy at independently established prices in government-regulated price merit order auctions. The competitive prices mean that for some agents it is cheaper to buy energy from a distant producer, even when the price of the transportation of that energy is considered. Moreover, some energy producers at times find themselves unable to produce the energy already contracted and must purchase this on the open market. Such flexibly scheduled purchases lead to fluctuations in the demand for the transmission lines.

The new policies have also modified the demand in other ways. Once the government increased the price of energy during the peak hours of the early evening (when both industrial and residential consumption are at their peak), industrial

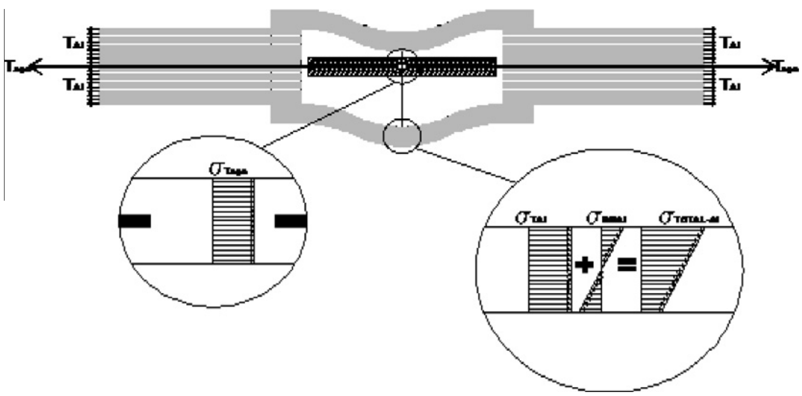

Fig. 7. Elastic tensions acting linearly over bent sleeve.

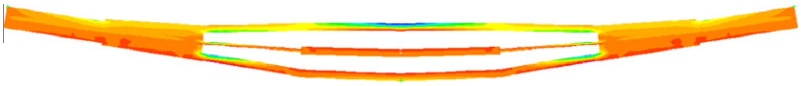

Fig. 8. Schematic diagram of state of tension in bent splice (aluminum external, steel internal) with concentration of stress on the aluminum sleeve upper side.

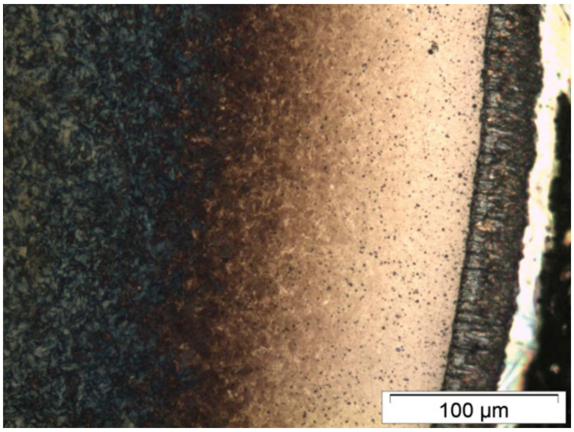

Fig. 9. Aluminum cable showing oxidation layer.

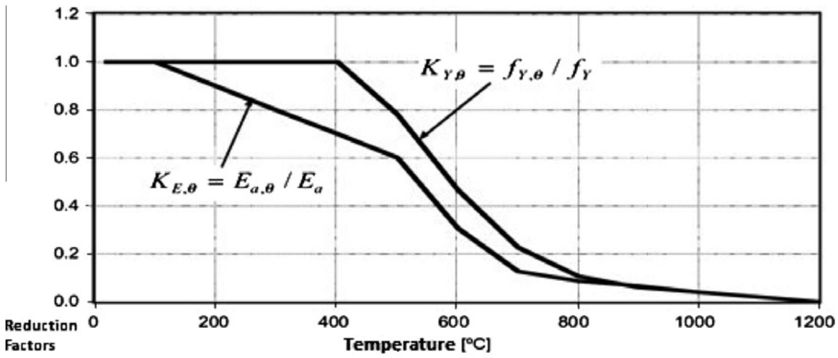

Fig. 10. Non-linear performance of thermo-mechanical behavior of steel and aluminum [2].

consumers modified their patterns of consumption, often purchasing private generators to supply energy during the more expensive peak hours. The reduction of consumption during these hours, however, led to the installation of a new pattern of usage containing three distinct peaks (corresponding largely to changes in shifts), and this has tripled the number of fretting cycles. This fretting due to current-induced temperature fluctuation compounds the effect of its fluctuation due to variations in atmospheric temperature. The greater are the number and intensity of these fluctuations, the greater the variation in temperature; since the coefficient of elongation for aluminum is three times that of steel, as shown in Fig. 10, the aluminum casing functions like a compressed spring, thus diminishing the tension required for rupture. Moreover, as the temperature increases, so does the sag, thus reducing the clearance designed to guarantee the safety of high tension lines; this effect must be compensated for by an increase in EDS, although this leaves the splice more vulnerable to failure.

The failure of the fourth incident was apparently the result of such fretting and EDS. The failure took place on a hot summer day when power demands were exceptionally high, due to the widespread use of air conditioners. Yet in the region affected, local generation is low. To compensate for this, additional energy had to be transmitted, and the lines were unable to deal with it. No other possible explanation has yet been found, and it is assumed that fretting and EDS were the culprits [3].

4. Discussions and conclusions

The problems of installation must be solved if the electrical supply is to be guaranteed. This would involve various aspects [4–6]. General cleanliness on the job is important, and trained supervision could also help in improving the quality of the cable installation. However, the policies adopted after the restructuring of the electric sector emphasize sub-contracting to cut costs. Sub-contracted network installations often depend on the work of poorly paid and unskilled workers who are more likely to ignore issues of cleanliness and carefulness on the job. The situation is aggravated by the fact that so little investment in the electrical sector was made for an entire generation that trained workers are no longer available, but have retired, making extensive – and expensive – training necessary, although sub-contractors are highly unlikely to invest in this. Moreover, cost-cutting frequently leads to improvisation instead of the use of the appropriate installation tools. All of these aspects must be controlled to avoid future power failures.

Some errors could, of course, be eliminated if the workers did not face such time pressure, and preventive maintenance should also be able to identify potential problems before it is too late. The points of weakness or stretches of line subject to exceptional fretting could also be strengthened by the affixation of external pre-formed aluminum wire splices. Although their installation would entail large expenditures, they are cheaper and more quickly installed than would be the replacement of a vulnerable compression splice.

Government policies will also need to be modified to prevent problems related to overload [7]. More local generation is critical, and must receive incentives. The existence of three peaks in demand (and the consequent increase in fretting) should be ameliorated by the adoption of a policy of various price levels, rather than the simple two-level (peak/non-peak) adopted today. Moreover, the cables should be re-capacitated to increase their flow capacity [8], although this would either involve the installation of more cables or the exchange of present-day cables [9] with newer and more thermal-resistant ones. Unfortunately all of these modification depend on the involvement of government energy agencies.

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