INTRODUCTION

The necessity of estimating the life span left for the ACSR conductors of the overhead electric lines appeared as an actual problem in the 90’s, as a following to the fact that their initial average duration, of 40-50 years, was or is going to be surpassed in a lot of instances, because the concept of development used for the energy consumptions was not realistic enough for the whole considered period, especially in as much as the last 25 years are meant. Generally there are three recognized factors that lead to reducing the mechanic characteristics of the ACSR conductors: excessive heating, due to overloading, dynamic mechanic efforts and the corrosive effect of the environment. The analyses of the conductors shape can be made on the lines and in the laboratory. Out of the multitude of the possible tests used for leading to the information about the degree of mechanic degradation in the conductors three types were evinced: qualitative and quasi-quantitative measuring of the zinc coating corrosion on the steel wires that make up the conductor core by using specially conceived devices that move along the conductor of energized or unenergized lines with or without electric tension, the breaking up test by tensioning the aluminum and steel strands of a conductor sample taken from the line. The three mentioned types of tests can be performed by using the specific methods for live-line work.

The results of the tests performed in Romania, introduced in this paper, have been compared to the results of the tests from elsewhere and then synthesized in diagrams predicting the remaining life span of the conductors according to their elapsed functioning years. Although the lines of high and very high voltage in Romania are not very old compared to those in other countries, the polluting conditions, very intense in some highly industrialized areas could lead to a stressed corrosion in the zinc coating of the steel strands, which determined us to consider beginning to measure the state of the conductors, in relation to the information regarding the possible corrosive effects of the environment.

FACTORS CONTRIBUTING TO ACSR CONDUCTORS AGING

Excessive heating of the conductors

The excessive heating of the conductors, due to electric overloading in the lines, leads to the annealing of the aluminum wires and the fluidization and even burning of the protective grease used in conductors manufacturing.

Dynamic mechanic efforts

These efforts are due to the wind vibrations and respectively to galloping. As to the effect of the wind vibrations it needs to be put a stress on the fact that it can be reduced or even eliminated if the the conductor tensions are limited, according to the recommendations in the field, in the presence or in the absence of the vibrations dampers. Of course, using vibration dampers and there where required, with the bundled conductors, the spacer-dampers, brings and extra guarantee from this point of view.

Galloping represents a rather isolated phenomenon, with an undecided periodicity but which can lead to excessive torsions of the conductors, beyond the normal limits.

The corrosion due to the environment

Generally there are two categories of corrosive agents, the industrial and the saline ones coming from the sea. The industrial corrosive agents get to the core of the steel conductors by help of the meteorological conditions, such as rain, fog or snow, corroding the zinc coating of the steel wires without affecting at all the aluminum strands. As the thickness of the protecting zinc layer is reduced, the corrosive effect is transmitted forward affecting the wire cross section of the steel strands proper. The saline corrosion is a different process, the zinc corrosion taking place more rapidly which creates electrolytic cells between the aluminum and the zinc coating which leads to the corrosion of the aluminum wires, too.

The protective grease used in manufacturing the conductors plays a special role in blocking the corrosive agents from getting to the aluminum and steel contact area, but the life span of a good quality grease does not go beyond 10-15 years, generally, and that happens only when the line is not overloaded and exposed to very hot and /or with intense ultraviolet radiations clime conditions over a long period of time.

METHODS OF ANALYSING THE ACSR CONDUCTORS OF THE ELECTRIC LIVE-LINES

Generally, conductors can be analyzed on lines or in the laboratory, on samples taken from the live-lines. In the first category there can be listed: the visual observation from a
distance by using optic instruments, the observation from a distance in infrared and the qualitative and quasi-quantitative analyses of the zinc coating thickness in the steel wires that make up the core of the ACSR conductor. The first two types refer either to the observation of some defaults in the outer coating of the conductor, or in the local heating of the latter as a following of some cross sections reductions, especially of the aluminum one, which prevent us from obtaining any information about the conductor corrosion. Using the corrosion detecting devices in the zinc coating on the steel wires or even of the aluminum wires represents a very efficient solution from a technical and even economic point of view in establishing the level of corrosion in the electric lines. Such devices, made in UK, USA, Japan and South Korea (according to the moment of being conceived) have already been used, but the only published results available are for Canada [1] and South Korea [2]. These devices, in their more performing forms, offer the possibility to be moved by remote control and to transmit all the obtained information by radio waves. The second category comprises [3]: the endurance test for wind vibrations, the endurance test for galloping, the sheave passing test, the torsion ductility test, the breaking up test in tension, the creep test, the measuring of the zinc coating of the steel strands, the electric resistance measurement, the metallurgical examination of the component strands, the chemical analysis of the outer strands and laboratory forced corrosion on strands.

ELEMENTS CHARACTERIZING THE MECHANIC STATUS OF THE ACSR CONDUCTORS

ACSR strands degradation is a time taking process affecting their mechanic resistance by the influence of the three factors already mentioned. There can be taken as major elements in characterizing the mechanic state of a conductor at a certain moment: the remaining depth of the zinc coating on the steel strands, the resistance to breaking up in tension of the steel and aluminum strands and the ductility in torsion of the steel strands. [4 ].

The depth of the zinc coating on the steel strands

Determining the depth of the zinc coating on the steel strands can provide information about the way the atmosphere has corroded the strand by the moment of taking samples, without the possibility of stating the time until the respective strand will be subject to a damage, in case it does not show any cross-section reduction in the steel strands. Predictions about the remaining life span may be made, though, by extrapolating the corrosive effects of the surrounding area of the spot where the sample has been taken.

Steel and aluminum strands resistance to breaking up in tension

The decreasing in resistance at breaking up in tension of the steel and aluminum components in the analyzed strands shows that, in future, under an excessive mechanic impact externally generated, but which could be within the initially calculated data, there can appear a major risk of damage. The decreasing in resistance with the aluminum strands may be due both to the annealing phenomena, if the respective electric strands have been electrically overloaded and to the dynamic efforts due especially to the wind vibrations.

Steel strands ductility in torsion

The ductility in torsion characterizes the respective strands from the point of view of the existence of some crystalline microstructure fractures, due to a great extent to the excessive dynamic efforts which appear during galloping there where this type of oscillations are frequent, but also to the daily torsion of the conductors and their component wires, because of the continuous variations in temperature.

EVALUATION CRITERIA FOR THE REMAINING LIFE OF THE ACSR CONDUCTORS

Specialists from Ontario Hydro [4] have put into evidence three criteria of evaluation, based on the three elements that characterize the mechanic status of the conductors: the depth of the zinc coating criteria, the resistance to breaking up in tension one and the ductility in torsion of the steel strands criteria.

The criterion of the zinc coating thickness is based on the results obtained by using the device of corrosion detection that moves along the conductors. The data obtained by the specialists at Ontario Hydro, who made measurements on 77 electric lines, aged between 16 and 79 years, which were then statistically worked on leading to an equation which shows the degradation degree according to the conductor age in working. Considering there are four levels of corrosion, any new measured value can be compared to the mentioned diagram enabling us to estimate the remaining life. By determining a 4th level of corrosion on a spot we can assume that it denotes a reduction of the zinc coating by more than 80% which imposes the urgent replacement of the conductor on the respective area.

The resistance to breaking up in tension criterion consists of comparing the measured value on a complete sample conductor or of a value resulting from summing up the values measured for all the component strands to the diagram resulting from the statistical processing of the whole volume of data obtained before, according to the conductor age in working. It may be considered that when the resistance to tension goes under 80% the conductor does no longer provide guarantees for being maintained and it needs being replaced immediately.

The ductility in torsion criterion consists of comparing the number of torsions of the steel sample until it breaks up to the diagram resulted from the statistical processing of the data already obtained. Generally, a number of up to 5 torsions for breaking up as an average for a layer define the necessity for the urgent replacing of the respective conductor.

USING LIVE-LINE TECHNIQUES TO GET SAMPLES OF CONDUCTORS IN ROMANIA

Although live-line work was experimentally introduced in
Romania at the end of the 70’s, detailed procedures and technologies have been issued after 2000. Because of that, before 2000 the necessary conductor samples for tests could be got during repairing from the disconnected target lines. Together with developing live-line maintenance works and the increased necessity of knowing the status of the overhead 220 and 400 kV line conductors, in 2004 it was proposed to get samples from electric lines undergoing no repairing works without disconnecting them. The ACSR conductor samples were to be taken from the jumper loops. Contrary to the span proper, the jumper loop conductor does not undergo any dynamic effort due to the wind vibrations or/and to galloping, so it is less “aggressed”. But in Romania all the 220 and 400 kV conductors of the overhead electric lines are endowed with Stockbridge dampers at the end of every span, which makes the wind vibrations have a less pronounced negative impact. On the other hand, galloping has been rarely met with the conductors and only on restricted areas. For this reason getting samples from jumper loop conductors has been considered satisfactory in this stage.

Two types of procedures have been considered according to the type of the tension clamps used. The first, referring to the tension clamps through which the conductor passes, being a jumper half and the second referring to the clamps to which the jumper connects independently. In the first case a new jumper loop is attached to the conductor in front of each tension clamp by help of some special clamps for electric connection, after which the two halves of the jumper are cut. In the second case a rather similar operation takes place. A new jumper, similar to the one mentioned above, with a provisory status (by-pass) is attached, the old jumper is loosened from the tension clamps, a new jumper is fastened to the tension clamps and then the provisory jumper is removed.

**THE RESULTS OF THE TESTS PERFORMED IN ROMANIA**

The first tests began in 1988 and continued until 1993; samples of conductors were taken from the overhead electric lines for 110, 220 and 400 kV. At that time, 58 samples out of which 19 on the whole conductor and the others wire by wire were tested for breaking up by tension. In 2004 there have been taken by using methods specific to live-line work 60 samples, out of which 9 have been tested at breaking up by tension wire by wire and 9 for ductility in torsion of the steel wire components. The results of the tests for breaking up in tension with aluminum wires are given in Fig.1 (for all the tests performed both before and in 2004) as a ratio of the resistance to breaking up and the nominal resistance to breaking up, as a function of the elapsed years.

![Fig. 1 Actual breaking stress rated to nominal breaking stress of aluminum wires (Romania)](image1)

Similarly Fig. 2 shows the results of the tests performed on the steel wires.

![Fig. 2 Actual breaking stress rated to nominal breaking stress of steel wires (Romania)](image2)

Fig. 3 presents the value distribution of the resistances to breaking up by tension of the conductors, as a function of the elapsed years. The graph diagrams for the average probability have been drawn in all the three figures. For the conductor, this diagram has the following equation:

\[
y = 1.4 - (0.2074 \cdot e^{0.0173 \cdot x})
\]  

(1)

In Fig. 4 this diagram is shown together with the diagrams obtained by Ontario Hydro, Canada [4] and Tae-Jon National University of Technology, S. Korea [1]. It must be mentioned that a modification has been made in the Canadian and S.Korean diagrams, so that the same factor should be represented on the ordinate, the actual breaking stress rated to the nominal breaking stress.
There has also been drawn the total diagram to represent all the tests known up to now from the specialized literature and that means from Canada, Romania and S.Korea. The equation corresponding to this diagram is:

\[ y = 1.4 - \left( 0.3579 \cdot e^{0.0061 \cdot x} \right) \]  

Comparing the wholesome diagram to the partial ones we can state that this is not very far from the Canadian and Romanian diagrams, leading to a lifetime of 8 years compared to the Canadian and of 9 years compared to the Romanian one. The lifetime for the S.Korean tests is much smaller, but the tests should be continued in S.Korea, too, in order to lead to a clear conclusion.

The results of the ductility tests in torsion are presented in Fig. 5. The average probability diagram has also been drawn for the number of torsions to the breaking up as a function of the elapsed years. Its equation is:

\[ y = 44 - \left( 7.735 \cdot e^{0.0392 \cdot x} \right) \]  

In Fig. 6 there can be seen both the diagram resulted from Fig. 5 and the diagram obtained at Ontario Hydro [4], as well as the diagram that takes into consideration all the tests, both from Canada and Romania.

**MANAGEMENT OF ACSR CONDUCTOR END OF LIFE PREDICTION IN ROMANIA**

The overhead very high voltage lines in Romania are at most 40 years old, but there are medium and high voltage lines that are almost 80 years old. An important factor that should be taken into account is the excessive industrial pollution which appeared after 1970 affecting the medium and high voltage lines supplying the electric power for these areas and also the very high voltage lines nearby. Taking into consideration that for most of the overhead electric lines the life time of the coating grease has also been surpassed, leading to an increased risk of corrosion with the conductors, urgent measures should be taken to analyze the status of the conductors in the EHV network.
In the first stage there should be identified the sectors nearest to the industrially or marine polluted zones, considering the pollution maps already drawn. These sections will be analyzed on one phase by using the devices for corrosion detection and when a high degree of corrosion will be stated, the other phases will be also analyzed. At the same time, jumper samples will be taken from the tension towers to perform resistance tests to breaking up in tension and ductility in torsion. When ample repairing works are made needing disconnecting some lines, samples of the conductor will be taken, from the spans, preferably from their middle, to perform the same tests and compare the results.

In the second stage, the EHV electric lines will be considered as a whole, but the corrosion detector will be used only for 10% of the spans, for one phase. The laboratory tests will be carried on in the same way as for the polluted zones. In a perspective, the same measures should be taken for the high and medium tension lines.

CONCLUSIONS

It is imperative that we could appreciate the life time left for the ACSR conductors of the overhead electric lines carrying and delivering the electric power. Getting over 40 years makes the EHV lines need have some conductors replaced in certain zones characterized by excessive pollution. In order to avoid relatively high costs implied by repairing the effects of damages as a following to conductors breaking up, favored by special meteorological conditions, as well as the compensations brought about by delivery failures while repairing the lines impose thorough analyses both on the lines and in the laboratory, as previously proposed. The possibility of detecting the corrosion and taking samples from the jumper loops by using live methods makes this action much easier.

BIBLIOGRAPHY


