INTRODUCTION

The scenery resulting from the introduction of the free market of electric energy makes it more and more necessary to increase the power transferred by electric lines and consequently to obtain a better exploitation of the existing lines, given the difficulty to obtain permits to build new overhead lines or to modify substantially existing ones (as in the case of adoption of a larger conductor: i.e. from 308 mm$^2$ to 585 mm$^2$).

One solution to this problem thus is offered by the reconductoring of existing lines with high temperature conductors.

After an analysis of its more critical 150 kV lines, Enel Distribuzione decided to start an experimentation of different types of these conductors in order to assess their behaviour on the lines. This paper reports the tests and installation activities carried out.

HEAT-RESISTANT CONDUCTORS CHARACTERISTICS

These conductors were firstly introduced in Japan in the ’60 in order to cope with the growing demand for power transferred by electric lines; thus new types of aluminium alloys resistant to high temperature were produced.

The use of heat-resistant conductors offers a valid solution for the increase of the power capacity of existing lines [1] by substituting previous installed traditional conductors (mainly ACSR for 150 kV lines of Enel Distribuzione).

In order to be practically feasible this operation should require minimum variations to the existing structures.

At this regard the maximum sag and the maximum tensile load of the original conductors should not be exceeded (however margins in clearance and mechanical load may exist and should be exploited when possible).

The respect of these requirements, together with the new load specifications, can be met by the choice of the appropriate characteristics of the new heat-resistant conductor.

In to widen the choice of these characteristics different types of conductors, realised with heat resistant aluminium alloy wires, were taken into consideration:

- INVAR reinforced conductors (ZTACIR);
- Gap-type conductors (GTACSR);
- Conventional and ultra compact steel reinforced conductors (TACSR).

In case of existence of very stringent requirements on maximum sag conditions (almost no margins in ground clearances) the choice the new conductor is made between the ZTACIR and GTACSR solutions.

In the first solution the core is made by a steel-nickel alloy (INVAR), which is characterised by very low expansion coefficient (3-3.5x10$^{-6}$/°C). In this conductor there exists a temperature (the so called “knee point temperature”) above which the conductor expands with the temperature expansion coefficient of the conductor core, which is far less than that of the whole conductor. The evaluation of the knee point temperature is of utter importance for the assessment of the maximum sag of the re-conductored line. Evaluation of this temperature can be carried out by computer methods and verified by laboratory tests.

The reduced sag of these conductors allows to operate the lines at temperature up to 210°C (with ampacities 2.5-3 times those of ACSR) without need to increase the height of the the towers. The cost of this conductor is about 5 times higher than traditional conductors.

Two experimental lines have already been installed in Lazio and Abruzzo for a total length of 55 km.

In GTACSR (“Gap-type” conductor) the steel core is surrounded by at least one layer of formed (trapezoidal, Z-shaped, ...) elementary wires (of heat-resistant aluminium alloy), separated from the core by a gap filled with grease (Fig. 1).

In this way the external layers can slide on the central core. At temperature installation the aluminium layers are mechanically unloaded; as a consequence the thermal expansion coefficient of the conductor for temperature above installation one is that of steel core (in this case the knee point temperature is equal to the installation temperature).

The maximum operating temperature is 150°C (with an ampacity increase up to 100%), the cost is about 2.5 times conventional conductors.

An experimental installation is foreseen at the beginning of 2005 in Lazio for a total length of 50 km.

The formation of TACSR is similar to ACSR with the only difference due to the adoption of heat-resistant aluminium alloy instead of normal aluminium. The maximum operating temperature is 150°C; the cost is about 1.3 times conventional conductors.

The problem with this conductor is due to the fact that the thermal expansion coefficient is the same of ACSR conductors, consequently its adoption is taken into consideration only in case of presence of considerable margins in the clearance of existing line. In 2003 an experimental line of 50 km were realized in Veneto.

Ultra compact TACSR, in which the whole steel rope of the core is covered by a thick layer of clad annealed aluminium (fig.2), thank to its very high ratio (close to 1) between the actual cross section and the cross section of a cylinder having the same diameter, can also be used to substitute traditional conductors of larger diameter, thus allowing in some cases the respect of maximum sag condition without increasing the
height of the towers. It should also be pointed out that in some cases (with low EDS loads and short spans) it is possible to take advantage of the presence of the ‘knee point’ temperature also for TACSR.

LABORATORY TESTS ON CONDUCTORS AND FITTINGS

The assessments and measurements of the actual characteristics of conductors and relevant fittings must be done by laboratory test. In particular the adoption of suitable fittings constitutes probably one of the more important and delicate element in the realisation of a line with heat-resistant conductors. In the great majority of the cases clamps and joints are compression type with conductive sleeves made by aluminium. A correct thermal dimensioning is therefore important in order to avoid that elevated temperature could lead to annealing phenomena with consequent reduction of the compression force between aluminium sleeve and conductor layers (with further increase of the temperature of the fitting, in a loop which could lead to possible breakage in the clamp). At this regard heat cycle tests on compression clamps and mid-span joints (Fig. 3) is fundamental for the evaluation of the thermal behaviour of these type of fittings.

As mentioned above the determination of the knee point temperature on a real span is important in order to estimate the clearances under maximum sag conditions on the line to be reconducted. At this regard sag-temperature curves were obtained on a 50 m indoor span. The results obtained from the experimentation allowed to calibrate the parameters for the mathematical model. Fig 4 reports the comparison between calculated and measured data of sag – temperature behaviour for ultra compact TACSR.

Another aspect which should be taken into consideration is the possibility to use composite insulators with these type of conductors. This verification should be carried out with reference to the maximum conductor temperature on a test set up which reproduces the actual condition of installation. Fig. 5 reports the thermal images of the test carried out on a typical 150 kV suspension configuration. This tests have confirmed that the adoption of normal fittings configuration allows to keep the temperature of the metal compression fitting of the composite insulators much below temperature that can be considered dangerous for the mechanical behaviour of the insulators (even for conductor temperature above 200°C).
In particular the experimentation carried out showed that, with the 150 kV suspension configuration, the heat transmission between conductors and insulators takes place mainly by air natural convection and not by conduction through metal fitting as it could be supposed. Other tests that were carried out on heat-resistant conductor are the following:

- Tensile test;
- Stress-strain test;
- Heat cycles test on compression type tension clamp and mid-span joint;
- Aeolian vibration test;
- Self damping test.

Given the present lack of international standards for testing of heat resistant conductors and relevant fittings, particular attention is necessary in the definition of technical specifications for these components. On the base of this consideration and starting from the tests carried out draft tests specifications were also produced for conductors and fittings.

RE-CONDUCTORING OF LINES WITH HEAT-RESISTANT CONDUCTORS

The installation of heat-resistant conductors on existing lines, as above anticipated, requires some preliminary verifications:

- Verification of the actual clearances on ground and crossed plants, in order to assess the clearance margins;
- Verification of the voltage drops, due to the higher electrical resistance than to traditional conductors;
- Verification of the structural characteristics of the towers.

The installation of TACSR and ZTACIR is not different from the installation of traditional ACSR. For the installation of ZTACIR in Lazio a new type of vibration damper, spirally wrapped around suspension clamps, has been experimented (with an increase in time installation with respect to traditional conductor). With reference to the lines installed in Lazio the use of heat resistant conductors allowed to increase the power transferred by previous 22.8 mm \( (308 \text{ mm}^2) \) conductor (calculated according to CEI 11-60 standard [2]) of about 40-50% given to very tight limitations on maximum tensile loads on towers and to route altitude characteristics.

The next installation of GTACSR in Lazio will present much more difficulties due to the intrinsic characteristics of the conductor and to the peculiarity of the line to be re-conducted. In order to allow that at temperature installation the aluminium layers are mechanically unloaded, thus allowing the exploitation of the characteristics of conductor, the following operations must be done:

- Pre sagging, using Aluminium gripping clamp for temporary sagging up to approx. 70% of final tension.
- Final sagging, by pulling only steel core using steel gripping clamp.
- After final sagging, the conductors are left for more than 12 hours so to spread aluminium wires equally to every span of tensioning section and then suspension clamps are clipped in.

As regard the difficulties linked to the existing line, in this case there is the need to substitute two suspension sets with two semi-strain sets, due to the excessive distance (9 km) between the existing dead end towers. Another problem is due to the fact that the line is available for re-conductoring (out of service) only during daylight; at night it must be in service again. The operation required for the installation of this conductor is consequently very complex. Here follows a description of the installation of a semi-strain set, representative of the difficulties above indicated.

**Phase 1:** after paying out of new conductor, aluminium gripping clamps are set up on the conductor of both sides tower (Fig. 6). Pre-sagging of both tensioning is made up to approximate 70% of final tension pulling by aluminium gripping clamps of both sides. The conductor is cut off considering sufficient length for by hydraulic cutter (Fig. 7).

**Phase 2:** following works are carried out at both side conductors of tower respectively.

![Fig. 6 – Installation of aluminium gripping clamps](image)

![Fig. 7 – Cut off of aluminium layers](image)

Aluminum dead-end clamps are inserted to conductors and aluminium layers are re-stranded with enough precaution to avoid any damage of aluminium wires. Grease on steel core is wiped up where steel gripping clamps are fixed and steel gripping clamps are set up on steel core and then final sagging is made pulling by steel gripping clamps. After leaving the sagged conductor for specified time, final sag is adjusted pulling by steel gripping clamp and then steel core is made straight to examine the length of steel core. Steel core is cut off at exact measured point.

**Phase 3:** steel clamps of both sides are compressed on steel cores and the clamps are connected with yoke plate (Fig. 8). Grease is applied to steel core and re-stranded aluminium layers are winded up as original shape of conductor.
Aluminium deadend clamps of both sides tower are compressed at correct position and aluminium gripping clamps are removed from conductor (Fig. 9).

![Fig. 8 – Realisation of steel clamps](image)

![Fig. 9 – Compression of aluminium clamps](image)

**SERVICE AND MAINTENANCE**

Heat-resistant conductors have Joule losses much higher than conventional ones, due to the higher service temperature. For this reason and for the higher carried current, voltage drop are significantly increased. All these aspect must be taken into consideration in the planning of the re-conductoring. As regard maintenance operation, no particular difference are foreseen for TACSR and ZTACIR with respect to traditional ones. In case of gap-type conductors repair operation may be more complicated: while helical repair rods can be used to repair small damages to the alloy layers, bigger damages may require to insert a length of new conductor using midspan joints. This operation will require firstly the realisation of the joints on the steel cores at ground level and then the compression of the aluminium sleeves on the aluminium alloy layers working from a hydraulic platform, in order to allow the complete settlement of the aluminium layers.

**ECONOMIC EVALUATIONS**

In case of upgrading of a high voltage 150 kV line equipped with 22.8 mm ACSR by adoption of a traditional 31.5 mm (585 mm²) ACSR, the cost will be about 100 k€/km (due to the need to realise new towers or to modify the structure of the existing ones).

In case of re-conductoring with a heat-resistant conductor, GTACSR for example, the cost will be about ¼ of the one with larger traditional conductor: about 25 k€/km.

On the other hand the higher temperature of service will produce higher Joule losses, with a difference in cost of about 5 k€/km per year (with increasing value with the time). Making the hypothesis of a rate of energy consumption increase around 4% and of a discount rate of 6%, the break even point of the costs of the two solution will be in 10-15 years.

In case of impossibility to upgrade the line by use of bare overhead conductors, as for the crossing of areas with particular environmental or landscape importance, underground cable must be used.

The cost of realisation of a line in cable will be about 300 k€/km. For the evaluation of the total cost of the line, it must also be considered that, in general, the length of the route of a cable line is greater than that of an aerial line. Another aspect which increases the cost of a cable solution is maintenance, more expensive for cables than for overhead lines.

On the other hand Joule losses will be lower: by comparison with a traditional 31.5 mm ACSR the difference can be evaluated in 2-3 k€/km. If again we make the hypothesis of a rate of energy consumption increase around 4% and of a discount rate of 6%, the break even point of the costs of the two solution in this case will be in 70-100 years.

**CONCLUSIONS**

The growing demand of electric power (and of the power input in the grid) involves a progressive increase in the power transferred by electrical lines. It is thus necessary to plan an upgrade of those lines where critical levels of power have been reached or will be reached within some years (on the base of network studies). This upgrade can be realised by substituting the existing conductor with a new one with greater cross section (i.e. from 308 mm² to 585 mm²). This solution involves the realization of new towers or the substantial modification of existing ones. These works require authorisations that are very difficult to obtain and, in any case, need long times.

The possibility offered by the re-conductoring of the line with heat-resistant conductors, that allows an increase of the line ampacity thanks to the possibility to run the line at higher service temperature, constitutes a valid solution to solve the problem without the need to increase the height or to modify the existing towers.

The choice of the characteristics of the new heat-resistant conductor must be done on the base of each site specific conditions (clearance margin, new load required, etc.). Great attention must be paid to qualification tests of conductors and relevant fittings. Evaluations on the power losses and on the voltage drops must also be taken into consideration for the appropriate selection of the conductor.

**REFERENCES**
