UPRATING USING HIGH-TEMPERATURE ELECTRICAL CONDUCTORS.

I. Zamora (*), A.J. Mazón (*), R. Criado (**), C. Alonso (**), J.R. Saenz (*)

(*) University of the Basque Country - Spain
(**) IBERDROLA S.A. - Spain

SUMMARY

The legislation currently in force that affects the construction of overhead electricity transmission or distribution lines establishes an extensive number of conditioning factors as regards licences, public exposition of projects, rights regarding the presentation of allegations, etc. It is not difficult to establish that, in numerous cases, the period than can elapse between the time the need for the installation of a new line is detected and its coming into service amply exceeds the time regarded as permissible by the utility.

Indefinite time scale planning certainly does not seem a feasible proposition, but rather that both concepts are antagonistic. Therefore, the search for alternative solutions to the construction of the said installations becomes increasingly more pressing.

Among the possible lines of action in order to palliate the problem raised, one of those that appears to be most accessible is the use of conductors with high thermal performance. These conductors could replace the current ones with an operation that could well receive the consideration of maintenance on the line, without requiring any special negotiation or formalities in order to obtain the appropriate “rights of way”.

However, the documentation and the know-how available to date require the consideration of a set of questions related basically with the electrical, thermal and mechanical performance of the conductors and their installation. Moreover, and always assuming that the action mentioned is technically feasible, the need to analyse the economic feasibility in depth is evident.

With the COALPRET research project, developed by the electric utility Iberdrola S.A. and the Electrical Engineering Department of the Basque Country University, an analysis has been carried out on the performance of electrical conductors that offer high temperature performance and their application in a 132 kV line on the Spanish Mediterranean coast. The scope of this project focused precisely on the technical and economic analysis of the use of conductors with high thermal performance in overhead lines as a replacement for the systems currently used and on the analysis of their effect on the rest of the system.

Among others, conductors of the types ACSS, ZTACIR y GTACSR have been considered:

- ACSS conductors: (Aluminum Conductor Steel Reinforced).
- Invar-cored conductors ZTACIR (Heat Resistant Aluminum Alloy Conductor Invar Reinforced).
- Gap-type conductors GTACSR (Gap Built-in Heat Resistant Aluminum Alloy Conductor).

The carrying out of an in depth study of these conductors’ parameters and characteristics is of great interest for the following reasons:

- The aforementioned conductors allow an increase in the power-carrying capacity of existing overhead distribution and transmission lines, without having to turn to neither the restringing of new lines nor the request for new administrative permits.

- Even though they have been used in both Japan and the United States all along the last two decades, there is not a vast experience or knowledge about their operating characteristics. At a European level there is just one case in England where these conductors have been employed in an uprating project (National Grid).

In the paper, the most significant results of the analysis carried out will be presented, which have made it possible to select the most appropriate type of conductor for the uprating of the 132 kV line considered.

UPRATING USING HIGH-TEMPERATURE ELECTRICAL CONDUCTORS.

I. Zamora (*), A.J. Mazón (*), R. Criado (**), C. Alonso (**), J.R. Saenz (*)

(*) University of the Basque Country - Spain
(**) IBERDROLA S.A. - Spain

ABSTRACT

This paper presents the most important results of the COALPRET research project, whose dual aim has been to carry out a general study of the characteristics of electrical conductors with high temperature performance and low sag, and apply these studies to the specific case of the Alcira - Gandía 132 kV overhead transmission line.

The final goal of the project is the replacement, in the Alcira-Gandía line, of the current ACSR conductors by another type of conductor with low sag characteristics. With this replacement, the aim is to increase the ampacity rating of the aforementioned line by at least 70%, with the smallest increase in sag, as there are currently numerous spans where the distances line to earth are very compromising.

INTRODUCTION

The legislation currently in force that affects the construction of overhead electricity transmission or distribution lines establishes an extensive number of conditioning factors as regards licences, public exposition of projects, rights regarding the presentation of allegations, etc. It is not difficult to establish that, in numerous cases, the period than can elapse between the time the need for the installation of a new line is detected and its coming into service amply exceeds the time regarded as permissible by the utility.

Indefinite time scale planning certainly does not seem a feasible proposition, but rather, both concepts are antagonistic. Therefore, the search for alternative solutions to the construction of the said installations becomes increasingly more pressing.

Among the possible lines of action in order to palliate the problem raised, one of those that appears to be most accessible is the use of conductors with high thermal performance. These conductors could replace the current ones with an operation that could well receive the consideration of line maintenance, without requiring any special negotiation or formalities in order to obtain the appropriate "rights of way".

However, the documentation and the know-how available to date require the consideration of a set of questions related basically with the electrical, thermal and mechanical performance of the conductors and their installation. Moreover, and always assuming that the action mentioned is technically feasible, the need to analyse the economic feasibility in depth is evident.

The so-called high temperature conductors were first introduced in countries like the U.S.A. and Japan more than two decades ago. While in the North American case environmental reasons, among others, obliged the electrical utilities to use high temperature conductors instead of resorting to the construction of new lines, in Japan, the reasons were to be found in the high demographic occupation of the country and the high cost of land. Although not in a generalised manner, conductors with high-temperature performance have also been used in transmission lines in different countries in the Arabian Peninsula, where the high ambient temperatures contribute towards reducing the transmission capacity of the lines.

The British National Grid Company intends to successfully complete the replacement of 7.5 km of AAAC conductor in one of its critical lines during the year 2000, with high temperature conductor without any modification of the supports in what constitutes the first practical application of the use of this kind of conductors in Europe

With the COALPRET research project, developed by the electric utility Iberdrola S.A. and the Electrical Engineering Department of the University of the Basque Country, an analysis has been carried out on the performance of electrical conductors that offer high temperature performance and their application in a 132 kV line on the Spanish Mediterranean coast. The scope of this project focused precisely on the technical and economic analysis of the use of conductors with high thermal performance in overhead lines as a replacement for the systems currently used and on the analysis of their effect on the rest of the system.

In this paper, the most significant results of the analysis carried out will be presented, which have made it possible to select the most appropriate type of conductor for the uprating of the 132 kV line considered.

GENERAL CHARACTERISTICS OF HIGH TEMPERATURE CONDUCTORS

Conductors with high temperature performance are electrically and dimensionally very similar to the conventional ACSR conductor, with its differential characteristic being its lower heat expansion coefficient. The direct consequence is that the conductors accept a higher temperature, for the same sag, which in turn brings about an increase in the ampacity of the line.

The carrying out of an in depth study of these conductors' parameters and characteristics is of great interest because that conductors allow an increase in the power-carrying capacity of existing overhead distribution and transmission lines, without having to turn to neither the restringing of new lines nor the request for new administrative permits.

Even though the conductors analysed in the COALPRET research project are called the high temperature type, this was not the most valued property for their application in the Alcira-Gandía line, where the safety distances to earth in many of the spans were very compromising, but rather their low sag characteristic. Conductors of the types ACSS, ZTACIR and GTACSR have been considered.

ACSS conductors (Aluminum Conductor Steel Supported).

Conductors of this type are used in the U.S.A. and Canada. The utilities in these countries do not always use this type of conductor for continuous operation at high temperatures and with an increase in the ampacity. They are installed in many cases in order to use this extra capacity in emergency situations against contingencies or in view of a forecast future increase in demand.

When ACSS conductors are used in order to increase the ampacity of a ACSR-conductor line with a certain limitation on the sag, it might happen that this replacement can not be carried out by means of conductors with a cross section equal to the original. This occurs due to the fact that the lower breaking strain of the ACSS makes it necessary to string it with a lower strain, which in turn causes the original sag to increase considerably, and meaning that it might exceed the pre-set limit value when its temperature rises. Therefore, before deciding on a certain ACSS conductor in order to carry out the uprating of the line, all the available solutions must be analysed by submitting them to the restrictions imposed by their stringing.

Invar-cored conductors ZTACIR (Heat Resistant Aluminum Alloy Conductor Invar Reinforced).

The main differential characteristic in relation to the conventional ACSR conductor is that its core is made of INVAR, instead of conventional steel. INVAR is a material composed of an alloy of steel and 36-38% nickel, whose most important property lies in the fact that it has a linear expansion coefficient practically invariable with heat. In addition, the conductor wires are composed of an aluminium alloy with a high thermal endurance and high conductivity (ZTAL). This combination of materials enables the current capacity of the line to be increased extraordinarily and a sag inhibition effect to be obtained.

INVAR conductors are characterised by having a transition temperature in the region of 85-100ºC, after which all the mechanical strength of the conductor is provided by the INVAR core. Above this transition temperature the sag inhibition effect takes place, so that it increases very little with temperature. Nevertheless, this characteristic means that the performance of ZTACIR conductors is very similar to the performance of ACSR conductors up to the transition temperature. The advantages of ZTACIR conductors become obvious after an operating temperature of about 85-100ºC.

Gap-type conductors GTACSR (Gap Built-in Heat Resistant Aluminum Alloy Conductor).

Whereas the two previous types of conductors had a geometrical configuration identical to the conventional ACSR conductor, gap-type construction conductors are characterised by having a characteristic structure, which is shown in figure 1.

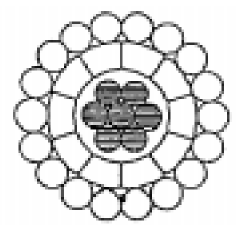

Figure 1. Structure of the GTACSR conductor

The aluminium wires in the internal layer, closest to the core, have a trapezoidal cross section in such a way that a gap is formed between the steel core and the aluminium layers. This gap is usually filled with grease resistant to high temperatures. The existence of the gap in this type of conductor gives it a high vibration absorption capacity.

This construction method makes it possible to reduce the friction between the core and the aluminium wires in such a way that the GTACSR conductors can be strung by tightening only the steel core and leaving the aluminium layers untightened. This fact means that the elongation of the conductor depends almost exclusively on the linear expansion coefficient and on the elongation characteristics of the steel core. Thus, at temperatures higher than those at stringing, only the steel core supports the stress, with the sag in the conductor depending only on the expansion of the steel. On the other hand, at temperatures lower than those at stringing, the stress is supported by the entire conductor, which performs in a similar way to a conventional ACSR. Nevertheless, in order to achieve this performance from the conductor, it is necessary to apply a special stringing procedure that proves to be more complex than those normally used in conventional ACSR conductors.

Comparative aspects

As a summary, table 1 shows a comparative analysis of the most important advantages and disadvantages of the high temperature conductors considered as compared to the more conventional ACSR conductors.

TABLE 1 - Comparative analysis of high temperature conductors vs. ACSR conductors

Conductor	Advantages	Disadvantages
ACSS	- Operating temperatures up to 250 ºC - Lower sag increase at high temperatures. - Higher self damping capability - Reduced creep.	- Smaller tensile strength. - More expensive
ZTACIR	- Operating temperatures up to 210 ºC - Lower sag increase for temperatures beyond the transition point.	- Smaller tensile strength. - For temperatures below the transition point the sag-temperature behaviour is similar to that of ACSR. - More expensive
GTACSR	- Operating temperatures up to 150 ºC - Lower sag increase for all temperature ranges. - High self damping capability. - Higher tensile strength.	- More complex stringing procedures. - More expensive

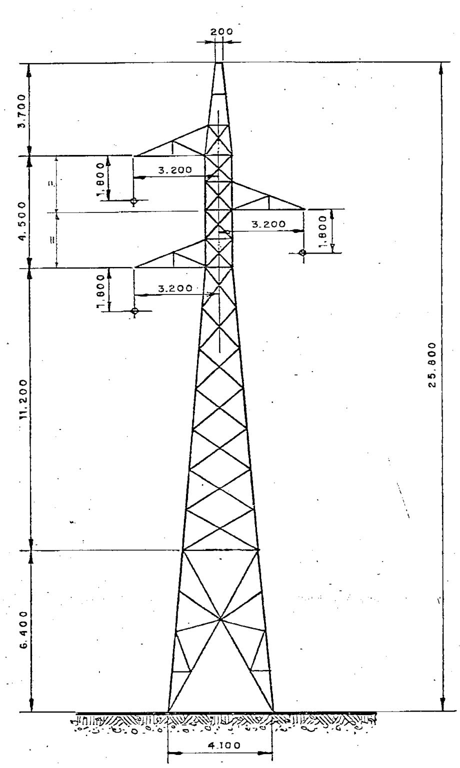

Figure 2: Structure type 84

CHARACTERISTICS OF THE ALCIRA-GANDIA ELECTRICAL LINE

This is a 132 kV overhead line with a single three-phase circuit, 31.9 km long, and originally composed of three HEN type ACSR conductors and a steel earth conductor with a cross section of 50 mm^2. The most typical type of tower used along the length of this line is the structure type 84, whose dimensions are shown in figure 2.

For the Alcira-Gandía line, the electrical, mechanical and thermal characteristics of the HEN equivalent high temperature – low sag conductors have been analysed. The results obtained are presented below.

Electrical characteristics

The electrical parameters have been calculated for high temperature performance conductors equivalent to the HEN type ACSR conductor. By carrying out a comparative study of the values of electrical resistances, inductive reactances and capacities, only slight variations in the resistance value have been found. This is due to the fact that all conductors would be supported by the same type of tower and that the geometry of the conductors is similar for all the types of conductors analysed.

Table 2 shows the values of the resistances for all the types of conductors analysed, and extends to cover different conductor operation temperatures. From the values that are shown in this table, it can be concluded that the ACSS and GTACSR conductors have similar electrical resistance values in the 60ºC to 150ºC range, and are slightly lower than the resistance of the ACSR conductor. For this range, the ZTACIR conductor shows electrical resistance values of about 7% higher.

TABLE 2 - Comparative analysis of electrical resistances

	Resistance a.c. - 50 Hz (Ω/km)			
Tª (ºC)	ACSR	ACSS	ZTACIR	GTACSR
60º	0,137	0,132	0,142	0,131
75º	0,143	0,139	0,149	0,138
90º	0,150	0,146	0,156	0,145
105º	-----	0,153	0,164	0,152
120º	-----	0,160	0,171	0,158
135º	-----	0,167	0,178	0,165
150º	-----	0,174	0,186	0,172
165º	-----	0,181	0,193	-----
180º	-----	0,188	0,200	-----
200º	-----	0,198	0,210	-----
210º	-----	-----	0,215	-----

Mechanical characteristics

Given that the aim is to replace the ACSR conductors in an already existing line, the type of high temperature conductor chosen is strongly conditioned by the fact that it allows the ampacity of the line to be increased without violating the minimum phase-to-earth distances set by the regulations in force.

In the analysis of the mechanical characteristics, the sag for each conductor has been determined in terms of the continuous operating temperature. Taking into account that, in the Alcira-Gandía line, at the maximum continuous operating temperature of the HEN type ACSR conductor (50ºC) there is a sag limitation of 8.52 m., it has been possible to determine the possible temperature increase with the new conductors.

Figure 3 shows that, for the given restriction in the line sag, represented by the worst case span, whereas the temperature increase obtainable by either ACSS or ZTACIR would be negligible, the use of a GTACSR conductor equivalent in size and weight to that currently employed (ACSR), would yield to a potential temperature increase of more than 30ºC.

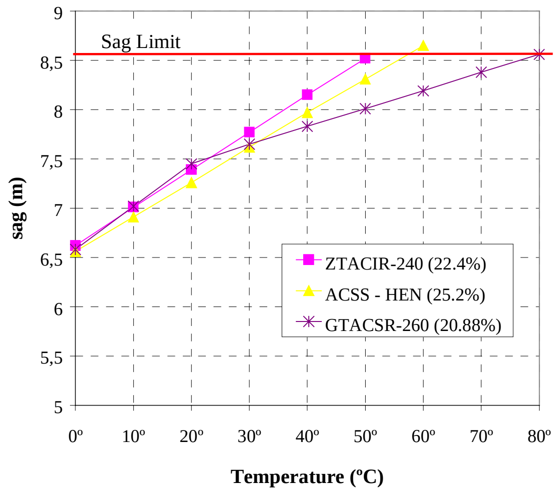

Figure 3: Sag-temperature performance

Therefore, it can be observed that the GTACSR conductor is the one that allows a greater increase in the operating temperature, from the 50ºC of the current ACSR to around 80ºC.

Thermal characteristics

In a general manner and in stationary conditions of wind speed, temperature, solar radiation and current flow, a conductor transmitting a certain electrical power is subject to heat balance determined by the following factors, referred to the time unit:

$$Q_c + Q_r = I^2 \cdot r + Q_s$$

In which:

- $I^2 \cdot r$: heat generated by Joule effect.
- Q_c: heat transmitted to the atmosphere by convection.
- Q_r: heat absorbed from solar radiation.
- Q_s: heat released by the conductor's own radiation.

The atmospheric conditions that have been considered are those relating to the Spanish Levante (Eastern Mediterranean coast), where the Alcira-Gandía line is located. These conditions are:

- Ambient temperature:	34ºC (summer)
- Wind speed:	0.6 m/s
- Emissivity:	0.5
- Line azimuth:	0º
- Sun azimuth:	180º
- Altitude of the sun:	73º
- Radiation losses:	0.1 W / cm^2

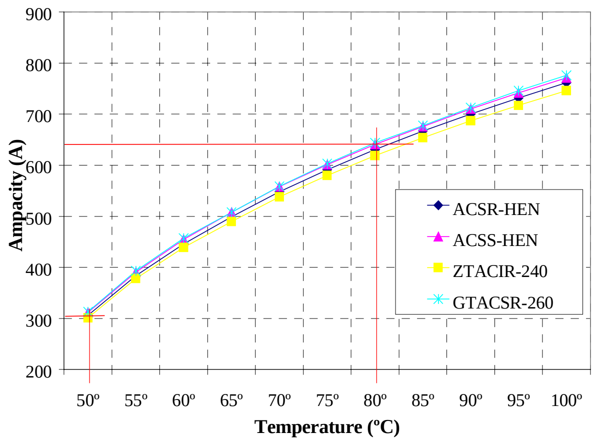

Figure 4: Ampacity-temperature performance

Taking into account these atmospheric conditions, the possible ampacity increase with the new conductors and with the existing sag limitation has been determined. In this way, figure 4 shows the ampacity values obtained for the different types of high temperature - low sag conductors.

According to figure 4, the increase in the GTACSR conductor operating temperature (from 50ºC to 80ºC) represents an ampacity gain of more than 300 A which doubles the power-carrying capacity of the line, with the wind and sun conditions specified.

Similar results have been obtained by considering different atmospheric wind and sun conditions. In all cases, the original aim of the project has proved to be possible, as the potential increase in the ampacity of the line is always beyond the 70% increase initially requiered, while at the same time respecting the safety distances.

Influence on other items in the network.

Besides the analysis of the electrical, mechanical and thermal caracteristics of these high temperature conductors, the COALPRET research project has assessed the potential influence of these conductors in the rest of the grid. Thus, the following aspects have been considered

- Influence on the system itself: analysis of the equipment installed in the substations at the ends of the Alcira-Gandía line, checking if they are no longer valid.
- Interference with other systems: crossings with other lines.

This study has guaranteed the technical feasibility of the restringing project employing the GTACSR instead of the HEN type ACSR conductor present at the moment.

CONCLUSIONS

Following the carrying out of the COALPRET project, the next conclusions could be considered as being most important:

- The Alcira-Gandía line has a sag limitation of 8.52 m., which conditions the maximum continuous operating temperature value of the conductors.
- The GTACSR conductor is the one that can operate at the highest temperature (80ºC) with the existing sag limitation.
- The ampacity rating of the line can be increased by more than 70%.
- The electrical resistance is lower than in the equivalent ACSR type conductor.
- The stringing process is more complex.
- No modification is required to the support towers.

Although the Alcira-Gandía 132 kV line, due to its criticality in the transmission of electric power along the so-called Mediterranean corridor, has been taken as the reference line for this project, new cases of transmission lines that would require a similar uprating study appear with certain frequency. If the replacement activities, which are planned for completion next year on the Alcira-Gandía line, prove to be successful, it is probable that uprating operations become generalised, not only in the network belonging to IBERDROLA S.A., but also in different transmission and distribution lines in Spanish territory.

REFERENCES

[1] F.R. Thrash, 1999, "ACSS/TW – An Improved Conductor for Upgrading Existing Lines or New Construction". IEEE T&D Conf., Vol. 2, pp. 852-857.

[2] M. Ishikawa, H. Ito, 1989, "Practical Application of an Extremely Low-Sag Invar Reinforced Increased-Capacity Extra-Heat-Resistant Aluminum Alloy Conductor". Sumitomo Electric Technical Review, No. 28, pp 161-171.

[3] M. J. Tunstall, S. P. Hoffmann, N. S. Derbyshire y M. J. Pyke, 2000, "Maximizing the Ratings of National Grid's Existing Transmission Lines Using High Temperature, Low Sag Conductor". CIGRE 2000, Paris.

[4] Hitachi Cable Ltd., 1999, "Introduction of Hitachi-Invar Reinforced Aluminum-Conductors", TD 80-12006.

[5] The Furukawa Electric Co. Ltd. "Thermo-Resistance Aluminum-Alloy Conductors Invar Reinforced". No. TD 89-035 E.

SET OF FIGURES

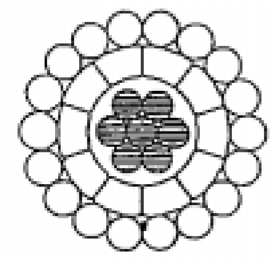

Figure 1. Structure of the GTACSR conductor

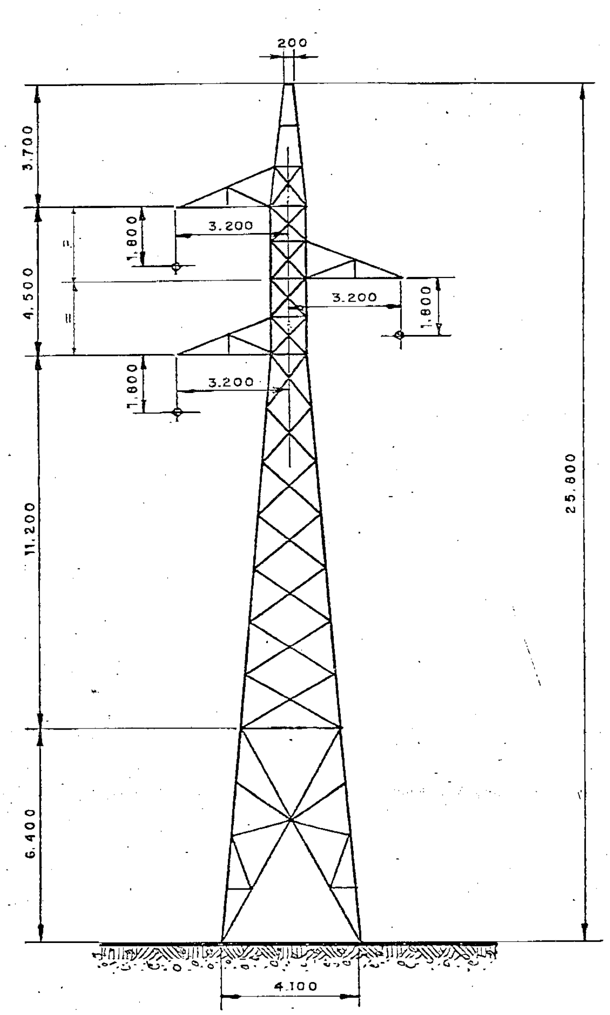

Figure 2: Structure type 84

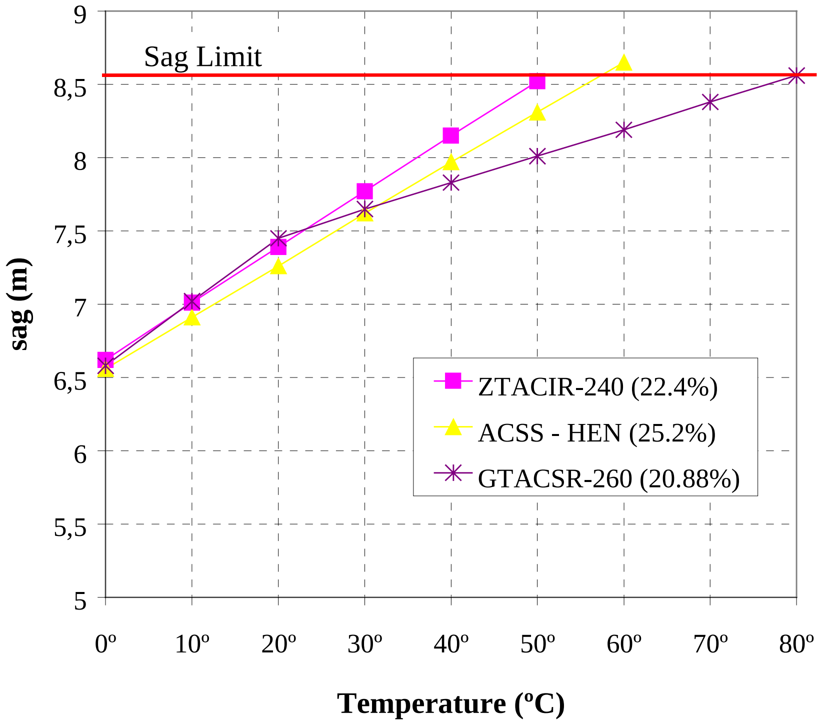

Figure 3: Sag-temperature performance

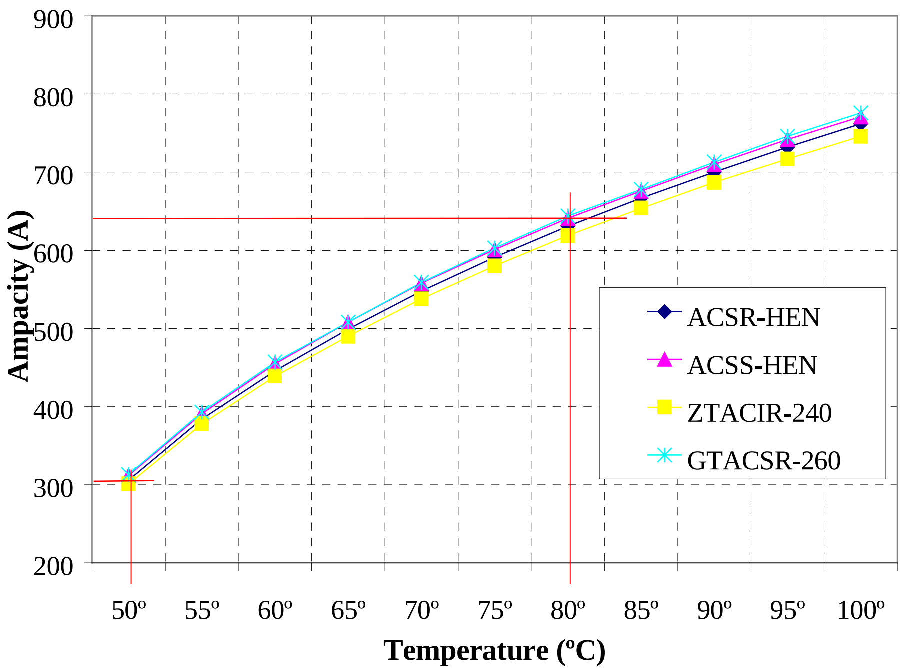

Figure 4: Ampacity-temperature performance