HTLS and HVDC solutions for overhead lines uprating

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1. Abstract

The increase in power demand has made that existing overhead transmission lines need to transmit more energy. In addition to this, the legislation of many developed countries hinders or even forbids the construction of new overhead lines because of their environmental impact. Furthermore, and as a result of this, some transmission lines can be close to its critical capacity limit.

In this paper, several uprating technologies are compared taking into account environmental conditions, maximum stress bearable by the towers and maximum sag as well as economical concepts to develop a mapping criterion of conductor selection.

Keywords: Line capacity, HTLS, overhead line uprating, HVDC, knee point.

2. Introduction

Nowadays, the permissions and licenses needed to build new lines and in some areas even the retrofitting of the previous lines are very difficult to obtain. Moreover there are many social objections against this kind of facilities. The previous drawbacks have made electric utilities to consider the uprating of existing overhead lines in order to manage with the demand increase.

There are different ways to improve an overhead line capacity: real-time monitoring, increase cable stress, replace ACSR conductor with High Temperature Low Sag (HTLS) conductor and transform the AC line into HVDC.

The cheaper method to get an overhead line uprating is real-time monitoring. By this method the line operator has the information to decide the maximum line current without exceed the conductor thermal and sag line limits, according to instantaneous weather conditions.

The second option consists of increasing conductor installation stress. This solution is feasible only if conductors and towers can withstand the new stress.

The main problem of these solutions is that usually, the upgrading is not enough to deal with the increase of the demand. For this reason, in a high percentage of uprating lines the options chosen are to replace conventional conductor by HTLS or transform the AC line into HVDC. In this paper the main features of these solutions are detailed.

There is a wide range of HTLS technologies commercially available. Fig 1 shows the improvements and costs of the different conductors compared with the other uprating solutions.

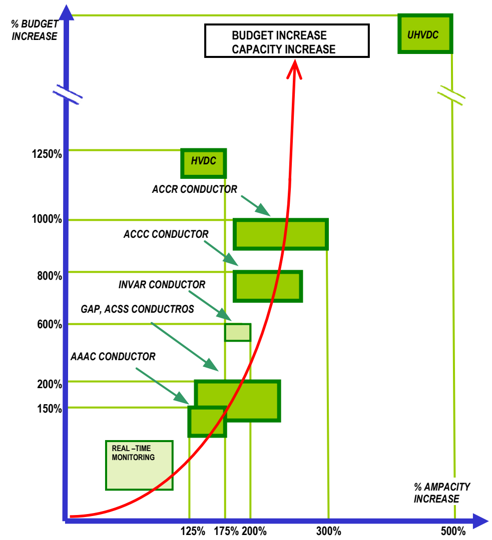

Fig 1. Capacity increase and cost of each uprating solution

The conversion of an AC overhead line to HVDC is the most expensive solution because it needs converters stations in both ends of the line. Nevertheless, HVDC has important advantages: low losses, line reliability improvement and it achieve the highest capacity increase. CO_2 emissions of each uprating have been calculated with the losses and taking into account an average emission factor of the utility. Line losses have been calculated with the exact equivalent circuit.

3. HTLS Conductors

Thermal limit of conventional conductor is around 90ºC, above this temperature the material suffers plastic deformations. To improve this behavior HTLS conductors are based on aluminum alloy and annealed aluminum, thereby they can operate between 150 and 210ºC without damages. One of the most important characteristic of the HTLS conductors is the knee point. The knee point is the temperature from which the whole conductor stress is withstood by the core. Therefore if the temperature is higher than the knee point the conductor presents excellent mechanical properties. Low coefficient of thermal expansion (CTE) and high tensile strength, guarantee low sag values. In HTLS, the pure aluminum of the ACSR conductors has been replaced by a high temperature aluminum alloy. The main features of the HTLS conductors considered in this paper are:

A. G(Z)TACSR conductor

This conductor has a gap between the core and the aluminum strand fill with grease stable at high temperature, as a result, aluminum can slide over the core. By this way the whole stress is supported by the core when the conductor exceeds installation temperature.

B. ACSS conductor

This kind of conductor relies on a core of steel wires surrounded by annealed aluminium strands. The annealed treatment improves the aluminium ductility and reduces its modulus of elasticity; both effects make that all the stress and tensile strength would be supported by the steel core, with better mechanical characteristics. The annealed treatment also improves the aluminium conductivity and its operating thermal limit. The conductor behaviour for high temperatures could be also improved if the steel core is coated with galvanized or a mischmetal alloy.

C. (Z)TACIR conductor

It is made up of high thermal resistance aluminium alloy strands, called TA1, surrounding an Invar alloy wires core.
The outer aluminium strands permit high temperatures operation, near to 150ºC. This temperature could be increased up to 210ºC with an aluminium-zirconium alloy. The core Invar alloy, composed of steel with 36-38% nickel, provides a material with a low CTE.
As long as the operation temperature increases, the aluminium experiments an elongation which causes that stress becomes supported by the core, getting a low sag values due to its low CTE.

D. ACCR conductor

ACCR conductors have a high temperature aluminium-zirconium strands covering a stranded core of fiber-reinforced composite wires.
The aluminium-zirconium alloy is made by adding zirconium to aluminium at high temperature, without rising the aluminium annealing-point, so when aluminium-zirconium alloy is cooled down, it keeps the aluminium mechanical resistance and improves its high temperature operating capacity.
The core consists of a metal matrix composed by wires made up of an ultra-high-strength aluminium-oxide-ceramic fibers fully embedded within high-purity aluminium, by this way the core wires obtains the strength and stiffness of steel, but with a lower CTE and density.

E. ACCC conductor

It is based on annealed aluminum over high strength carbon fiber with glass fiber of reduced CTE. The composed core has excellent mechanical properties, like low CTE or a rated strength which double the steel one, that guarantee a sag value almost constant. The glass fiber prevents the carbon fiber from high temperature damages so the operation temperature can be increased.

F. AAAC conductor

This kind of conductor is all made up of wires composed of aluminium alloy 6201 fibers (within magnesium and siliceous), in concentric strands and with the same diameter.
The conductor maximum operating temperature is not higher than conventional conductor one, so AAAC is not a HTLS. However, as the whole section is composed of aluminium this conductor can transmit a higher current than the conventional.

To select the conductor that better fits with the new line conditions is necessary to study its maximum sag and current. Both parameters depend on installation stress and the knee point of the conductor. Installation stress is limited by the existing towers lines and knee point temperatures varies from 15 or 20 ºC in G(Z)TACSR to 100ºC in (Z)TACIR.

4. HVDC conversion

The key points to consider in a HVDC uprating are the next:

- **Low conductor losses.** In HVDC solutions capacity increase is accomplished by rising nominal line voltage. Therefore current flow through the conductor is the same than in the previous AC line and conductor losses due to Joule effect will maintain constant.
- **Maximum nominal line voltage.** This parameter depends on the tower features. Maximum nominal line voltage can be changed if the existing towers are modified.
- **Insulator string behaviour in dc.** DC isolation is more complex than AC due to the no polarity alternation in current. According to [1] in some cases an improve protection against corrosion can be apply to get higher voltages, in other cases, specially when very high voltages are needed, AC insulators have to be replaced by specific DC insulator with different geometry.
- **Line configuration.** There are different ways to lay out the DC conductor over the towers but bipolar is the best one. It has two voltage level and symmetrical polarity in each pole. In spite of being more expensive, it maximizes the line capacity. If towers cannot be modified, the layout depends on the DC tower geometry. If towers can be modified the best option consists on replace the 6 existing cross-arm (when the AC line have 2 circuits) with 2 longer and more resistant cross-arm, one for the positive polarity and the other for the negative.

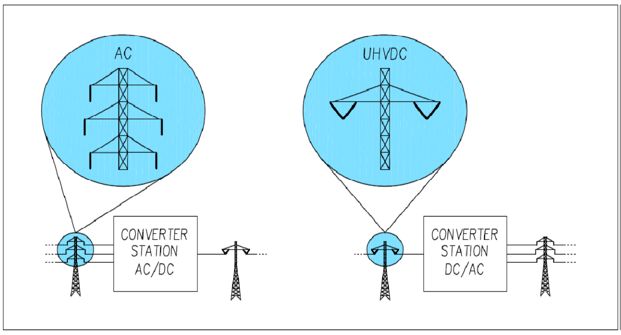

Fig 2. UHVDC tower modifications

5. Case Study

In order to analyze the different uprating solutions, a study in a real overhead line has been made. The line length is 23km and the conductor installed is a LA-280 Hawk. The line owner pretends to increase the line capacity up to 150MVA per circuit to cover the demand increase in the line area.

The overhead line is made up of 2 circuits with one conductor per phase. The line voltage is 110kV and the average span is 350m length. According to [2], the maximum sag and tensile strength must be calculated under zone A conditions, which means that the altitude of line is less than 500 meters over the sea level.

To be sure that the new conductor not exceeds the maximum sag and stress bearable by existing towers, the measured values with the current conductor (ACSR) are the limits for both parameters.

A. HTLS conductor uprating

The HTLS conductors behaviour has been studied with PLS-CADD[3]. This program calculates the main line parameters depending on conductor properties and weather conditions defined by user. Knowing the limits in sag and stress value set by the previous conductor, PLS-CADD evaluates the biggest section of each HTLS conductor that can be installed.

With the line conditions previously mentioned, the results show that the HTLS conductors with the best response are G(Z)TACSR with an uprating of 168%, the ACCR which reach up to 195% and the best one is the ACCC that make possible double the line capacity till 226% of the power transported with the original conductor. Although technically the better conductor would be ACCC, installation costs must be studied to determined the most suitable conductor. Table 1 shows the uprating achieved with each technology.

Table 1. Uprating achieve with each technology

TECHNOLOGY	UPRATING %
HTLS G(Z)TACSR	168
HTLS ACCR	195
HTLS ACCC	226
HVDC	141-175
UHVDC	500

B. HVDC uprating

Maximum nominal line voltage has been calculated by changing the line to HVDC with the same towers, insulator strings and conductors. As the uprating got with HVDC can also be achieved with HTLS conductors both solutions have been compared to analyze which is better. Depending on the line performance HVDC uprating varies between 141% and 175%.

In the last case (UHVDC), tower and insulator strings modifications are taken into account to calculate the maximum uprating with HVDC. In this case, the optimal solution is based on replace the tower cross-arm. The original towers have 3 cross-arm per circuit with a security distance among them. As in bipolar DC system there are only 2 phases, the 6 cross-arm can be replace by 2, longer and stronger. By this way the nominal voltage could be increased without damage. The new cross-arm must be place on the highest current cross-arm but in order to reduce the maximum stress on the tower base they are usually placed in the intermediate cross-arm position. Other conditions to be fulfilled are the distances between the conductors and the zero voltage components. This problem, which is derived from wind action, can be avoided replacing I-strings by V-strings. With this solution the uprating achieved rounded 500%.

6. Installation costs

A. HTLS uprating cost

The mainly differences in cost between HTLS conductor and ACSR are acquisition price and in some cases, installation costs over existing towers. Approximately, the HTLS conductor prices vary between 1.5 and 10 times the ACSR cost. The G(Z)TACSR cost is twice the ACSR, the ACCC conductor more than 7 times and the ACCR between 9 and 10 times.

Conductor installation costs are similar to ACSR, only in the case of the G(Z)TACSR this cost increase because of its different configuration. Due to its special behavior its installation is more complicated, these conductors need specific machines and tools and they installation time is longer. Both aspects make that G(Z)TACSR installation double the cost of ACSR installation.
The rest of the costs have not been considered because they are similar in HTLS conductors than with conventional conductors.
Uprating costs with HTLS can be evaluated as 2.3 millions € if the conductor selected is G(Z)TACSR. If the objective current are higher and ACCC or ACCR conductor have to be installed the uprating cost would be 5.2 and 6 millions € respectively.

Table 2 shows uprating costs with each technology.

Table 2. Uprating cost with each technology

TECHNOLOGY	UPRATING COST (m €)
HTLS G(Z)TACSR	2.3
HTLS ACCR	5.2
HTLS ACCC	6
HVDC	6
UHVDC	> 6

B. HVDC uprating cost

In HVDC uprating the main cost is the converter station. The former substations need to be modified to add the converter system (converter transformers, converter, smoothing reactor, filters, etc.) These changes mean a large initial cost but the results show that the capacity increase and the great loss reduction achieved can decrease the total cost in several years of line operation.
[4] says that the converter stations for an overhead line with 150MW could be around 13 millions €. Nevertheless, it is thought that this price can be reduce to 6 millions € if the components are bought separately and turn-key solution is avoided.

If the solution is UHVDC the previously showed cost is increased due to tower modifications and insulator string replacement.

7. Operation costs

The main HVDC advantage is that in contrast to HTLS uprating, with DC line the capacity increase is reached raising voltage level while with HTLS it is got raising current level. As Joule effect depends on current and not on voltage level, with HTLS conductor losses are increased in a quadratically with capacity increase, however HVDC solutions make possible the uprating without loss increase.
Station losses are higher in converter station than in conventional, this makes that for short lines HTLS uprating results would be better than HVDC uprating. Moreover the losses increase with line length is more marked with HTLS conductor than with HVDC solution.

Fig. 2 shows power, current, line losses and CO_2 emission for both solutions, with G(Z)TACSR conductor in AC and with HVDC. All the parameters are referred to the ACSR conductor values. In a 23km line energy losses in DC solution are lower than losses with AC, in spite of converter losses double conventional station losses.

CO_2 emission is higher in the HVDC line because the factor used to calculate them only depend on the active power so reactive power of HTLS line is not considered.

$$CO_2 emissions = eal\ power\ losses * Emission\ factor \quad (1)$$

where $Emission\ factor = 0{,}586\ \frac{t\ CO_2}{MWh}$

CO_2 emission in a 23km line varies between 163% (HTLS) and 172% (HVDC) respect conventional conductor emissions. Despite this drawback, is important to say that DC conductor losses (0,56 p.u) are half than AC conductor losses (1,14 p.u.).

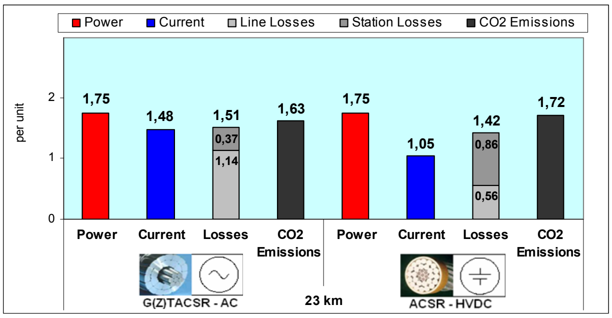

Fig 3. HTLS and HVDC 23km line uprating

The advantage of HVDC is clearly show when the line lenght is increased. Fig 3 compares both solutions in a 150km line and it shows that the HVDC losses became half than HTLS losses. CO_2 emission is also greater in the HTLS solution. With this line length CO_2 emission in the HVDC case transmitting 150MVA is similar to emission with the conventional conductor transmitting only 85MVA.

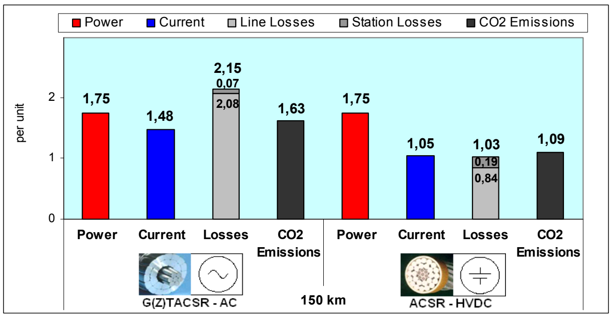

Fig 4. HTLS and HVDC 23km line uprating

To evaluate the investment profitability is neccesary to asses in a economical way the losses decrease. From [5] and [6] company income from distribution activity is 1.85 cent.€/kWh. Discounting the profit margen (supposed 10%), distribution costs can set as 1.65cent.€/kWh.

Without considering the benefits (enviromental, economial and social) of the CO_2 emission reduction, the decrease of energy losses with the HVDC solution enable that, although in a 23km line always will be greater HVDC solution costs than HTLS ones, if the length line is increased till 150km in 10 years of line operation the cost of HVDC is lower.

8. Conclusions

According to manufacturers, replacing ACSR conductor by HTLS the uprating varies from 125 to 300%, in the studied case and under the specific line conditions the maximum uprating reached is 230%.
When the line is transformed to HVDC the capacity of the line increases up to 175%. In this case the new line

keeps the previous insulator strings, towers and conductors. Only the substation must be changed.
Whether the whole facility is modified in order to get the maximum capacity increase, HVDC solutions achieved up to 500%.
In those cases in which a extreme uprating would be necessary, above 500%, both solution, HVDC systems with HTLS conductors, can be applied together and so their benefits are multiplied.
Economically, when the line length is around 23km, the best solution to get an uprating of 150% is HTLS conductors, nevertheless, when the line is longer HVDC uprating is the most inexpensive.

Acknowledgements

The authors wish to express their gratitude to Endesa Network Factory for their collaboration in this project.

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