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Evaluation of the effects of Climate Change on Air Transmission Lines, using PLS-CADD Software tools and Hierarchical Analytical Processes (AHP). Case: Paraguay.

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Abstract: *Observing the global climatic problem due to the excess of greenhouse gases (GHG) emitted into the atmosphere, mainly Carbon Dioxide CO_2, the lack of commitment of the developed countries to the unrestricted control of the Kyoto protocol, make the situation global climate accelerate the deterioration of the planet; the current energy situation in Paraguay, the results of the National Energy Balance (BEN) prepared by the National Electricity Administration (ANDE) which concluded that there would be power to meet load demand until the year 2035, makes necessary the search of new alternatives for the generation of electric power [1].*
The growing increase in the demand for electric power associated with the lack of investments in the areas of distribution and maintenance of the electricity sector. Added to this the difficulties for the construction of new transmission airlines, due to the inconveniences in the release of the easement strip, this raises the difficulty in supplying electricity reliably and continuously to much of the country, especially in the hottest periods, leaving operating close to its capacity limits electrical system. This article seeks to analyze the behavior of the Transmission Lines in the face of the effects of climate change and its consequence with the increase of the ambient temperature and how this would limit the transmission capacity and what would be the most advisable mitigation or adaptation mechanisms under a sustainable vision.

Keywords - *Climate Change (CC), Transmission Line (LT), Analysis of Hierarchical Processes (AHP), High Temperature and Low Arrow (HTLS), Intergovernmental Panel of Experts (IPCC), Software PLS-CADD.*

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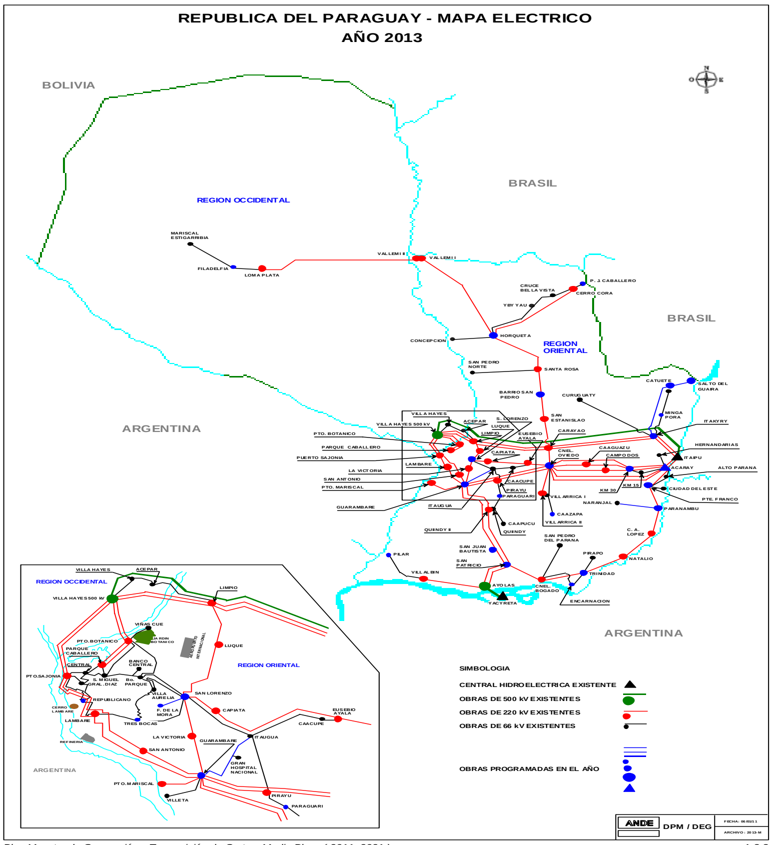
I. Introduction

With the commissioning of the 500kV Itaipú-Villa Hayes Air Transmission Line. There is a need to increase the transmission capacity of electric power in both the Sistema Norte and the Sistema Sur, with the commissioning of power autotransformers 2x375MVA, 500 / 220kV in the Yacyretá bar, which contracts the unfailing need to repower the Air Transmission Lines in the South System (see Fig.1). In this way, economic and social growth in the country can be accompanied, taking into account the future installation of numerous industries, with which the consumption of electric power would increase practically twice the current consumption. In addition, the start-up of the 500kV Itaipú-Villa Hayes Line with a charge injection close to 2000MW has to be taken into account, and the second Yakreta-Villa Hayes 500kV line with a charge injection close to it is under construction. to 2000MW, which implies a reorientation of the power flow in the Paraguayan Electric System (SEP), especially in the trunks of the North and South Systems and with it the creation of a new electrical center of gravity, in which can discard an out of service due to the contingency of the 500kV line [1]. In the medium term, 500kV ringing would be completed, which would give greater reliability to the electrical system and allow ringing at voltage levels of 220kV / 66kV.

This means that 220kV main lines must be prepared to contain this power in the event of an unforeseen event. On the other hand, the unrestricted increase of greenhouse gas (GHG) emissions is increasing the temperature of the planet. The consequences include the melting of glaciers, the increase in rainfall and the frequency of extreme weather events, and changes in weather stations. The accelerated rate of climate change, together with the increase in population and income worldwide, threatens not only food security everywhere, but the energy balance [11], [25], [26].

An important aspect is also the social impacts associated with climate change associated with the interruption of Balbuena electrical energy transmission, which may be related to food decomposition, effects in hospitals, effects observed more frequently to populations more vulnerable [29]



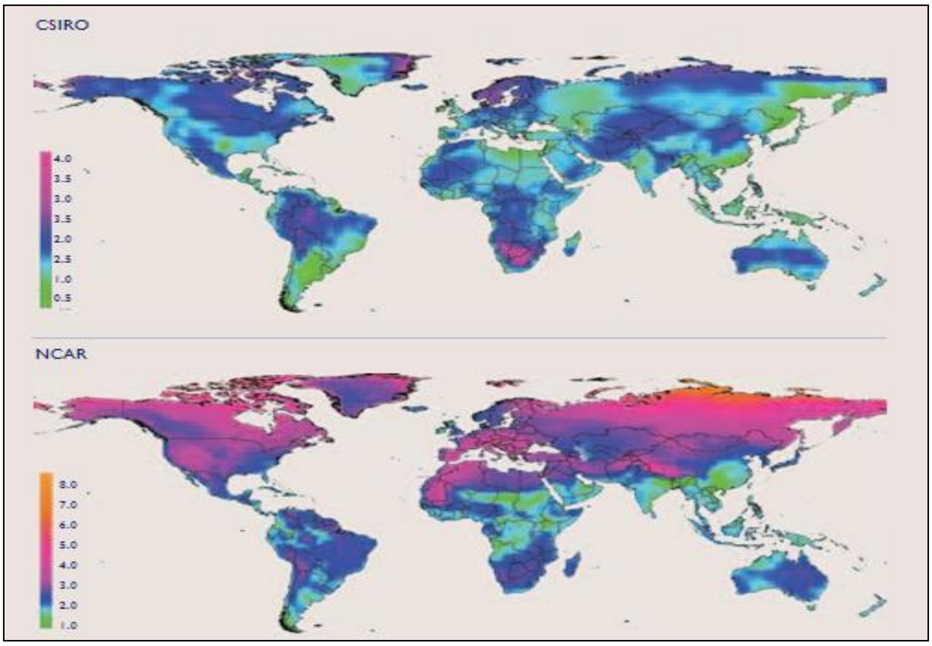
Plan Maestro de Generación y Transmisión de Corto y Medio Plazo (2011 -2021) A.3-3

Figure 1. Master Plan of the Paraguayan Electric System. Source: ANDE (2013-2023)

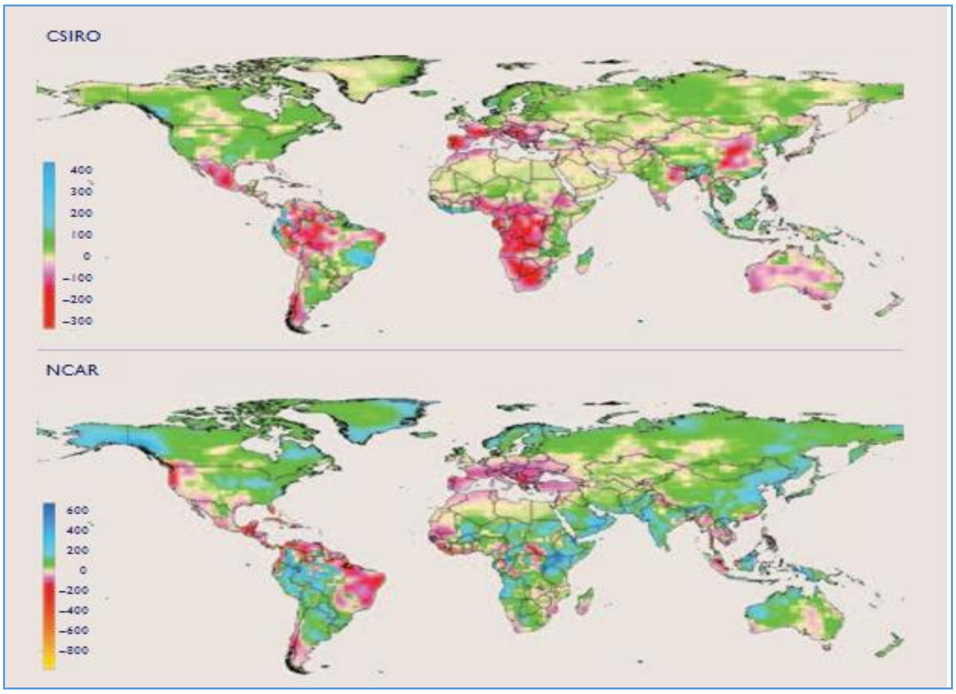
II. Theoretical framework

Simulations of climate change are intrinsically uncertain. Two models have been used to simulate the climate of the future using scenario A25 of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, for its acronym in English). The first one correspond to the model of NCAR (National Center of the United States for Atmospheric Research, for its acronym in English). The second one correspond the model of CSIRO of Australia (Organization of Scientific and Industrial Research of the British Commonwealth or "Commonwealth" ", for its acronym in English). We will refer to the combination of execution of these models under the conditions of scenario A2, such as the scenarios "NCAR" and "CSIRO" [22], [23].

Both scenarios project higher temperatures in 2050, which cause greater evaporation and increased precipitation as water vapor returns to the planet's surface. The more humid NCAR scenario estimates average rainfall increases on the earth's surface of around 10%, while the drier CSIRO scenario estimates an increase of 2%. Graph 1 shows the change in the average maximum temperature between 2000 and 2050 for the CSIRO and NCAR scenarios. Graph 2 shows the changes in average rainfall for the CSIRO and NCAR scenarios. In each set of graphics, the colors of the legends are used identically; each specific color represents the same change in temperature or precipitation in both scenarios [22], [23].



Graph 1. Changes in average maximum temperature (º C), 2000 - 2050. Source: [26], [28], 2009.

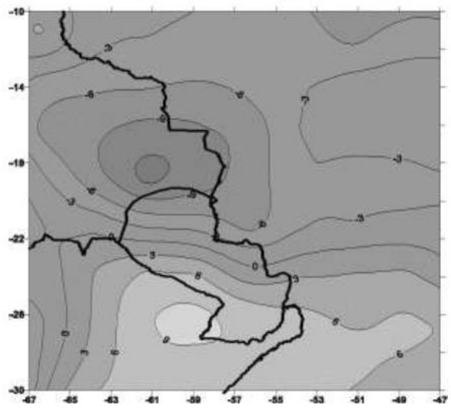


Graph 2. Change in precipitation (mm) 2000-2050. Source: [26], [28], 2009.

A quick look at these graphs shows that there are fundamental differences between the two scenarios. For example, the NCAR scenario presents average maximum temperatures that are substantially higher than the CSIRO. The CSIRO scenario shows a substantial decrease in rainfall in the Western Amazon, while NCAR shows decreases in the Eastern Amazon. The NCAR scenario shows higher rainfall in sub-Saharan Africa than the CSIRO scenario. North China has higher temperatures and higher rainfall in the NCAR scenario than in CSIRO. These graphs qualitatively illustrate the range of potential climate outcomes that are obtained with current modeling capabilities and provide an indication of the prevailing uncertainty regarding the impacts of climate change [24], [26], [27], [28].

According to Figure 2 for the Csiro scenario for the western region of the Amazon, there is a decrease in precipitation regimes, which are related to the increase of the temperature and an increase in the changes of the maximum average temperature for the same period verified. in Graph 1. Looking at Paraguay according to the output of the NCAR model for temperature change, an increase is observed up to 2 ° C associated with an increase in precipitation regimes of up to 200mm for the same period according to Graph 2.

Graph 3 shows a regional simulation of the percentage change in rainfall generated through a regional model PRECIS (Providing Regional Climates for Impacts Studies) developed by the Hadley Center of the Office of Meteorology of the United Kingdom. This model is given by 19 vertical levels and two possible horizontal resolutions of 0.5 by 0.5º or 0.25 by 0.25º of latitude by longitude, this simulation was generated through the edge conditions of the global climate model HADCM3 for the period (2081-2090). Graph 3 shows a variation in rainfall that varies according to the area on the territory, with variations ranging from + 6% to values of -9% on Paraguay, these negative values are observed in the northern region of the Paraguayan Chaco [30].



Graph 3. Percentage change in precipitation 2050. Source: [30], 2012.

III. Analytical Framework

The uncertainty arises that it will occur with the transmission capacity in the 220kV transmission. The ambient temperature in Paraguay would have an increase of 2ºC (See Graph 1), as the Lines would be limited. The conventional conductors of type AL 1350 with steel core type ACSR (Aluminum Conductor Steel Reinforced), are traditionally used in our country in power transmission. Both at the voltage level 220kV, 66kV and at the maximum projected operating temperature of the same is 90ºC in the most unfavorable climatic conditions (40ºC of ambient temperature during daytime hours and 35ºC of ambient temperature during night hours). When the conductor exceeds 90ºC for more than 3000 cumulative hours, the annealing process begins in the conductor wires and afterwards the deterioration of its mechanical characteristics [2], [5], [15].

The table shows the limitation in transmission capacity under the scenario of climate change and as the temperature of the driver exceeds 90 ° C for the most unfavorable climatic condition, in addition to exceeding the elastic state of the driver would violate the safety distance of the ground. The transmission capacity of the LT would be limited to 750A and the equivalent of 10MVA would not be transmitted (See Table I).

Table I: Transmission Capacity of the ACSR Driver in the different climate scenarios. Source: Own and [8], 2018

	Ambient Temperature (°C)	Conductor Current (°C)	Conductor´s Temperature (°C)
Without Climate Change	40	775	90
With Climate Change	42	775	92.1
Current Limitation	42	750	90

Faced with this scenario of uncertainty and under multiple criteria (MMCC) of decision, the tool of the Analytical Hierarchical Processes (AHP) will be used to find the valid alternative to overcome this inconvenience. The methodology consists of assembling matrices in level 2 criterion and matrices in level 3 alternatives. Weights (1-9) are given where weight 1 means that the variables are not strongly bound to meet the objective and the weight 9 represents that the variables are strongly linked to meet the objective, with the allowable consistency ratio of the matrix being less than 10% [17], [18], [19], [20].

The objective will be to increase the transmission capacity under Sustainable Vision, under the criteria of technical feasibility, economic viability, social viability, sustainability, the alternatives proposed to achieve the objective will be the construction of a new line of transmission, reconsidering the existing line with the conventional methodology, reconsidering the existing line with HTLS technology (see fig.2).

With regard to what criteria the objective will be achieved, we find: criteria of technical feasibility and economic viability, the technical-economic feasibility of retraining is sought and how these interact to achieve the objective, social viability refers to legal barriers and. For the release of the easement strip of the Transmission Line, sustainability refers to the fact that the increase of the load is not only sustainable in the short term but sustainable in the long term. Among the proposed alternatives to increase transmission capacity are: 1) The construction of new transmission lines, taking into account that the annual growth rate of the electrical system is 10%, which is equivalent to the transmission capacity of a line of 220kV [1]. 2) In regard to the retraining of the Line by the conventional methodology. We find intermediate columns placed half-empty, change of existing conductors for drivers of greater weight and diameter, which implies the verification of structures and foundations. Placement of false anchoring to gain height of 1m (66kV) up to 2m (220kV) in points where the ground clearance is compromised, with this artifice the capacity of the transmission line can be increased by 30%, without the safety distance of the Ground driver is compromised. 3) Regarding the use of high temperature and low arrow conductors, we find the replacement of the current conductor with one of the same diameter and weight that has a transmission capacity of 300% without changing the arrow in the most unfavorable climatic conditions [12] [16].

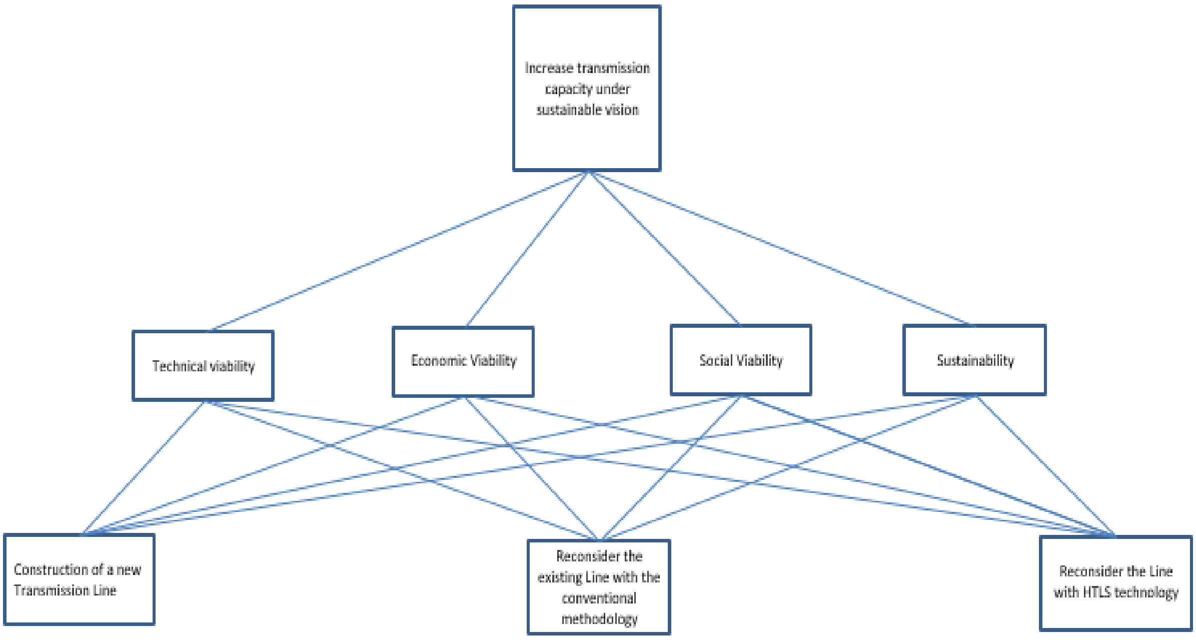


Fig. 2: Hierarchical decision tree that allows to increase the transmission capacity of LT under a sustainable vision. Own Source, 2018.

Applying the Multiple Criteria Theory (MMCC) of the Hierarchical Analysis of the AHP, a 4x4 matrix is verified in level 2 (criterion) and a 3x3 matrix in level 3 (alternatives). Regarding level 2, it is verified that the 4x4 matrix has a consistency ratio (CR) of 0, random inconsistency index of 0.9, λmax of 4, for some order weights; Technical Feasibility 0.1250, Economic Viability 0.1250, Social Viability 0.1250, Sustainability 0. 6250. The consistency ratio (CR) is less than 0.10, so the matrix has a reasonable consistency and is valid. Regarding level 3, it is verified that the 3x3 matrix obtained and compared with the alternatives of each one of the criteria; Technical feasibility criteria, the consistency ratio (CR) of 0.065; Economic viability, consistency ratio (CR) of 0; Social viability, consistency ratio (CR) of 0, Sustainability consistency ratio (CR) of 0.094. The consistency ratio (CR) is less than 0.10, so the matrix has a reasonable consistency and is valid [20].

Table II: Target matrix and weights of the proposed alternatives. Source: Own, 2018.

Objective: Increase the capacity of Transmission under sustainable vision	Technical viability	Economic Viability	Social viability	Sustainability		Prioritization (P)
Technical viability	1	1	1	1/5		0,1250
Economic Viability	1	1	1	1/5		0,1250
Social viability	1	1	1	1/5		0,1250
Sustainability	5	5	5	1		0,6250

	Technical viability	Economic Viability	Social viability	Sustainability				
	w1	w2	w3	w4		P		Final Weighting
Construction of new LT	0,052437	0,090909	0,066667	0,129027		0,1250000		0,10689
Reconsider Conventional Method	0,579077	0,454545	0,466667	0,081180		0,1250000		0,23827
Reconsider with HTLS	0,368486	0,454545	0,466667	0,789793		0,1250000		0,65483
						0,6250000		

Once the consistency ratios of the criterion matrix and the matrix of the alternatives have been demonstrated, they are within the admissible parameters, we proceed to make the corresponding weights with their corresponding weights and it is observed that among the alternatives proposals to evaluate the most convenient methodology. Rethink with HTLS (0,65); Recall Conventional Method (0,24); Construction of new LT (0,11), (see fig.3).

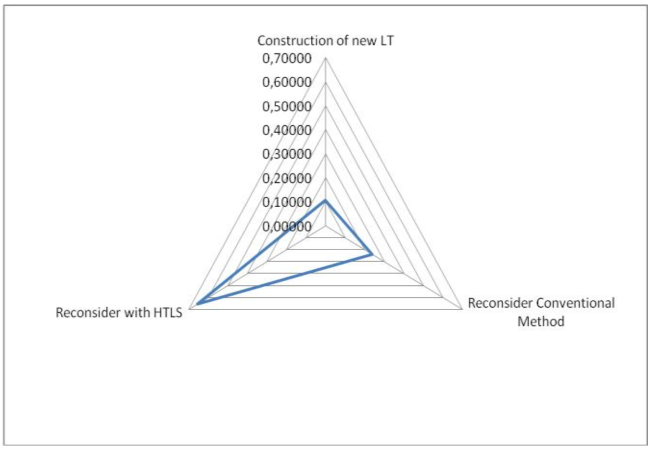


Fig. 3: Results of the evaluation where the objective is to find the alternative to Increase the Transmission Capacity under Sustainable Vision. Source: Own, 2018.

HTLS Type Conductor with ACCC composite core technology

Among the more efficient HTLS type conductors we found the composite core type (see Fig.4). The same can be defined as a material obtained from the agglutination of two or more elements, exercising functions of matrix and reinforcement. The matrix confers the structure of the composite aluminum, in terms of the reinforcing materials they raise the mechanical, electromagnetic or chemical properties [21].

Fig. 4. HTLS conductor with ACCC technology. Source: [9], 2018.

In this category of conductors with a composite core we find the ACCC type conductor (Aluminum Conductor Core Composite). In ACCC type conductors, the core is composed of carbon fibers covered by an insulating layer in epoxy resin, whose function is to prevent the oxidation process. A similar function fulfills the zinc oxide coating in conductors with a steel core, thus avoiding galvanic corrosion [7].

The composite nuclei have coefficients of thermal expansion up to three times smaller, which considerably reduces the deflection of these conductors. These types of conductors have less technical losses than heat-resistant conductors, they are lighter than the conventional conductor with an ACSR steel core, but they require special sheaves for assembly. They tolerate halfway joints. In addition, the core components have different coefficients of expansion, so internal fissures cannot be ruled out for this technology, requiring special attention during assembly and commissioning [9]. These fissures contract losses of the corona effect. These drivers require special equipment for assembly. In addition, they require changes to existing fittings and terminals, given that conventional ones operate at 90ºC in extreme conditions [13].

Unconventional High Temperature and Low Arrow (HTLS) conductors allow an increase in the power transmission capacity of up to 300% of the rated power compared to ACSR type conductors. Having the same weight, diameter and arrow, so the use of conductors with this technology is a very attractive alternative, avoiding in most cases adjustments in the structures, mostly reticulated with hot-dip galvanized steel, allowing a significant saving in investment [9].

Table III: Geometric and thermal properties of the ACSR and ACCC conductor. Source: Own and [8], 2018

Conductor	Solar Heat in the Cable (w/m)	Radiation Cooling (w/m)	Convection Cooling (w/m)
ACSR Grosbeak	12.982	17.397	63.419
ACCC Grosbeak	12.982	17.743	63.515

For the requested mechanical conditions, the conductor voltage in the final state Creep (20% of the breakdown voltage of the conductor) and in the final condition maximum wind (40% of the breakdown voltage of the conductor) were not exceeded taking into account a wind speed of 145km / h. In addition, the emergency condition in the final condition (17% of the breakdown voltage of the conductor) for all the hypotheses proposed above none of the proposed cables must exceed the maximum values mentioned (see Tab IV). The standard vain used for the simulation and corresponding study in the selection of the economic driver will be 400m, planialtimetria flat for this condition the driver's arrow must not exceed 14m in the largest load request and the most unfavorable climatic condition [6], [15].

Table IV: Comparison of the mechanical behavior between the ACSR Driver and ACCC. Source: Own and [8], 2018.

Conductor	Rupture Tension (kg)	Final condition Maximum Wind	EDS final condition	arrow (m)
ACSR Grosbeak	11,209	35%	18%	14
ACCC Grosbeak	13,522	30%	19%	11

In the analysis carried out with the criteria mentioned in the previous paragraph, the load-bearing tree of a structure of the reticulated, hot-dip galvanized type was considered. The safety distance of the driver to the ground under the most unfavorable climatic condition (40 ° C) for the ACSR type cable (775 A) and under the most unfavorable climatic condition (42 ° C) for the ACCC type cable (1000 A). The conditions of wind vain will not be altered, but the conditions of vain weight will depend on the weight of the driver and the breaking voltage of the same [2], [8]. For the conditions established above and with the results obtained (see Tab IV) it can be seen that the ACCC type cable would not present any inconvenience for its selection in replacement of a conventional ACSR conductor. In terms of technical analysis, especially in the arrow (11m) and the geometric characteristics such as diameter and weight, maintaining a ground clearance of 7m, for a load injection of 1000A (see Tab.III and Tab.IV).

Table V shows the thermal behavior of the ACSR conductor under an ambient temperature of 40 ° C (SCC) and 42 ° C (CCC) and to the ACCC conductor under an ambient temperature of 42 ° C (CCC), where the latter presents a greater cooling by radiation and by convection.

For the comparative analysis of Ampacities between conductors the following conditions were taken into account: Wind speed 0.6m / s, angle of incidence of the wind on the conductor at 90º, height of the driver above sea level 300m, latitude -25º, emissivity 0.5, absolutivity 0.5, under these parameters and using the modeling according to the IEEE Standard std 738-1993 (see fig.5)

Table V: Comparison of the thermal behavior between the ACSR Driver and ACCC. Source: Own and [8], 2018.

	Solar Heat in the Cable (w/m)	Radiation Cooling (w/m)	Convection Cooling (w/m)
Without Climate Change ACSR 636MCM	12.982	17.397	63.419
With Climate Change ACSR 636 MCM	12.982	17.743	63.515
Without Climate Change ACCC 636 MCM	12.982	24.254	81.353

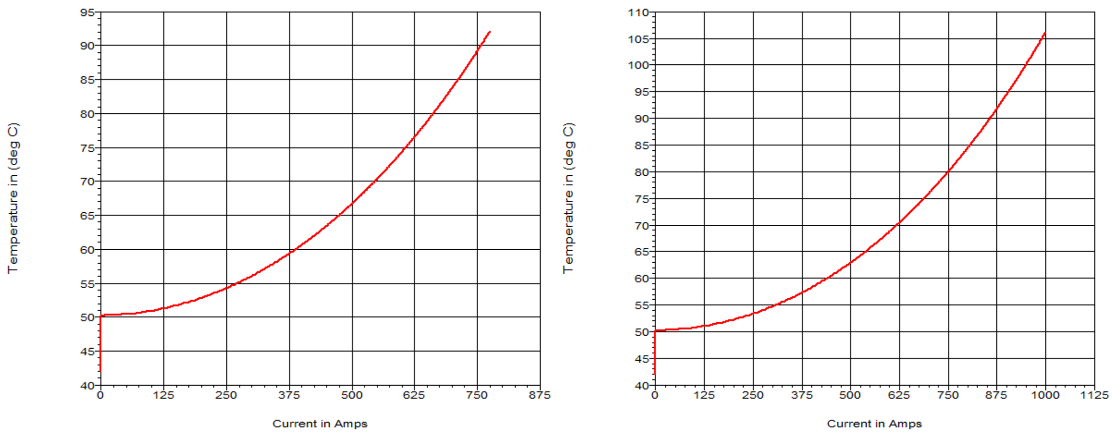


Fig. 5 Comparison of Ampacities between ACSR Driver and ACCC type conductor under ambient temperature of 42ºC. Source: Own and [8], 2018

It is important to emphasize that the Ampacity calculations were elaborated using equal values of emissivity (0,5) and abscess (0,5). On the other hand, this varies with the Transmission Line in service, which affects the temperature of the driver. Taking into account that the behavior of the driver with more than 10 years is that of a black body where the emissivity decreases and Absorption gradually increases. This results in an increase in the temperature of the cable and a reduction in the transmission capacity of the cable due to safety distance violation or limitation in the exchange of temperature with the environment [10].

IV. Evaluation of the electric and magnetic field for ACCC type conductor.

According to the results obtained in the PLS-CADD Software (see Fig. 6) we can observe the behavior of the electric field and the magnetic field in a cross section of the 220kV overhead transmission line with the ACCC conductor. The values are kept within the admissible limits in the security band which in our case is 50m [14].

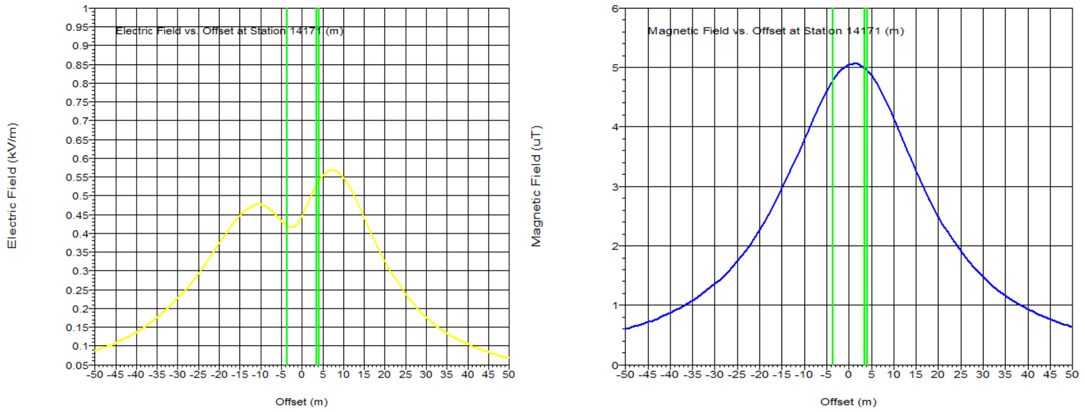


Fig. 6: Results of the evaluation of the electric field and magnetic field in the width of the easement strip of a 220kV transmission line with ACCC conductor. Source: [8], 2018

The maximum values of the electric field and the magnetic field are in the axis of the line in 0,5kV / m and 5μT respectively. These values are consistent with the admissible values of International Standards, so there would be no disadvantages in the implementation of HTLS technology in replacement of conventional conductors of the same weight and diameter for a current of 1000 Amperes [3] [4].

V. Conclusion

The behavior of the ACSR type conductor for a 220Kv Air Transmission Line has been evaluated. Taking a span of 400m, under the most unfavorable climatic conditions, without Climate Change (SCC) and with Climate Change (CCC), observing that the transmission capacity it is limited not only by the plastic behavior that the driver could have but also by the safety distance to the ground. Given this situation of uncertainty and the multiple criteria available for retraining a line, we opted for the use of the Hierarchical Analysis Process (AHP) to see which of the options was the most sustainable for a transmission line , since the conventional methodology of retraining is barely sustainable but not sustainable for the annual and current growth rate of 10%. For the comparison, an HTCC type ACCC cable of the same geometrical characteristics (diameter, weight) as an ACSR type cable was used. It was found that under the transmission capacity (1000A) and more unfavorable conditions of climatic conditions there was no problem, in terms of mechanical conditions, electric field, magnetic field, so the use of HTLS technologies in the design of new transmission lines or retraining thereof is sustainable, taking into account the costs of saving material for the manufacture of towers.

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