Retraining Air Lines 220kV Transmission in the Paraguayan Power System using High Temperature Conductors and Low Sag (HTLS) and their feasibility

Recapacitación de Líneas de Transmisión Aérea de 220kV en el Sistema Eléctrico Paraguayo, utilizando Conductores de Alta Temperatura y baja flecha (HTLS) y su factibilidad

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ABSTRACT
In the present study was assessed the technical and economic feasibility to change in high voltage aerial transmission lines conventional ACSR conductors by High Temperature and Low Sag (HTLS) conductors of similar diameter and weight with the aim to increase the transmission capacity of these lines without the need to change the towers made of galvanized steel. It could be shown comparing the energy losses and the respective investment cost of 4 different types of HTLS conductors, that the GTACSR type conductors offer the highest economic advantage under the considered scenario.

Keywords: High Temperature and Low Sag conductor – ACSR - Grosbeak conductor – repowering.

RESUMEN
En el presente estudio se evaluó la viabilidad técnica y económica de la sustitución de conductores convencionales del tipo ACSR en líneas aéreas de transmisión en alta tensión por conductores de Alta Temperatura y Baja Flecha (HTLS) de similar diámetro y peso con el objetivo de incrementar la capacidad de transmisión de estas líneas, sin necesidad de cambiar las torres hechas de acero galvanizado. Se pudo demostrar mediante la comparación de las pérdidas eléctricas y el respectivo costo de inversión para 4 distintos tipos de conductores HTLS que los del tipo GTACSR ofrecen la mayor ventaja económica bajo el escenario considerado.

Palabras clave: conductor de alta temperatura y baja flecha (HTLS) - ACSR - conductor Grosbeak - recapacitación

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Introduction

We are observing globally climatic changes due to the excess of greenhouse gas emissions (mainly CO_2) and the lack of commitment of most of the industrialized countries to reduce their emissions according to the goals of the Kyoto Protocol. Only the implementation of new energy alternatives like the renewable energies and the implementation of energy efficiency measures on a huge scale would help to reduce these greenhouse gas emissions. Countries like China, Japan and the USA, as well as most of the European countries are incentivizing through subsidies, feed-in tariffs and other economic mechanisms the development of renewable energies, like solar, wind and biomass energy. In South America mainly Brazil, followed by Argentina and Uruguay are committed with the development of renewable energy technologies (Mitjans, 2013).

One of the main goals of this study is to present a better alternative to the construction of thermal power plants near the centers of electricity demand to balance the capacity lack of the 220 kV transmission lines coming from the existing hydraulic power plants by analyzing different technical alternatives to increase their transmission capacity. Such a thermal power plant exists actually for example in Salto del Guairá, located at the northern end of the Itaipú lake. These alternatives shouldn't involve the change of the existing isolators, neither the variation of the mechanical loads received by the towers using conductors with a similar diameter and weight as the existing conductors, which have to support actually during most of the time higher loads than their nominal capacity of the lines until the new 500 kV transmission line Itaipú-Villa Hayes will be fully charged (ANDE, 2013).

In the present article is considered a current of 800 Amps to make a technical and economic comparison between four different High Temperature and Low Sag (HTLS) conductor technologies considering that none of them are reaching the knee point.

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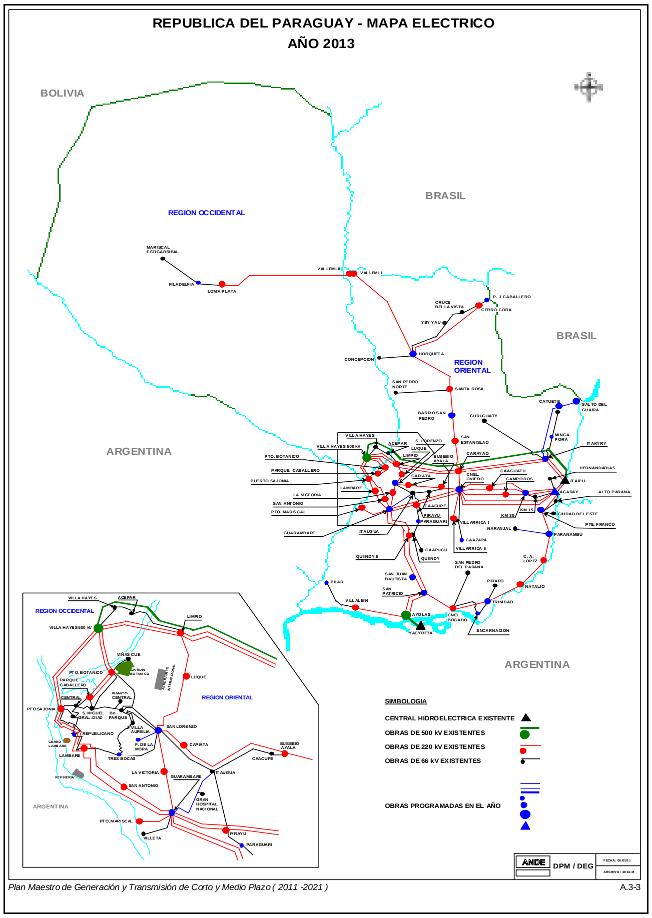


Fig. 1: Master Plan of the Paraguayan Electric System (2013 – 2023). Source: ANDE, 2013

Besides, the value of the ohmic resistance has a quasi-lineal behavior, what allows assessing their thermal and mechanic performance for the required conditions (CEMIG, 2010).

For technical analysis one stage with each of the technologies existing wires in the international market and high temperature low sag (HTLS) using criteria of International Standards and Technical Specifications of the state company ANDE was raised. It was verified that the conditions of maximum mechanical stress are not overcome by changing driver conventional ACSR 636 MCM, "Grosbeak" Code by one of high temperature and Low Sag (HTLS), the same diameter and weight type without changing the required insulators in the existing transmission line. For this purpose a pilot overhead transmission line of 100 km in length, an ampacity in normal operation 550Amperios, but operating with a load of 800 Amperios in 220kV voltage level was considered.

The comparison of electrical losses between each of the technologies mentioned above line length was evaluated. Among the economic variables an interest rate of 10% anual over a period of 20 years, the cost of Itaipu Binacional rate of 22.60 US $ / kW-month and a load factor for the transmission line 50 is considered % (ANDE, 2013).

Actual situation of the Paraguayan electric system

Due to the recent commissioning of the 500 kV aerial transmission line Itaipú-Villa Hayes there is a need to increase the transmission capacity as well as in the Northern System Carayaó-Horqueta 1x220 kV, as in the Southern System with the commissioning of the autotransformers 2 x 375 MVA 500/220 kV at the Yacyretá bar, what generated the unfailing need to potentiate with HTLS conductors the aerial transmission line Ayolas-San Patricio 2 x 220 kV (see fig. 1).

This way could be accompanied the economic and social development of the Southern Region of Paraguay considering the installation of many industrial plants provoking practically a doubling of the actual energy consumption. Besides, it should be taken into account that the commissioning of the 500 kV line Itaipú-Villa Hayes, making possible the injection of an additional power of 2000 MW, provoking a reorientation of the power fluxes in the Paraguayan electric system, mainly in the Northern and Southern Systems, generating a new electric gravitation center. In case of an out of service of this 500 kV line the main 220 kV lines should be able to contain this power (ANDE, 2013).

The conventional AL 1350 conductors (Aluminum Conductor Steel Reinforced ACSR) are the conductors traditionally used in Paraguay for transmission lines of the 220 and 66 kV levels. Their maximum projected operation temperature is 90°C under the most adverse climatic conditions (40°C ambient temperature during daytime and 35°C during nighttime). When the conductor surpasses 100°C during more than 3000 accumulated hours, starts an annealing process in the filaments of the conductor and then the decay of its mechanic properties (NEXANS, 2010). The nonconventional conductors of the HTLS type allow to increase the transmission capacity up to 300% of the nominal power compared to conventional ACSR type conductors with the same weight, diameter and slag. This makes this technology a very attractive alternative in most of the cases without the need of adaptation of the supporting towers made of reticulated galvanized steel representing important savings in investment costs (CEMIG, 2010).

Conductors with HTLS technology

HTLS conductors with thermal resistant technology (T-ACSR)

This type of conductors has a similar thermal expansion coefficient as an ACSR type conductor, reason why the mechanic behavior of the T-ACSR type conductor is like a conventional conductor. For this reason it's a much cheaper than any HTLS conductor. But the T-ACSR cable has a much higher breaking strain than a normal ACSR 636 MCM cable. This can be verified through the polynomial data of this conductor corresponding to the values of a conductor with steel core. This means that the complete cable (core and crown) is submitted to a much higher tensile stress, in the way that it is possible to install a cable with a similar diameter as the ACSR 636 MCM Grosbeak code cable. Besides, it can be obtained a much smaller slag during load injection considering the most adverse climatic conditions (ANDE, 2010).

It is important to mention that the traction to which is submitted the conductor generates a geometrical deformation of the threads of the aluminum crown usually of the heat-resistant type. This in turn leads to a distortion of the electric field of the cable and to losses of active power, as well as facilitates the formation of a hot spot or the crown effect. The temperature in this kind of cables oscillates between 80°C during normal operation conditions and 90°C during an emergency regime. This proves that the T-ACSR cable has practically a similar behavior as a conventional ACSR cable of the same size and the same code (ANDE, 2006).

The installation mode of this cable is similar to the conventional steel core cable tolerating splicing in the middle of the span, but it generates a lot of electric losses due to the steel core, which is a semiconductor, leading to a considerable heating of the conductor compared to other technologies with the same ampacity and environmental conditions. There is no need for special lockwashers during mounting.

HTLS conductors with composite core technology (ACCC and ACCR)

These conductors are of the compound core type (see fig. 2). It could be defined as a material obtained by agglutination of two or more elements exercising matrix and reinforcement functions. The matrix confers the structure of the compound aluminum while the reinforcing materials improve the mechanical, electromagnetic and chemical properties.

Within this category of conductors with compound core exist the ACCR (Aluminum Conductor Composite Reinforced) and the ACCC (Aluminum Conductor Composite Core) conductors. The core of the ACCR conductors is made of aluminum oxide (Al_2O_3) on an aluminum matrix, while in the ACCC conductors it is made of carbon fibers covered by an insulating layer of epoxy resin. A similar function exercises the zinc oxide recovering in the conductors with steel core preventing galvanic corrosion (ASTM N° B232).

Fig.2: ACSR and ACCC conductor, Source: CEMIG, 2010

The compound cores have a thermal expansion coefficient up to three times lower, what reduces considerably the slag of these conductors. The conducting layers of ACCR are composed of an aluminum zirconium alloy permitting continuous operation temperatures of up to 210°C. This kind of conductors has lower technical losses than the thermal resistant conductors, have a lower weight than conventional conductors with steel core ACSR, but need special lockwashers during their mounting. They tolerate splicing in the middle of the span. Also, the components of the core have different expansion coefficients, what could provoke internal cracks, what requires a special attention during mounting and commissioning (CEMIG, 2010). These cracks provoke losses of the crown effect. These conductors require special mounting equipment and the replacement of the existing ironworks and terminals, due to the fact that they are operating at only 90°C under extreme conditions (ANDE, 2009).

HTLS conductors with Gap Type technology (GTACSR)

The Gap Type ACSR conductors (GTACSR) have a layer of synthetic material between the steel core and the aluminum conducting crown, what reduces considerably the slag of these conductors (see fig. 3). This synthetic material in fact is a high temperature grease permitting an independent movement between the steel core and the thermal resistant crown, resulting in a thermal expansion coefficient almost two times lower than in a conventional ASCR conductor (CEMIG, 2010).

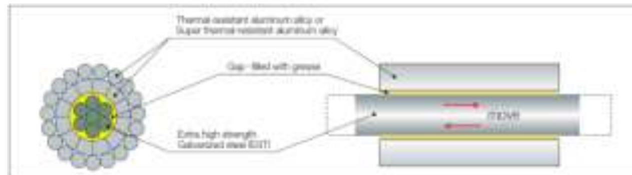


Fig. 3: GTASCR conductor. Source: CEMIG, 2010

This conductor supports a temperature of up to 240°C. Its installation is somehow difficult, because it doesn't allow splicing in the middle of the span. For this reason it has to be done at the towers converting the suspending towers into anchoring ones. So, those will have 3 anchoring chains with its corresponding insulators without mattering that those are of tempered glass or polymeric silicon rubber. Therefore, it's necessary to install small triangle shaped profiles in the brackets occasioning in the towers a surge of up to 20% of the Everyday Strench in the original line (CEMIG, 2010).

Another point to take into account is the need to study the load tree of the towers, independently if their foundation are of the self-supporting or the fettered type. In the second case this study has to be more detailed. To this has to be added a loss of around 30% of the conductor length due to the splicing at the suspending structures and not in the middle of the span. In fact, these losses differ for each transmission line repowering project with this kind of conductor, what makes necessary to do a detailed study concerning these losses with the aim to reduce them to the minimum.

As well it has to be considered, that in the points of splicing the conductor loses its diameter homogeneity causing a distortion of the electric field and as a consequence of this a huge crown effect and active power losses. For the elaboration of the laying and tightening table it has to be considered that it has to be done each span separately after having converted the suspending structures to anchoring structures and not as it is usually done by the PLS-CADD software. Besides, have to be changed the existing ironworks and terminals due to the fact that they are suited to a temperature of only 90°C under extreme conditions. This technology is actually installed and operating in the aerial transmission lines Coronel Oviedo-Guarambaré (2 x 220 kV) and Coronel Oviedo-San Lorenzo (1 x 220 kV). 1100 km of this kind of conductor have already been installed in the frame of the "Summer 2014 Program". With this conductor operating the transmission capacity reached 340 MVA in each one of these three circuits (ANDE, 2013; ANDE, 2010; ANDE, 2011).

Technical considerations on conductors with HTLS technology

As benchmark parameters for the comparison of the different HTLS type have been considered the diameter (similar or slightly smaller than the ACSR 636 MCM Grosbeak code cable) to prevent the crown effect, and the specific weight of the conductor to make unnecessary the reinforcement of the towers and its foundations (see table 1).

Table 1: Comparison of different HTLS technologies (diameter, weight, resistance).

Technology	Diameter (mm)	Weight (kg/km)	Resistance* (Ohm/km)
ACSR 636M CM	25.16	1302	
GTACSR	24.4	1301	0.0943
ACCC	25.15	1245	0.0791
T-ACSR	25.16	1302	0.1154
ACCR	24.25	1227	0.1167

* 800 Amps, 25°C ambient temperature

It's important to stress, that for each one of the proposed conductors the tension for the final condition at creep (20% of the breaking tension of the conductor) and at maximum wind speed (40% of the breaking tension of the conductor) haven't been surpassed considering a maximum wind speed of 145 km/h. Besides, for all the proposed technologies the emergency condition at final condition (17% of the breaking tension of the conductor). The standard span used for the simulation and the corresponding economic study of the conductors is 400 m, which are common for 220 kV aerial transmission lines. Besides, for flat land the sag for any of the conductor types should not exceed 14 m for the maximum load and the most adverse climatic conditions (ANDE, 2006; FURNAS, 2008).

Table 2: Comparison of different HTLS technologies (temperature, traction, sag).

Technology	Conductor temperature (°C)	Traction EDS (%)	Traction maximum wind (%)	Sag (m)
GTACSR	87	20	39	14
ACCC	82	19	40	11
T-ACSR	97	20	38	13
ACCR	91	19	40	12

For the analysis realized with the above mentioned criteria has been considered the load tree of a reticulated type tower made of galvanized steel. The security distance between the cable and the ground for the most adverse climatic conditions (40°C) and the maximum load is 8 m. The span conditions for wind are not modified, but those for weight depending on the weight of the conductor and its breaking tension (NBR N°5422).

For the above established conditions and looking at the obtained results (see table 2) it can be observed, that none of the selected technologies can be rejected to substitute the ACSR 636 MCM Grosbeak code cable of the technical point of view, mainly concerning the sag and the geometric characteristics of the cable such as its diameter and its weight.

Computational results

As the computations were performed simulations with the Anaredes Software to compare the same size, weight and diameter between conventional wire and conductor HTLS type, (see table 3), the electrical behavior that would have a overhead transmission line (ANDE, 2013).

Table 3: Electrical parameter of the overhead Transmition Line.

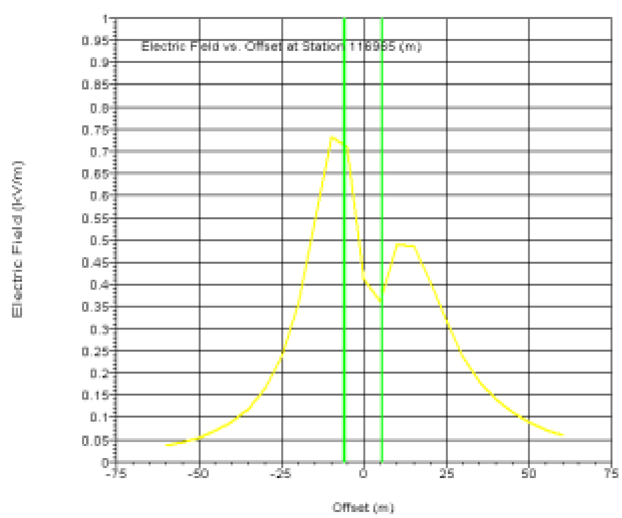
	Parameter Line		
	Resistance	Reactance	Capacitance
	Ohm/km	Ohm/km	Micro siemens/km
Old Wire ACSR 300MCM Code, Ostrich.	0,21418	0,39994	2,8546
New Wire HTLS ACCC 160MCM, Code Helsinki.	0,17937	0,40927	2,8107

As shown, although the line resistances to be slightly lower, the values of inductive reactance and capacitance are not affected, since the inductance and capacitance of the line are mainly determined by the geometrical arrangement of the conductors. With the change of wire, it would have a higher thermal capacity, but power transmission limitations caused by the high level of reactance are removed.

Assessment of the electric and magnetic fields in conductors with HTLS technology

According to the results obtained with the PLS-CADD software we can observe the behavior of the electric and the magnetic fields in a cross section of a 220 kV aerial transmission line applying each of the HTLS technologies (see fig. 4). The values are all within the admissible limits inside the security lane, which in our case has a width of 50 m (Ley N°976/82).

The maximum values of the electric and the magnetic fields reach on the axis of the line 0.7 kV/m and 6.5 μT respectively. These values are in line with the international standards. So, there are no reasons against the HTLS technologies to substitute the conventional conductors with the same weight and diameter considering a current of 800 Amps (Díaz, 2008).



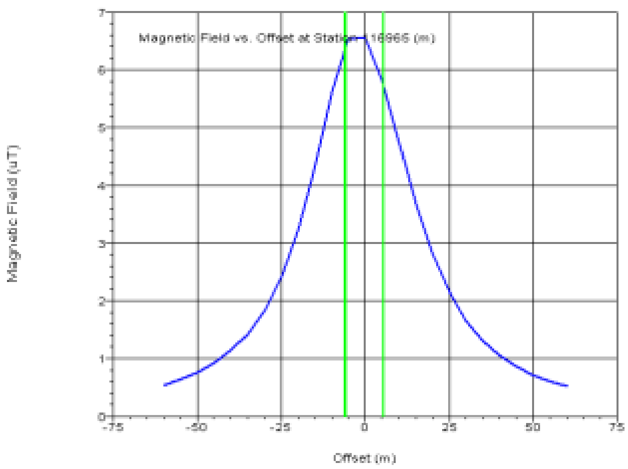


Fig. 4: Results of the electric and magnetic field on the width of the servitude strip of a 220kV transmission line with HTLS technology conductors

Economic considerations on conductors with HTLS technology

For the economic considerations have been taken into account the reference costs of the respective conductors, energy losses for a 220 kV simple circuit (R,S,T) transmission line with a length of 100 km, a load of 800 Amps and the reference cost for the mounting of the conductors. Within the economic variables have been considered an annual interest rate of 10% for a period of 20 years, the electricity fee at Itaipu with 22.6 US$/kW-month, a load factor of the transmission line of 50% and a present value for the technical losses of 2540 US$/kW, which was used to analyze and the electric losses for each one of the HTLS technologies (Itaipu, 2010).

Table 4: Cost and energy lost comparison of HTLS conductor technologies for a 100 km long three phase transmission line. Source: (ANDE, 2010; Itaipu, 2010)

Tech-nology	Materials (US$)	Mounting (US$)	Energy loss (US$)	Total cost (US$)	%
GTACSR	2,400,000	4,000,0000	11,497,056	17,897,056	100
ACCC	4,200,000	6,000,000	9,643,872	19,843,872	111
T-ACSR	2,100,000	4,000,0000	14,069,568	20,169,568	112
ACCR	7,500,000	6,000,000	13,399,008	26,899,008	150

Table 4 shows for each HTLS technology the cost for repowering a conventional line considering the respective cost for materials, mounting and energy losses. The lowest total cost is obtained using GTACSR conductors. ACCC and T-ACSR cables are 11 and 12% more expensive. ACCR cables are even 50% more costly. Compared to a new 220 kV aerial transmission line with conventional ACSR 636 MCM Grosbeak code cable having a specific cost of 160,000 US$/km, considering a 40 years life span, but not the energy losses, the GTACSR cable is just 12% more expensive, but it has a 45% higher ampacity limit (ANDE, 2010).

Outlook

Each one of the above presented technologies of HTLS conductors could be used for the repowering of existing aerial transmission lines independently of the tension level in which the load increase is planned. It has to be stressed that the present technical and economic study only considers a load repowering but not the increase of the tension. This should also be analyzed to get a more complete situation of the viable possibilities.

For this purpose could be analyzed for example a 60 km long 66 kV aerial transmission line to be repowered to 132 kV. For the repowering would be used HTLS conductors with diameter and weight equivalent to those of ACSR 300 MCM Ostrich code cables, commonly used in the Paraguayan grid system for this tension level, as well as tempered glass insulators. This way could be modified the energized line and assessed the crown effect, which could exist due to the increase of the quantity of insulators. The study would conclude with computer simulations to find the optimum length of a 66/132 kV line using HTLS conductors and increasing the quantity of the existing glass insulators without changing the diameter and the weight of the conductors checking whether the tension drop will not surpass 0.9 pu (ANDE, 2013).

Conclusions

According to the comparing technical and economic analysis in the present study none of the proposed HTLS technologies can be rejected, as all of them are according to the technical standards regarding energy transmission. Observing the economic aspects we see that the GTACSR has a clear advantage compared to the other options considering the proposed scenario. But on the other hand it presents higher difficulties for its mounting.

In the case of T-ACSR conductors, despite of its lower material cost, it doesn´t have a lower total cost due to the higher costs of the energy losses. But it's precisely this point which is fundamental to take into account for the decision making between one or another technology. Nevertheless, for short transmission lines this aspect will not have this misbalancing effect. Another point to mention is that these cable technologies cannot be used only for transmission lines, but also inside stations, specifically for the bars, taking into account that the load to which they can be subjected in case of a failure at the bars concerning their short circuit level.

It has to be stressed that independently of the chosen HTLS technology there is no need to change the insulators, neither the ones of tempered glass nor the polymeric ones made of silicon rubber or the line post type rigid ones, because in this case the repowering is for load and not for tension level. Dissipation of the additional heat due to the load increase is done in the ironworks, which necessarily have to be changed, because those for conventional conductors are designed to operate at only 90°C (ANDE, 2009).

As a final point has to be mentioned that the manufactures of HTLS conductors compared to a conventional ACSR 636 MCM Grosbeak code cable of the same diameter and weight guarantee a 300% higher ampacity, without modifying the sag. But in most of the cases this is not possible, because this load increase is referred only to the thermal capacity of the conductor due to their low ohmic resistance, but it doesn't take into account the electric capacity, for which variables such as capacitancy and inductancy for long transmission lines present admissible values and are limiting the electric capacity and by consequence its thermal capacity, due to the similarity of these variables with the conventional conductors with steel core.

References

ANDE, Especificaciones Técnicas N° 03.02.01.45: Suministro de conductor de aluminio con alma de acero ACSR, Licitación Pública Internacional LPI N°162, 2006.

ANDE, Especificaciones Técnicas N° 03.06.02.11: Conjunto de aisladores y herrajes para conductor y cable de guardia, Suministro de conductor de aluminio con alma de acero ACSR, 2009.

ANDE, Especificaciones Técnicas: Suministro de conductores de Alta Temperatura y Baja Flecha, HTLS. Licitación Pública Internacional LPI N° 613, 2010.

ANDE, Especificaciones Técnicas N° 04.01.11: Cambio de conductor con bypass, Licitación Pública Internacional ANDE LPI N° 606, 2011.

ANDE, Plan Maestro de la Administración Nacional de Electricidad (2013-2023), 2013.

ASTM N° B232: Standard Specification for Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Reinforced (ACSR)

CEMIG, Estudio de Superconductores, CIGRE- Workshop Internacional, 2010.

Díaz R., Los campos electromagnéticos de frecuencia industrial y los riesgos para la salud, Investigación y Desarrollo, pág. 5., 2008.

FURNAS - CENTRAIS ELECTRICAS S.A., Apuntes del Curso de Especialización en Construcción de Líneas de Transmisión, realizado en Rio de Janeiro, Brasil, 2008.

Itaipú Binacional, Costo referencial de tarifa mensual US$/kW-mes, 2010.

Ley N° 976/82 art.1 de la Administración Nacional de Electricidad, que amplía la Ley N° 966/64, 1982.

Mitjans F., Generación Eléctrica Hibrida Eólica Solar para el fortalecimiento del Chaco Paraguayo, Maestría en Energía para el desarrollo sostenible, Universidad Católica de Asunción, 2013.

NEXANS Brasil, consulta realizada en 2010.

NBR N° 5422: Construcao da Línha da Transmicao.

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