An 800 kV HVDC bipole to reinforce a regional interconnection and integrate a large amount of variable renewable generation

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- The Brazilian power system experienced a significant expansion over the last two decades.
- Throughout this expansion, the main north-south transmission corridor became a bottleneck and its expansion became a priority.

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- This paper presents the planning concept and the main technical requirements for the new

❑± 800 kV HVDC,

❑4,000 MW bipole,

❑planned to be implemented in Brazil, connecting the **North/Northeast regions at Graça Aranha** Substation, to the **Southeast region, at Silvânia** Substation (near the capital Brasilia), a distance of 1,500 km.

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Figure 1 – New 800 kV DC bipole from Graça Aranha to Silvânia

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- Another extraordinary necessity came from the strong enhancement of variable **renewable generation in the Northeast region.**
- After an initial selection including AC and DC alternatives, a pure 800 kV DC solution, resulted in the best technical and economical solution to reinforce the north/northeast - south/southeast transmission capacity.

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- This system is planned to be the first HVDC long transmission in the country **not associated with any power generation project.**
- At the two connection points selected to insert the new link there are meshed 500 kV AC networks, with SCRs above 3.0, and conditions for direct and reversed power transmission.
- The conductor size reviewed and optimized, considering updated costs of investment and energy losses.
- Another reference from the previous project was the converter topology requirements.

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The insertion of this new HVDC link will

- improve the performance of the 500 kV AC network parallel to the link.
- relieve the AC system, increasing its capacity to absorb additional variable renewable generation.

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2. PLANNING REQUIREMENTS AND AN HVDC TRANSMISSION SOLUTION

2.1. A new regional interconnection reinforcement

- A new reinforcement in the main north-south AC corridor became a priority to avoid congestion.
- Extremely dry weather in the southeast of the country during 2014 and 2015, where most of the load is concentrated, resulted in a large amount of thermal generation and rising energy prices.
- In addition, extra, seasonable hydro generation in the north became available.

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2.2. A large amount of variable renewable generation

- The expansion of variable renewable generation in Brazil is mainly concentrated in Northeast region of the country, which has undergone outstanding growth in the past ten years.
- Wind power is the leading source of this movement, although in recent years solar power has rapidly increased its participation.

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- The installed capacity of wind power in Northeast region evolved from nothing ten years ago to 11 GW by the end of 2017 and produced nearly 65% (Sep/ 2017) of the Northeast's energy necessities.
- It is expected that the installed capacity of wind power will reach 24 GW in this region by the end of 2026, with an additional 9 GW from photovoltaic solar plants.
- Geographical distribution and evolution of wind farms are illustrate in Figure 2.

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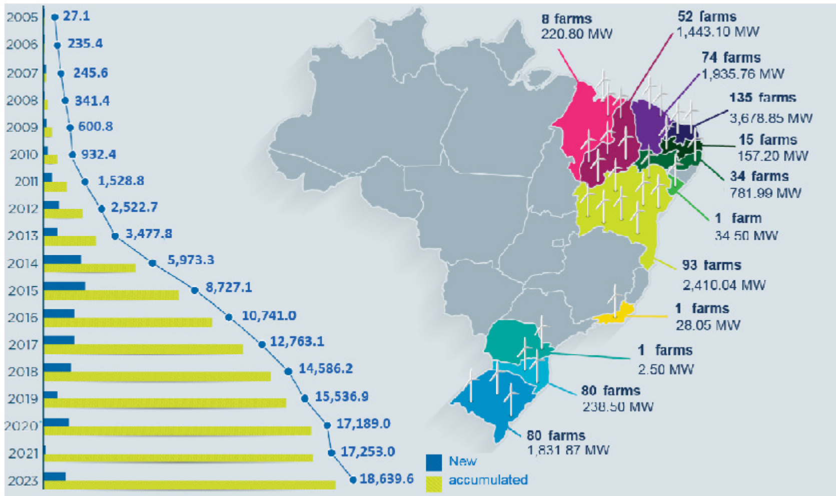

Figure 2 - Geographic distribution and evolution of wind farms

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2.3. An HVDC solution among other alternatives

- The following alternatives were analyzed:

i. A mixed technology solution composed of an 800 kV DC bipole, 5,000 MW, and an approximately 1000 km long 500 kV AC transmission corridor with capacity to transmit 2,500 MW, both interconnecting the North and Southeast regions.

ii. A solution composed by two 800 kV DC bipoles, 4000 MW, at distinct connection points, interconnecting the North/Northeast regions to the Southeast/Central West regions

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- The first alternative resulted in a higher cost, especially due to the necessity to install series capacitors with high current capacity in the new 500 kV AC transmission corridor in order to divert power flow from the existing and limited north-south AC corridor.
- The second alternative, a pure HVDC solution, resulted in the best technical and economical solution.
- The original solution was reviewed, establishing a new solution with only one 800 kV HVDC bipole, 4000 MW.

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2.4. Network characteristics to accommodate the new HVDC link

- The selection of the southeast connection point, at Silvânia 500 kV Substation, accommodates the advantages of being at the main load center area and relatively distant from others existing HVDC converters, in order **to reduce multi infeed impacts.**
- At the two connection points selected, separated by about 1,500 km, there are meshed 500 kV AC networks, with SCRs above 3.0, and conditions for direct and reversed power transmission.

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2.5. Additional benefits

- An important benefit of this HVDC solution is to relieve the AC system in the North/Northeast regions, increasing its capacity to absorb additional variable renewable generation.
- The amount and cost of additional thermal generation, produced during the dry season in the Southeast **can be reduced** with this regional interconnection transmission.

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3. SYSTEM PERFORMANCE

- The new embedded HVDC link is responsible for integrating a region with large amounts of wind power and therefore is required to operate in **reverse power mode.**
- For most of the year it will transmit energy from the North to the South region of the country, and during a few months it will operate in the opposite direction.

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- This new HVDC link is able to improve significantly the performance of the 500 kV AC network parallel to the link.
- This improvement is due to the link's controllability and its ability to prevent possible transmission line overload in the latter.
- One key aspect for this is the location of the converter stations.
- To ensure adequate dynamic performance, **three synchronous condensers (-90/150 Mvar) installed at the Southeast region's converter station** were recommended.

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- The AC network is able to provide good support for the HVDC link in the eventuality of faults in it.
- During the blocking of one of its poles it was not necessary to order overload to the remaining healthy pole.
- However, considering the large energy export potential of the Northeast region, it was recommended that **the new link have a 50% overload capacity for 5 seconds, followed by a reduction of 33% over a 30 minutes period.**
- As for the worst contingency, a simultaneous blocking of the two poles, the system proved to be stable with fewer operational measures than other bipoles in the Brazilian system.

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4. DESIGNING THE HVDC SOLUTION

4.1. ± 800 kV DC transmission line basic concept

- The new transmission line was conceived based on Belo Monte's line, a project with 6 conductors per pole with a majority of guyed towers, as illustrated in Figure 3, but had its conductor size reviewed and optimized, considering the actual costs of investment and energy losses.

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Figure 3: ± 800 kV Belo Monte's bipole I transmission line

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- An important issue, as in Belo Monte's project, is the lack of specific standards for 800 kV DC transmission lines.
- The line's conceptual design was made in accordance with the Brazilian standards for transmission lines, and including recommendations from **CIGRE Brochure.**
- For the electrical field under a DC transmission line, there is an instruction from the Brazilian Regulatory Agency (ANEEL), establishing at ground-level a maximum limit of **20 kV/m, with 5 kV/m at the edges of the right-of-way.**

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- A software package developed by Cepel, the Brazilian Electrical Energy Research Center, was utilized for this duty, testing a range of ACSR conductor sizes.
- For each conductor size the program calculates all technical requirements, including **tower weight, height, and corresponding dimensions**.
- This stage yielded conductors in a range from 1272 MCM (Bittern) to 1590 MCM (Lapwing), as illustrated in Figure 4.

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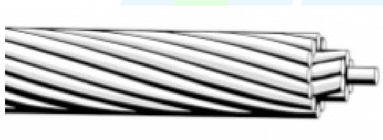
1272 Bittern ACSR Aluminum Conductor Steel Reinforced



1590 Lapwing ACSR Aluminum Conductor Steel Reinforced

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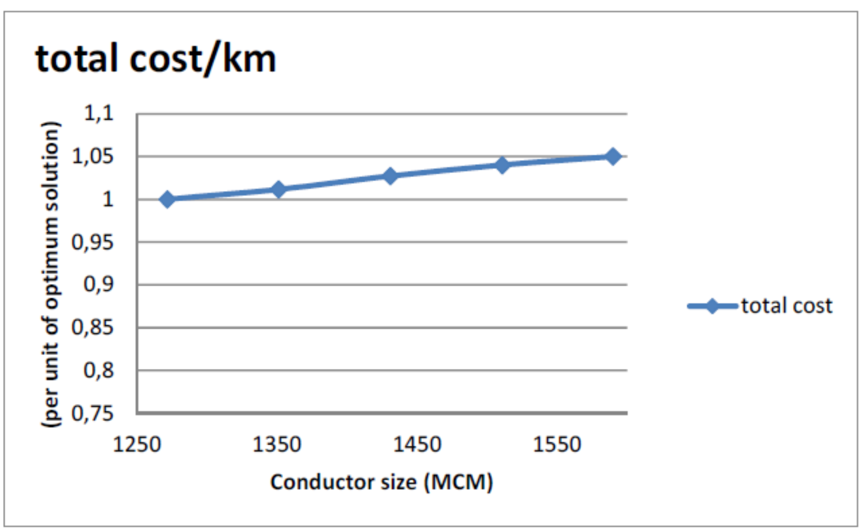

Figure 4 - Transmission line overall cost as a function of ACSR conductor size

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4.2. Additional references from a previous project

- Considering the advantages of repeating the basic specification of a successfully implemented project, the larger conductor taken from the set of solutions selected in the first stage, corresponded to the planned **Belo Monte line's conductor (1590 MCM).**
- The strategy of using an existing line design reduces the time needed to build the line, advancing the in service date for the HVDC link.
- A reduction in the line's time schedule can be obtained, for example, by utilizing transmission line components already tested and manufactured.
- Similarly, the tower foundation projects can be advanced.

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4.3. Converters dimension, basic arrangements and operation modes

- The requirement for reverse power transmission (S-N), with a smaller rating than normal power direction (N-S), and the transmission line losses (resulting from the larger 1590 MCM conductor), resulted in a first approach to define the Silvânia converter's nominal power (3890 MW, DC).
- The requirement for nominal voltage during reverse power mode, in order to minimize transmission line losses, also was adopted.

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- Another reference from the previous project was the adoption of some flexibility **with the converter topology requirements**, considering the possible weight and also the size of equipment.
- This important constraint addressed the planning decision to give some kind of freedom for converter arrangement and concepts, not imposing a specific number of 12-pulse converter bridges per pole (series or parallel), as illustrated in Figure 5, for series connections.

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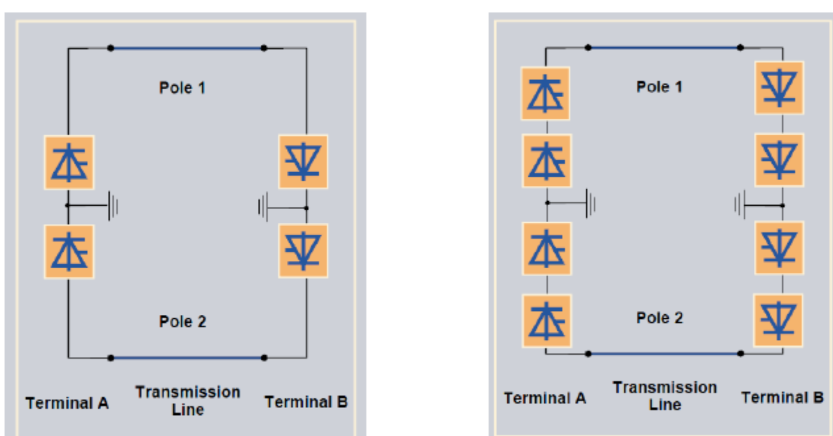

Figure 5 – Converters station with one or two 12 bridge pulse per pole

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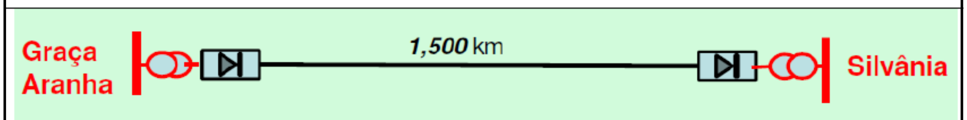
4.4. Summary of technical characteristics

Table I ± 800 kV DC Graça Aranha to Silvânia link main technical characteristics



Normal Power Direction: Graça Aranha to Silvânia Nominal DC power: 4,000 MW at Graça Aranha Nominal voltage at Graça Aranha: ± 800 kV Silvânia operating as inverter: 3890 MW	**Reverse Power Direction**: Silvânia to Graça Aranha Nominal DC power: ~3,300 MW at Silvânia Nominal voltage at Silvânia: ± 800 kV
Minimum power transmitted: 10% of nominal power **Overload capacity**: 33% during half hour after pole or bipole lost; 50 % during 5 seconds	
Operation modes: bipolar, monopolar with metallic return, monopolar with ground return. Minimum DC voltage: 0.7 of nominal voltage Maximum DC voltage: 830 kV	
Transmission line length: 1,500 km Conductor: 6 ACSR, 1590 MCM "Lapwing", per pole.	

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5. FINAL STAGES FOR THE PLANNING PROCESS

- Those final studies for HVDC links, include electromagnetic transients switching, dynamic performance and multi infeed analysis.
- A detailed review of the transmission line route, with field inspection focusing on **environmental and social impacts** is also mandatory.
- At that stage the conceptual design for the new substations is concluded.
- Those final planning studies may require some adjustments to the initial requirements, establishing the solution to be offered in the auction.

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6. CONCLUSION

- This transmission link, was conceived in order to fulfill the necessities of a regional interconnection reinforcement and the integration of a large amount of variable renewable generation.
- The current characteristics of the AC meshed network facilitate the accommodation of the **HVDC LCC solution**, which shall relief this regional AC system to integrate more generation.

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- Additional benefits include enhancement of **controllability**, **improvement in the performance of the 500 kV AC** parallel of it, and **reduction of thermal generation in the Southeast region.**
- The transmission line had the conductor size reviewed and optimized considering the updated losses cost, but the results were similar to the referenced project.

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- Other concepts from the experience obtained with the implementation of Belo Monte's system gave important feedbacks, as some flexibility with the converter topology requirements.
- The main technical characteristics of the new HVDC bipole were established.
- The final stage of the planning studies may require some adjustments to the initial requirements.

THANK YOU