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Sectionalizing transmission lines, an expansion planning challenge, amplified by unexpected emerging variable renewable generation and environmental restrictions

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SUMMARY

This paper presents an analysis of the Brazilian network expansion planning experience in sectionalizing transmission lines (STL), including impacts on the existing installations, which is a challenge amplified by unexpected emerging large scale Variable Renewable Generation (VRG) and environmental restrictions. During its geographical expansion process, and until recently, STL was not frequently used in the transmission expansion planning but after the national power sector restructuring, in the later 90s, as well as the regulated network free access, it became an attractive possibility. In order to avoid the drawbacks of unexpected sectionalizations of series compensated TL, High Surge Impedance Loading (HSIL) TL designs have been recommend as an alternative. VRG large expansion has been impacting the network, initially through wind generation connections in the Northeast region, but recently, solar generation is emerging. Expansion planning programs had to reinforce local and long-distance transmission interconnections with the Southeast region where the largest load center is located. The Free Contracting Environment (ACL) and the network free access regulation are facilitating this movement but adding uncertainties for the transmission planning process. As indicated by a presented statistic, in some specific situations, STL turns out to be an attractive planning alternative. Nevertheless, the crescent amount of desired, but unexpected VRG power accessing the network, represents an additional challenge for the network transmission expansion planning. In conclusion, STLs, despite its challenges, has become an important alternative and a trend for the transmission expansion planning strategy as well as an attractive and decisive option to enhance the large amount of VRG integration in Brazil.

KEYWORDS

Sectionalizing transmission lines - Free access - Unexpected emerging VRG.

1. INTRODUCTION

The Brazilian power system is a synchronous interconnected and meshed network, integrating the extensive national territory, with 145,600 km of transmission lines (TL) with nominal voltages starting from 230 kV up to 800 kV, as illustrated in **Figure 1** . In the next five years, this number is projected to increase 26.4 %, totaling 184,054 km.

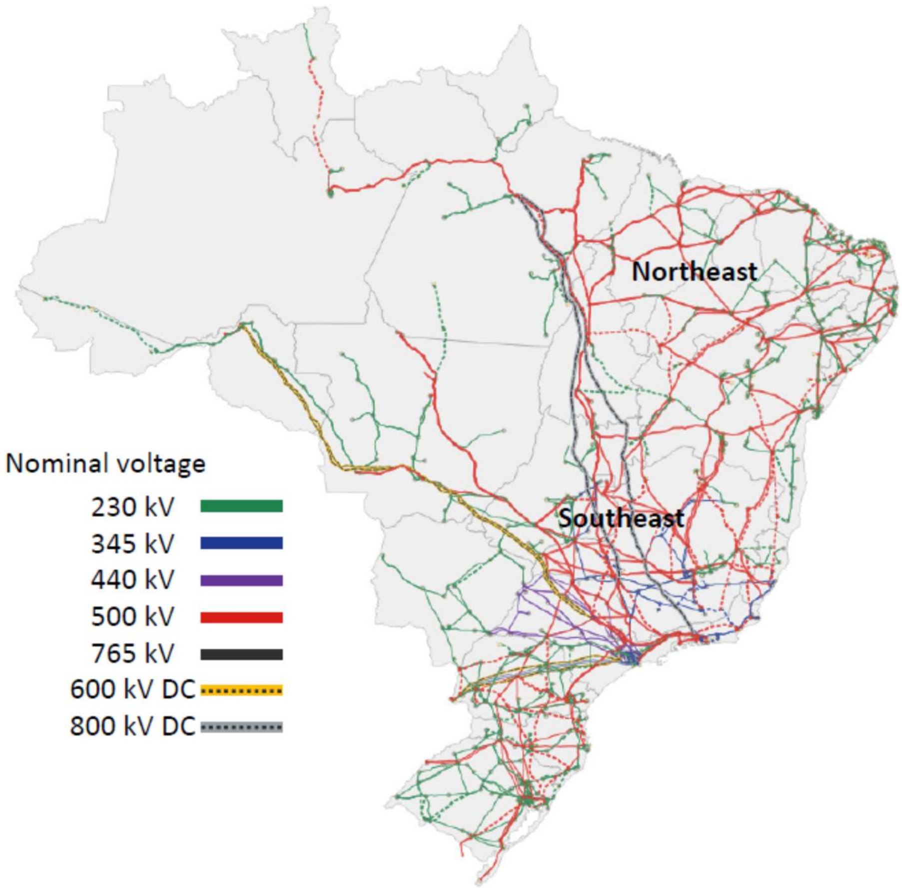

Figure 1 – Brazilian meshed network [1 **]**

During its geographical expansion process, and until recently, Sectionalizing Transmission Lines (STL) was not frequently used in the transmission expansion planning, being mostly used for distribution systems.

Nevertheless, after the national power sector restructuring in the later 90s, as well as the regulated network free access, STL gradually became an attractable possibility for the expansion planning process. Flexibility, cost-reduction, simpler footprints and less time to implement, reducing business risks, were part of the expected advantages. Consequently, despite the implementation difficulties, the national expansion planning program has gradually included STL as options for the best technical, economic, and environmental alternative recommended for the grid expansion.

This paper presents an analysis of the recent planning experience regarding STL in Brazil, including impacts on the existing installations, which is a challenge amplified by unexpected emerging large scale Variable Renewable Generation (VRG) and environmental restrictions.

2. MAIN CHALLENGES OF STL

STL means to open the circuit at a determined split point and make an in/out connection at a third substation, resulting in two new circuits with their own protection and controls as depicted in **Figure 2**. The third substation may be totally new or an existing one reinforced with new equipment, switchyards, and/or voltage levels.

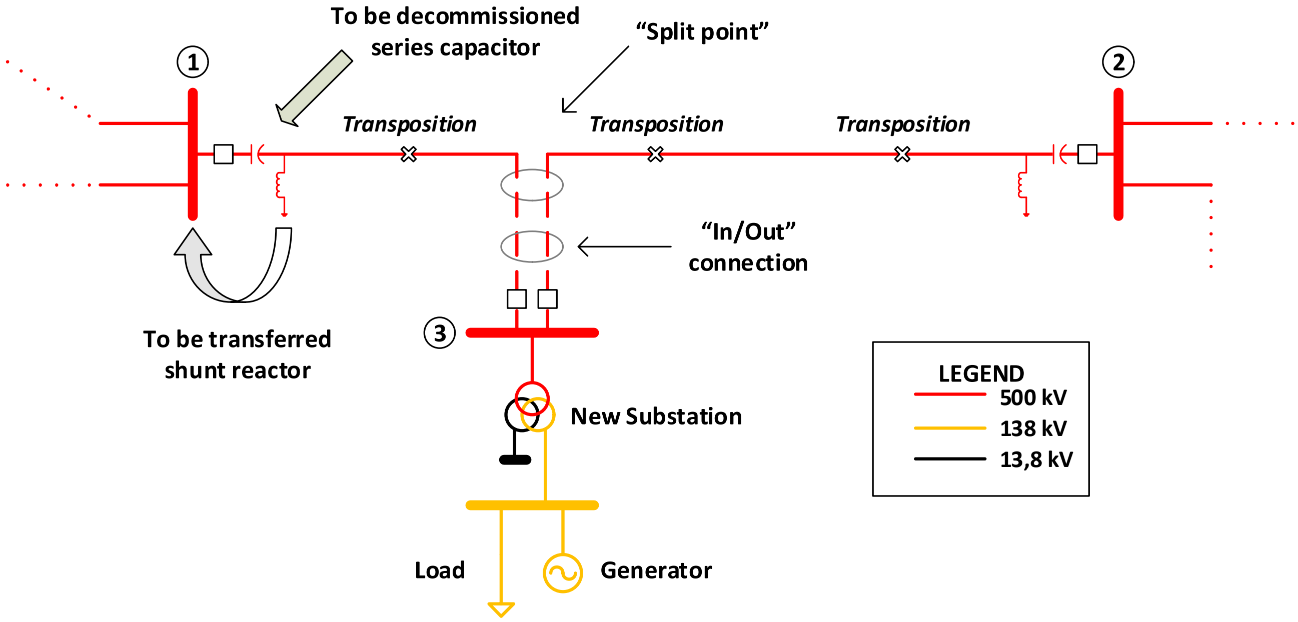

Figure 2 – Illustrative example of a sectionalized 500 kV TL

The Brazilian power sector regulation allows a new utility to acquire the sectionalization concession by an authorization process and when it is the result of a transmission expansion plan by public auctions. Therefore, different utilities have to interact during the implementation process. As there are impacts in the existing TL and terminal substations, many technical aspects and requirements must be dealt with by the new utility. Also, adjustments and reinforcements in the existing infrastructure can be more or less complex and costly depending on the physical conditions of the existing assets.

2.1. Shield wires and phase transpositions

For technical and economic reasons, it is a common practice to use shield wires of smaller cross section along the majority of TL route and larger ones only near its terminals. When the split point is located far from the terminals and near to the new substation the short-circuit level may increase at this point, what eventually will require the replacement for a few kilometers of existing shield wires. Depending on the tower's mechanical conditions, some important structural reinforcements will be necessary. Additionally, as imposed by the grid code, in order to improve communications, it is necessary to install an Optical Ground Wire (OPGW) in sectionalized TL with only conventional shield wires. This can be not simple to implement, costly or even not feasible for older TLs. In the latter case it will be necessary to adopt an alternative communication technology.

According to the Brazilian grid code when a TL is sectionalized voltage unbalances still must not exceed 1.5 % [2]. If this limit is violated the new utility will have to adjust the existing transpositions, eventually decommissioning and installing new towers at different locations.

2.2. Reactive compensation

Relevant impacts may arise when sectionalizing a reactive compensated TL. Series capacitors, e.g., are very specific equipment, rated with reactance and current for each application. A sectionalized TL has its total series reactance completely changed, in comparison with the original TL, so that, one of the new circuits may become overcompensated, what is not desirable due to potential resonance and line protection problems [3][4]. Thus, all the associated apparatus should be decommissioned and probably unutilized. It has to be noted that Brazilian transmission planning has been taking advantage of High Surge Impedance Loading (HSIL) TL designs [5] [6] as an alternative solution to traditional designs in order to avoid the drawbacks of unexpected sectionalizations of series compensated TL. In the past 10 years, near 15,000 km of 500 kV HSIL(1,680 MW) TLs, as illustrated in **Figure 3**, have been recommend in alternative to most used traditional network 500 kV TLs (SIL of 1,000 – 1,200 MW) that have series reactance about 65 % to 40 % greater.

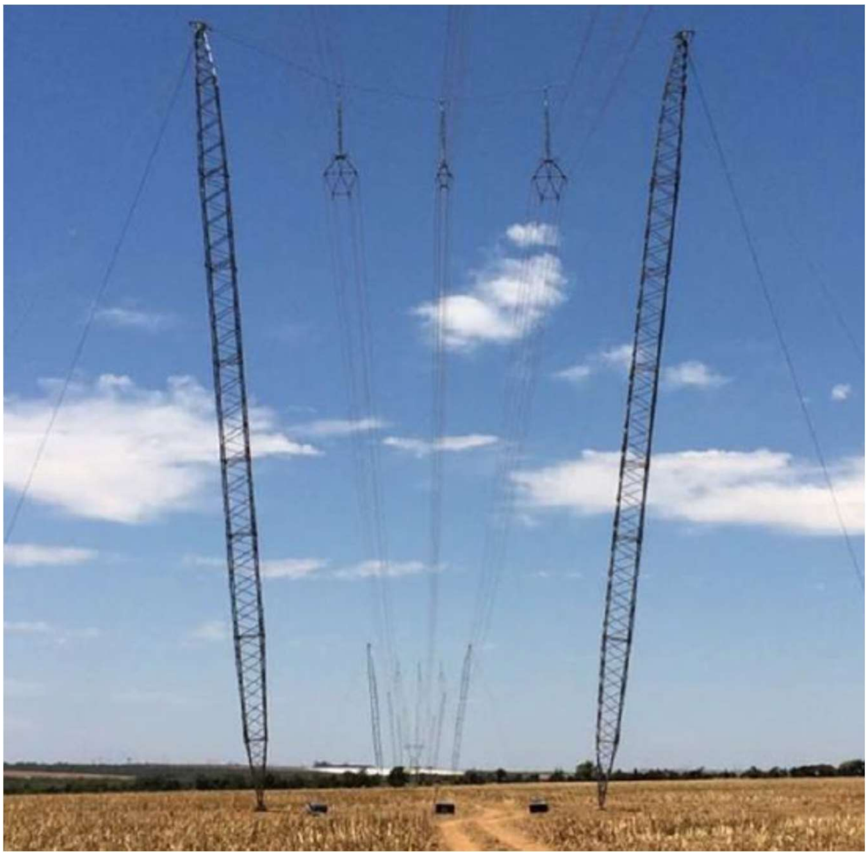

Figure 3 – HSIL transmission line with cross rope tower implemented in Brazil [7]

A TL with shunt reactors also may become under or overcompensated after a sectionalization, which leads to the need of reviewing system's operation performances. The most common consequences are: degradation on the single pole automatic reclosing performance (greater secondary arc currents or voltage resonances [8]); and current zero-missing phenomena [9] through switched circuit breakers. Fortunately, in most cases there are sufficient countermeasures. Nonetheless, depending on the shunt reactor physical conditions and specifications, relocate it to other TL terminal or to the nearest busbar has also been adopted, as a pragmatic solution.

2.3. Protection, control, communications and terminal equipment

For STL it necessary to make some adjustments on the protection and control functions and communications in order to match them with the new installations. It also may be necessary to replace existing bay equipment (voltage and current transformers, surge arresters, circuit breakers, switches and others). This may happen due to obsolescence and/or limit violations (e.g., switching overvoltage after relocating a TL shunt reactor).

3. VRG LARGE EXPANSION IMPACTS THE NETWORK

Initially, VRG had a fast development through wind generation in the Northeast region of Brazil, reaching an installed capacity near 100 % of this regional load in approximately 15 years. Expansion planning programs had to reinforce local and long-distance transmission interconnections with the Southeast region where the largest load center is located. Recently, an unexpected large-scale solar generation projects (to connect 7 GW in 5 years and estimated to double in 10 years) is emerging in another region, between the Northeast and the Southeast regions, demanding more local and interconnections transmission reinforcements. The energy export capacity of the Northeast region enhanced by VRG shall increases form the actual 6 GW to 15 GW in 5 years (2026), plus additional 18 GW until 2033, pressing the planning expansion studies to review and also to conceive new transmission corridors including long distance High Voltage Direct Current HVDC links[10].

The Open Power Market, also known as the Free Contracting Environment (ACL), and the network free access regulation are facilitating this movement as well as increasing uncertainties in the grid connection locations and in time to implement VRGs. These uncertainties represent addition challenges for the transmission planning process.

4. EXPANSION PLANNING STL

Until the national power sector restructuring, in the later 90s, STL was not frequently considered by the Brazilian transmission planning. In practice, this planning strategy only became an effective alternative during the decade of 2010 basically imposed by technical, economic, environmental and social restrictions.

4.1. Basic strategies

In the context of the transmission expansion planning, STL turns out to be an attractive alternative as detailed in the following basic situations:

a. *Establishing new supply points to the distribution grid.* When there is a congestion in the High Voltage (HV) distribution grid and the investment to solve it through distribution assets is too high, the construction of a new transmission substation to supply the distribution grid may become competitive. If there is a TL passing through the region where the distribution congestion is located, then the TL sectionalization can be a competitive alternative, both in the economic and environmental perspectives. These aspects can be even more relevant when the distribution grid in question is off the main grid, which is something very common in the North region. These distribution grids are usually supplied by polluting and expensive fossil fuel thermal plants, which can be decommissioned after the implementation of a new injection point from the main grid. Additionally, with a higher insertion of Distributed Generation (DG) in some areas of the distribution grid, the new substation obtained from the sectionalization might also be beneficial for increasing the distribution grid hosting capacity for DG, allowing the power injection from the low voltage to the HV.

b. *Establishing new connection points for VRG.* In some cases, the best wind or solar resources are verified in areas where the main grid is not densely meshed. In other places, these resources are located in areas where the existing substations cannot be expanded anymore – due to urbanization, environmental restrictions or due to a high number of connections made by previous generation projects. In order to increase the competitiveness of VRG, as part of the planning strategy, it is economically attractive to invest in new substations to host these potential projects. It is very common to have existing TLs passing through the aforementioned areas, making the TL sectionalization economically and environmentally attractive. In order to replace a depleted or confined substation, sectionalizing one or more transmission lines connected to the existing substation is sometimes the only way to solve congestions or to provide a new connection point for new VRG projects.

c. *Establishing new connection points to the transmission grid.* The integration of one or more substations, depending on their location, may occur through STL. If a substation is close to the TL route, sectionalizing it, compared to the new connections with the substations of the region, would enable a connection with lower socio-environmental impact and lower cost. In addition, it ensures a connection at two different points maintaining network reliability without the need for new TLs.

d. *Relieving TL overload.* In the event of a TL overload, especially in a meshed part of the grid, several alternatives are analyzed to solve the problem. From recommending new TLs in the region to STL at a specific point of the network, which could contribute to redistribute and, consequently, to reduce the flow in the overloaded stretch.

4.2. Practical results

A statistic containing the number of sectionalized TLs with nominal voltage from 230 kV to 500 kV, resultant from the transmission expansion planning activity, implemented or to be implemented in dates from 1999 to 2033 is presented in **Table I**. These sectionalized TLs have been projected to have their concession granted by auction (mostly) and by authorization processes.

Table I - Number of transmission lines sectionalized by expansion planning activities

Period of time	Nominal Voltage (kV)				Total by period
	230	345	440	500	
1999-2012	0	0	0	0	0
2013-2015	9	0	0	4	13
2016-2018	9	0	2	2	13
2019-2021	38	4	5	14	61
2022-2024	30	6	2	11	49
2025-2027	30	7	0	7	44
2028-2033	7	2	0	6	15
Total by voltage	123	19	9	44	195

The last triannual period (2019-2021) represents a large increase in the number of TLs sectionalized, in comparison to the past triennials, and seems to be a trend for the future to increase these numbers considering that the planning activity shall maintain the strategy of STLs. The largest number of 230 kV and 500 kV lines, in comparison with other line voltages, reflects the predominance of these TLs in the Brazilian network.

Table II presents the original length of the lines, before the sectionalization, and the length of in/out connections. As can be seen from **Table II**, the majority of the original lengths of sectionalized TLs are shorter than 200 km (75.9 %) and the majority of in/out connections lengths are shorter than 10 km (59.8%).

Table II – Original TL and in/out connection lengths of sectionalized TLs

Original TLs length		In/out connections length	
Less than (km)	% Of the total number of TLs	Less than (km)	% Of the total number of TLs
20	12.9	2	28.4
50	30.0	5	47.9
100	48.8	10	59.8
200	75.9	20	76.8
300	93.5	50	91.8
400	99.4	100	98.5
450	100.0	200	100.0

Most of the TLs with these nominal voltages and lengths (shorter than 200 km) do not shunt reactive compensation, which reduces the number of cases that require relocation of shunt reactors or series capacitors. These results, with short in/outs lengths, also indicates an important benefit of this STL strategy, which is to reduce or avoid building additional kilometers of TLs and, consequently, contributing to reduce environmental and social impacts for the transmission expansion.

5. FREE ACCESS TO THE NETWORK

Several of the actual basic principles of the Brazilian electricity sector, such as the compulsory bidding procedures for the concession of public services, the free access guarantee to the transmission and distribution systems, the definitions of Independent Power Producer as well as the Free Consumers[1] were established by law, during this sector restructuring, in 1995.

As established by law (nº 9074/1995), all market stakeholders can freely access the distribution system or the main transmission system. Free Access is the right to use the electricity networks services, regardless of their ownership, in order to transport electricity from generation plants to consumers, provided there is enough system capacity to allow a safe connection.

The access to the transmission or distribution systems is a regulated process that involves several different agents in the Brazilian electricity sector. In order to ensure the feasibility of any access to the grid, several interactions with the distribution or transmission agents as well

[1] Consumers that can choose from whom they buy electric energy supply through bilateral contracts negotiated freely.

as the National System Operator (ONS), the Energy Research Office (EPE)[2], and the National Electricity Regulatory Agency (ANEEL) are necessary.

Both distribution and transmission agents are responsible for confirming the physical feasibility of the proposed connections considering the characteristics of the existing and the planned installations. EPE and ONS, on the other hand, verify the available system capacity and assess the impacts of the new generation or load connections on the system performance. Eventually, ANEEL acts as the granting authority responsible for granting concessions, authorizations, and permits for the exploitation of such services.

In order to access the transmission network, the agents must make a formal requirement to ONS and present all the electric studies established by the grid code. ONS then analyses the results of these studies, especially the impacts of the required connection on the system performance, and publishes a specific technical report containing the preliminary conclusions from the Operator's point of view. Depending on the results of this assessment, especially if grid reinforcements are necessary to avoid any system constraints, the ONS also requires EPE's opinion about the impacts on the system from the long-term planning perspective.

Whenever EPE is involved in this process, the agents must carry out additional specific studies considering different alternatives for the connection of their projects, including STLs or direct connection to existing substations. The conclusions of these studies indicate the best connection alternative in accordance with the existing expansion planning criteria and the grid code. Once the best connection alternative is determined, ONS publishes a specific report that supports the authorization or concession granting process performed by ANEEL.

The access to the distribution network follows a similar process. However, the distribution agents are responsible for both physical and system performance assessments.

6. UNEXPECTED EMERGING VRG

Considering the aforementioned processes related in item 5, the number of projects trying to access the grid in different regions of the country has exponentially increased in the latest years. This recent trend is related to the growth of the ACL, in which the participation of VRG projects is predominant. These projects are scattered throughout the country and tend to access different areas of the transmission or distribution networks either form direct connection to existing substations or STLs.

Consequently, in addition to the number of TLs sectionalized by transmission expansion planning, there are a crescent number of TLs sectionalized by unexpected VRG. Differently from the planned system configuration, some of these TLs have long lengths (from 250 km up to 400 km) and quite often integrates interregional transmission corridors (some longer than 1000 km). Nevertheless, by the current strategy to implement HSIL TLs, which avoids series compensation, provides a reduction on the expected impacts on the system performance, even though TL's shunt reactors are commonly relocated.

Table III presents a resume of the amount of VRG capacity already approved to be installed in the grid from 2022 to 2026 under the ACL by sectionalizing existing transmission lines (in addition to directly access on existing substation).

[2] In Brazil, the transmission planning activities are carried out by EPE, which supports the Ministry of Mines and Energy (MME) energy policies with studies and research on energy planning.

Table III – VRG capacity associated to STLs, using the free access rights to be installed from 2022 to 2026 in the ACL

VRG type	Total installed capacity by type (MW)	Number of STLs by nominal voltage			Total number of STLs by VRG type
		230 kV	345 kV	500 kV	
Wind	3,279	3	0	9	12
Solar	7,145	8	2	9	19
Total	10,424	11	2	18	31

These VRG projects nominal installed capacity range from 65 MW to 1166 MW and from 84 MW to 980 MW considering solar and wind power respectively. For the solar photovoltaic generation, the amount to be installed will double its actual grid installed capacity (4,132 MW). Such amount of desired, but unexpected VRG power accessing the network, represents an additional challenge for the transmission planning.

7. CONCLUSIONS

This paper presented an analysis of the recent planning experience regarding STL in Brazil, including impacts on the existing installations, which is a challenge amplified by unexpected emerging large scale Variable Renewable Generation (VRG) and environmental restrictions.

Despite the implementation impacts when an existing TL is sectionalized, and its necessary countermeasures, the national transmission expansion planning program has gradually included this strategy as an attractive option when selecting the best technical and economic expansion alternative. Power system network is becoming increasingly complex considering the environmental and social restrictions and also a large-scale VRG expansion, particularly in the Northeast region, which contributed for the new trend of using STL in Brazil.

In addition, the connection of emerging VRG, strongly motivated by the free access to the transmission systems and by the Free Contracting Environment (ACL), have forced planners to anticipate special solutions such as the HSIL lines. These emerging and unexpected VRG projects nominal installed capacity are gradually reaching larger sizes when compared with the existing projects and this specific characteristic also contributes to the adoption of such solutions.

In conclusion, sectionalizing TLs, despite its challenges, has become an important alternative and a trend for the transmission expansion planning strategy as well as an attractive and decisive option to enhance the large amount of VRG integration in Brazil.

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