AMPACITY AND REGULATORY CHALLENGES FOR DYNAMIC LINE RATING ADOPTION FOR BETTER GRID USE IN WIND POWER TRANSMISSION

Joaci Lima Oliveira [1]; Patrícia T.S. Asano [2]

[1] *Center for Engineering, Modeling and Applied Social Sciences, Federal University of ABC (UFABC), Santo André, Brazil, lima.joaci@gmail.com;*
[2] *Federal University of ABC, Santo André, Brazil, patricia.leite@ufabc.edu.br.*

ABSTRACT

A significant portion of the Brazilian transmission network is in regions characterized by strong winds, where wind farms are concentrated such as in the Northeast region of Brazil. The energy transmission capacity of said transmission lines is determined based on thermal limits, by technical standards for meteorological variables to limit the maximum current levels on the conductor. The cables of the electrical network installed in areas with high wind potential are susceptible to better cooling, creating opportunities for the analysis of mechanisms that can contribute to a better utilization of the transmission lines. This work presents a concise approach to the topic, exploring the window of regulatory opportunity for the use of dynamic ampacity calculation in segments of the Brazilian National Interconnected System.

Keywords: Ampacity, Grid use, Sector regulation, Transmission lines, Wind generation.

Introduction

Currently, wind generation accounts for over 13% of the Brazilian electric matrix, and this share of the source follows in a rising curve. The Northeast region, in turn, concentrates over 90% of the installed wind potential [1]. In terms of investments, as shown in Fig. (1), the amount directed towards this source surpassed the quantity of resources allocated to hydropower projects. As such, Wind Generation is the primary destination of investments in energy auctions conducted between 2005 and 2023 [2].

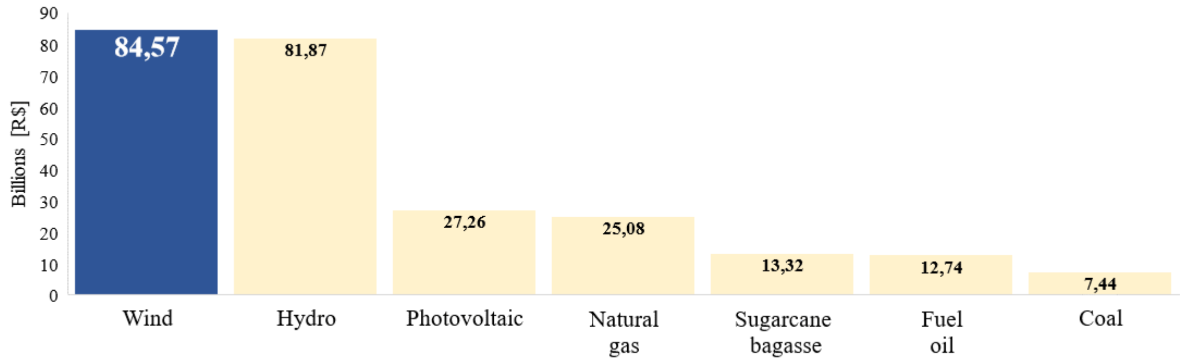

Figure 1 – Investment by energy source (Energy auctions 2005-2023)

However, the expansion of the necessary transmission system for transporting this electrical energy has not occurred at the same pace, with the network still being a bottleneck for a portion of the wind generation in Brazil [3].

In overhead power transmission lines, the current-carrying capacity is determined based on the sag conductor. This variable, in turn, is influenced by the conductor's temperature. This temperature is

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affected by the ambient conditions surrounding the line, as there is a heat exchange between the cable and the surrounding environment [4].

To determine the current-carrying capacity of overhead lines, technical standards employ a deterministic methodology to represent meteorological data such as wind speed, solar radiation, and ambient temperature, using a critical statistical criterion [5]. However, the critical conditions assumed in these standards have a low probability of occurrence, resulting in conductors being subjected to temperatures below thermal limits for significant periods—meaning that a portion of the network remains underutilized [6].

Conceptually, the maximum current allowed in a transmission line while considering safety limits is referred to as ampacity. Real-time monitoring systems exist that allow the acquisition of meteorological data involved in calculating this limiting current. Thus, the use of real-time meteorological data to determine line dynamic ampacity is particularly advantageous in areas with high potential for wind generation, as areas with strong winds facilitate greater cooling of the network and consequently enable an increase in the maximum line current [7].

Given this context, this work presents a concise review of the topic and highlights some regulatory challenges within the Brazilian electricity sector that have discouraged this type of approach in segments of the National Interconnected System (SIN) that could benefit from the application of real-time monitoring systems.

Thermal evaluation of the conductor

In the scenario involving a conductor cable of an overhead power transmission line, the ampacity issue can be modeled as a heat transfer process in a long cylinder with radius (r), length (L), and area: $A = 2\pi \text{rL}$ (please refer to the representation of the elements in Fig. 2).

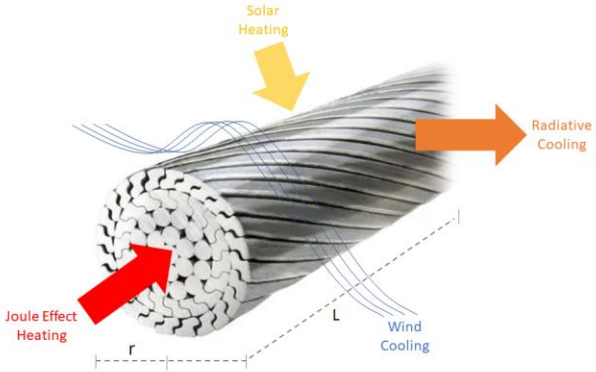

Figure 2 – Thermal effects on an overhead line cable

In this model, thermal equilibrium involves a balance between the energy entering the system, the energy leaving the system, and the energy generated within the system, as depicted in the Eq. (1) [8].

$$\begin{bmatrix} Total\ energy \\ at\ the \\ system's\ input \end{bmatrix} - \begin{bmatrix} Total\ energy \\ at\ the \\ system's\ output \end{bmatrix} = \begin{bmatrix} Variation\ of \\ total\ energy \\ in\ the\ system \end{bmatrix} \quad (1)$$

In broad terms, the energy balance in terms of an average cable temperature can be expressed through the following correlation:

$$M.Cp \frac{dT_{elem}}{dt} = P_j + P_s + P_m - P_R - P_c \quad (2)$$

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where T_{elem} is the average temperature (between the core and the surface of the conductor); ***Cp*** is the specific heat; ***M*** represents the linear mass density of the conductor; P_j is the heating due to Joule effect; P_s is the heating due to solar radiation; P_m is the magnetic heating; P_R is associated with cooling due to radiation; and P_c is the cooling by convection. Thus, the rate of change within the cable is equal to the sum of the energy entering and leaving through conduction and radiation processes [9].

Expanding the previous expression (Eq.02), the solution for the conductor cable's ampacity in steady-state conditions due to the involved thermal effects is given by:

$$I = \sqrt{\frac{P_r + P_c - P_s}{R_{ac}(T_c)}} \tag{3}$$

where ***I*** represents the ampacity, given in amperes *(A).*

This expression allows us to determine the ampacity of the conductor at a specific moment and is used to establish the static limits of the lines, according to the standards on the subject [10].

Ampacity and Dynamic Line Rating (DLR)

There are a variety of systems that enable the use of real-time meteorological variable information for calculating the transmission capacity of the lines [11]. The Fig. 3 illustrates some of the models of Dynamic Line Rating (DLR) developed for this type of approach.

Figure 3 – Models of Dynamic Line Rating (DLR) (1: Ampacimon; 2: DLR Sensor Sumitomo; e 3: Lindsey TLM Conductor Monitor)

The application of models like these can result in electrical charging gains of around 50% compared to static limits. However, in Brazil, the implementation of such devices has still been limited to pilot projects or studies due to the level of complexity and barriers such as lack of incentives, particularly regulatory ones.

Research and applications in Brazil on this field are still in their early stages when compared to the volume of publications and developments outside of the country. This highlights the need for greater investments in this area.

Regulatory Challenges

A. Energy Transmission

The remuneration of energy transmission companies that were auctioned occurs through the Allowed Annual Revenue (RAP – "*Receita Anual Permitida*") defined on the transmission auction and is paid to the when the commercial operation of the installation is identified. In these cases, the revenue is readjusted every four or five years, according to the contract.

For transmission companies that had their concession contracts renewed, as established in Article 6 of Law 12.783/2013 (regarding the renewal of concessions in the electricity sector), they are remunerated through the RAP paid for the provision of the public transmission service. This amount is calculated based on Operation and Maintenance costs and regulatory capital remuneration.

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However, it's worth noting that receiving the RAP depends on the availability of the lines, not the volume of transported energy. Additionally, companies face penalties in cases where structural tower failures or design errors are detected, among other responsibilities. In the event of such failures, regulatory mechanisms are applied to reduce the RAP due to the unavailability of transmission facilities ("*parcela variável*").

Thus, the current regulation of remuneration, while making the revenue of transmission companies more predictable, does not incentivize the application of devices that allow the use of the network according to its real-time availability. This is because, besides not being remunerated for additional transmission capacity, their revenues can be reduced in case of failures. Therefore, there is no incentive to justify the risks involved in using devices for better utilization of transmission capacity.

Therefore, as currently regulated, transmission companies tend to focus on expanding the transmission capacity of the network through new projects. However, the expansion of the National Interconnected System (SIN) also comes with challenges involving resource allocation, delays in construction, environmental licensing impacts and challenges, among others.

As several transmission concession contracts are ending in the following years, discussions around the renewal of concessions conditions [12] create an opportunity to promote regulatory measures that enable the application of real-time monitoring and ampacity calculation. For instance, recognizing them as enhancements or improvements to already implemented projects, and for new projects, implementing contractual incentives for this type of approach.

B. Energy Generation

On the other hand, there are generators facing difficulties in accessing avenues for wind energy distribution [3]. In these cases, the possibility of increased network loading could make it feasible to connect new wind farms or expand existing ones without extensive or lower investments in expanding the existing transmission system. In this regard, it is necessary to enhance regulation involving remuneration and network loading to enable the adoption of systems for dynamic ampacity that allow for a more efficient use of the network. A starting point for these incentives could occur, for instance, through the sharing of gains and risks among the involved entities.

Conclusions

The Brazilian electricity matrix has been expanding with an increasing share of renewable sources, where wind generation plays a significant role. Despite the growing presence of this source in the energy mix, there are still bottlenecks for the connection and distribution of wind energy within the transmission system.

The energy transmission capacity in the lines, even though influenced by the atmospheric conditions around the conductor, is still calculated based on conservative limits. The dynamic network loading limits are positively correlated with wind speed, and the use of monitoring systems to determine transmission line ampacity can enable significant gains in energy integration into the grid. This gain is particularly pronounced when it comes to wind generation, as they are predominantly located in areas with similar wind regimes, transmission lines experience greater cooling, which enhances their ampacity. Better utilization of transmission grid by using dynamic ampacity monitoring in areas of intense wind generation can postpone the need for network expansion in specific regions.

However, this type of approach is in its early stages and are limited in the country, with little incentive for implementation by entities responsible for operating transmission projects. According to current regulations, energy transmission companies tend to maintain interest in operating the network according to existing rules and seek to expand their transmission capacity only through new projects, as their Allowed Annual Revenue (RAP) is defined in contracts, and the risks of failures and penalties associated with increased loading through Dynamic Line Rating (DLR) do not result in higher remuneration. The discussion of regulatory changes to incentivize the better usage of existing infrastructure is timely and can bring benefits to society.

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References

[1] ANEEL. Sistema de Informações de Geração (Siga). Available in: https://app.powerbi.com/view?r=eyJrIjoiYmMzN2Y0NGMtYjEyNy00OTNlLWI1YzctZjI0ZTUwMDg5ODE3IiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Access at: August 14, 2023.

[2] ANEEL. Leilões. Available in: https://app.powerbi.com/view?r=eyJrIjoiYmMzN2Y0NGMtYjEyNy00OTNlLWI1YzctZjI0ZTUwMDg5ODE3IiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Access at: August 14, 2023.

[3] OLIVEIRA, J. L., ASANO, P. T. L. *Sistemas de Monitoramento e Ampacidade de LTs: uma Correlação entre Geração Eólica e o Aumento de Capacidade de Transmissão da Rede*. SNPTEE - Belo Horizonte, 2019.

[4] BUSH, R. A. *Experimental verification of a real-time program for the determination of temperature and sag of overhead lines*. IEEE, 1983.

[5] IEEE. *Standard for calculating the Current-Temperature Relationship of Bare Overhead Conductors*. IEEE Standards Association, New York, n. 738, 2012.

[6] NASCIMENTO, C. A. M. D. *Cálculo da Ampacidade de Linhas Aéreas de Energia Considerando a Influência da Camada Limite da Atmosfera* – Doctoral thesis. Universidade Federal de Minas Gerais. Belo Horizonte. 2009.

[7] FERNANDEZ, E. et al. Review of dynamics line rating systems for wind power integration. Renewable and Sustainable Energy Reviews, Bilbao, n. 53, 2016. p. 80-92.

[8] ÇENGEL, Y. A.; GHAJAR, A. J. *Transferência de Calor e Massa: Uma abordagem prática*. 4ª. ed. Porto Alegre: McGraw-Hill, 2014.

[9] OLIVEIRA, J. L. *Estudo do critério de ampacidade para o carregamento das linhas de transmissão próximas a parque eólico* – Dissertação de mestrado. Universidade Federal do ABC. Santo André, 2019.

[10] ABNT. NBR 5422: "*Projeto de linhas aéreas de transmissão de energia elétrica*". Rio de Janeiro. 1985.

[11] KARIMI, S.; MUSILEK, P.; KNIGHT, A. M. *Dynamic thermal rating of transmission lines: A review.* Renewable and Sustainable Energy Reviews, Calgary, n. 91, Ago 2018. p. 600-612.

[12] BRASIL. Decreto n.º 11.314, de 28 de dezembro de 2022. Regulamenta a licitação e a prorrogação das concessões de serviço público de transmissão de energia elétrica em fim de vigência. Diário Oficial da República Federativa do Brasil. Brasília, DF, v. 245, 29.dez.2022. Sec. 1, p. 8.