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Energization simulations of a half-wavelength transmission line when subject to three-phase faults—Application to a field test situation

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ABSTRACT

The purpose of this paper is to supply technical data for the proposed field energization of 500 kV transmission lines present in the Brazilian interconnected system, forming a line, henceforth called AC-Link, slightly over a half-wavelength in 60 Hz. The purpose of the test is to investigate overvoltages and currents that result from the energization of the AC-Link. This paper shows the results of simulations performed in ATP (Alternative Transients Program) when considering the occurrence of three-phase faults along the AC-Link during energization. The results obtained show that, in certain situations, the overvoltages and energies in the arresters may reach very high values and some specific mitigation procedure should be implemented.

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1. Introduction

With a national territory of over 8.5 million square kilometers and a population that exceeds 200 million people, Brazil faces the challenge of increasing its electrical energy generation capacity in an integrated, profitable, and sustainable form. Great part of the remaining hydraulic potential in Brazil is located in the Amazon region at a distance of about 2000 km to 3000 km from the main load centers in Brazil, located in the Southeast and Northeast regions of the country, as illustrated in Fig. 1. In the search for adequate solutions for bulk power transmission over such long distances, non-conventional transmission lines [1] may be adopted. One such non-conventional alternative is the transmission in alternate current with a line of length slightly over the half-wavelength, or approximately 2500 km at 60 Hz, the frequency in use in Brazil.

Although there are studies about half-wavelength transmission since the 1960's [2,3], there is no such line in operation in the world. This leads to a great deal of precaution and reservation among the engineers responsible for the Brazilian electrical system expansion in allowing this alternative even to be taken into further consideration.

For this reason, in response to a Strategic Research and Development Project proposed by the Brazilian Electric Energy Agency—ANEEL, an energization switching under well-defined conditions was proposed to be performed in a transmission line that would resemble an AC-Link [4]. This transmission line will be formed from the series connection of the North-South I and II interconnections and part of the Northeast-Southeast interconnection [5]. Together, these 500 kV lines form a link of 2600 km in length, slightly over the half-wavelength at 60 Hz. This is an AC point-to-point transmission line, with no need of intermediate substation switching.

The purpose of the test is to investigate overvoltages and currents that result from the energization of the AC-Link. All series compensations of the existing lines should be short-circuited and all shunt compensations should be open-circuited. However, the surge arresters in the intermediate substations cannot be disconnected from the network since this procedure would demand an excessive amount of time for the energization test setup. Therefore, it is necessary to verify if the overvoltages that result from the energization test and the resulting energy absorbed by the surge arresters will not damage them. Although the test will be conducted under good weather conditions, due to the AC-Link extension it is highly probable that part of the circuit may be subject to rain and lightning. One possibility that should be analyzed with care is the energization under different fault conditions, which may result in very high overvoltages along the line. In this paper, the possibility of energization under three-phase faults is considered.

The results presented in this paper are important because they indicate the necessity of adjusting the protection of the system assets during the energization test, such as generator, transformer and surge arresters. It will be shown that when the fault occurs in

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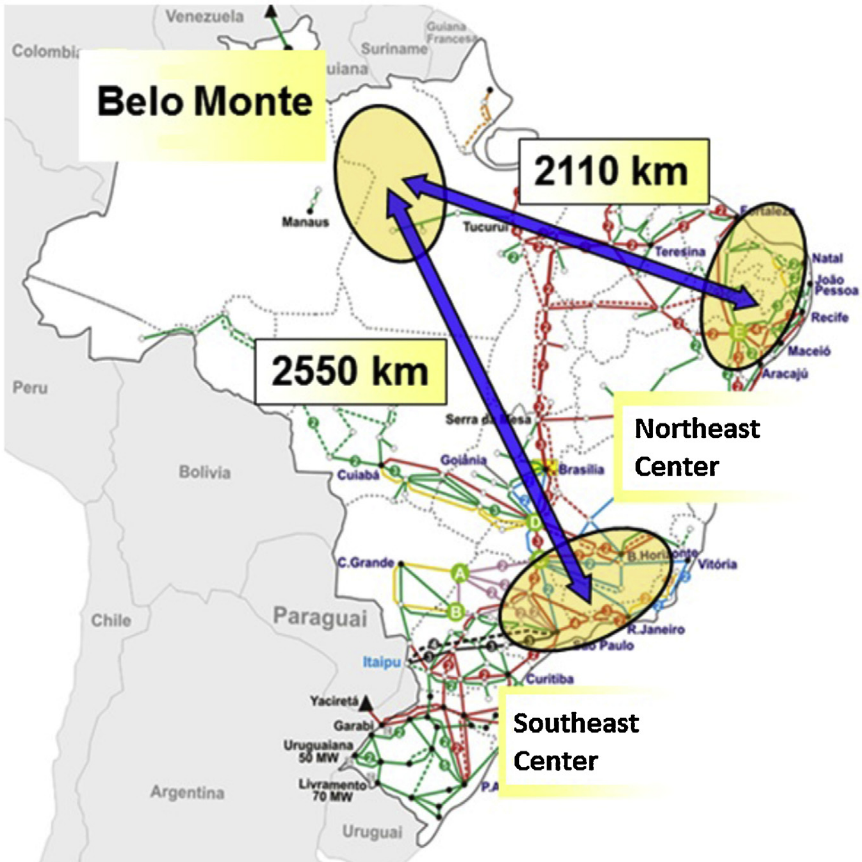

Fig. 1. Distances from the generation in the Amazon region to the main load centers in the Southeast and Northeast.

certain well defined AC-Link regions, the overvoltages may reach very high values and, therefore, some specific mitigation procedure should be implemented. Two different line models were used to model the line and different results were obtained.

The paper is organized as follows: Section 2 presents the basic characteristics of the half-wavelength transmission line. Section 3 describes the system analyzed and Section 4 shows the simulation results considering the energization of the line under three-phase faults. Finally, the conclusions are presented in Section 5.

2. Basic characteristics of the half-wavelength transmission line

The equivalent two-port network of a transmission line may be written in the frequency-domain as:

$$\begin{bmatrix} V(x) \\ I(x) \end{bmatrix} = \begin{bmatrix} \cosh(\gamma x) & -Z_C \sinh(\gamma x) \\ -\dfrac{1}{Z_C}\sinh(\gamma x) & \cosh(\gamma x) \end{bmatrix} \begin{bmatrix} V_e \\ I_e \end{bmatrix} \tag{1}$$

where $V(x)$ and $I(x)$ are the positive sequence voltage and current at any point of the line, respectively; V_e and I_e are the positive sequence voltage and current at the sending end terminal, respectively; γ is the positive sequence propagation constant, and Z_C is the positive sequence characteristic impedance, which are given by

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{2}$$

$$Z_C = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{3}$$

where R, L, G, and C are the positive sequence transmission line resistance, inductance, conductance, and capacitance, per unit length, respectively, and ω is the angular frequency.

From (1) it is possible to write the voltage and current at the sending end as a function of the voltage and current at the receiving end, V_r and I_r, respectively, as shown in the following equation:

$$\begin{bmatrix} V_e \\ I_e \end{bmatrix} = \begin{bmatrix} \cosh(\gamma l) & Z_C \sinh(\gamma l) \\ \dfrac{1}{Z_C}\sinh(\gamma l) & \cosh(\gamma l) \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \tag{4}$$

where l is the length of the line.

If the line is operating at no load, $I_r = 0$ and $V_r \neq 0$. In this situation, the relation between the voltages at the sending and receiving ends are given by

$$\frac{V_r}{V_e} = \frac{1}{\cosh(\gamma l)} \tag{5}$$

The propagation constant is

$$\gamma = \alpha + j\beta \tag{6}$$

where α is the attenuation constant and β is the phase constant. For a lossless line, $\alpha = 0$ and $\gamma = j\beta$. Eq. (5) then becomes

$$\frac{V_r}{V_e} = \frac{1}{\cosh\left(j\beta l\right)} = \frac{1}{\cos\left(\beta l\right)} \tag{7}$$

Since the phase constant $\beta = 2\pi/\lambda$, where λ is the wavelength of the transmission line at a given frequency (5000 km at 60 Hz)

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