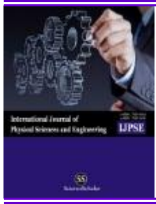

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Transposition of Medium and Long Transmission Lines

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Abstract

The transmission lines must be balanced electric circuits, theoretically, it must be an equivalent circuit that takes into account the uniform distribution of the parameters along the line. When it comes to transporting energy over long distances it is necessary to consider the effect of the capacitance, since each phase has a different capacitance causing each line to introduce an imbalance to the electrical system, for this reason, it is necessary to study the transposition of the cables. In the present work, several simulations of transmission lines with and without transposition are made, and the voltage unbalance that occurs as the line is longer has been verified. The simulations have been carried out under conditions of balanced load and fixed voltage in the arrival bar. Using the Sim Power Systems tool from Matlab, it was possible to check the behavior of the parameters of the line, depending on the geometric layout of the structure and its length. By applying this software, the objective is achieved by checking the stress unbalance problems suffered by a transmission line when transposition is not made.

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Contents

1. Introduction

The voltage and current relationships establish that there are 4 parameters that are distributed along the transmission line; these are resistance, inductance, capacitance, and conductance. In terms of capacitance, 60 Hz open conductor lines that are less than 80 km long are considered short. The lines of medium length are between 80 km and 240 km in length, and those with more than 240 km in length are long lines (Grainger, 2002).

Before making the construction of long transmission lines and to avoid difficulties with the electromagnetic and electrostatic balance, it is necessary to first review the electrical designs, for this reason, it is necessary to make a transposition study in these, before proceeding to its final design and construction. Phase transpositions in electric power transmission lines began from the 1920s and with greater emphasis between the 1980s (Hennesey, 2016; Cedeno *et al.,* 2017). The lines in which the transpositions are applied are those that operate with voltages from 110 kV. In countries like Ecuador, they are applied from voltages of 138 kV. When they travel great distances. In the technical literature, the transposition is described very lightly and in other texts (Nagrath, 2008), (Guirado *et al.,* 2006), is not considered, so it is difficult for undergraduate students to understand the reasons why must perform.

In Ecuador, the EP Electric Corporation (CELEC-EP), in the transmission lines greater than 80 kilometers, with voltages equal to or greater than 138 kV, these are designed with transpositions to avoid voltage unbalance in the transmission lines. In the academy, students receive the explanation of why transpositions of power lines are made, but their mathematical application cannot be demonstrated in a simple way; so the objective of this work is to simulate the effects produced in a long line with transposition and in this way many theoretical formulations that will allow you to understand this phenomenon are simplified. In general, the effects of unbalance are summarized in the appearance of negative sequence components and zero sequence components, which result in additional power and energy losses; and in rotating machines, heating occurs that limits the nominal load capacity, reduction in power transport in the distribution systems and propagation of the unbalance to other network connection nodes.

In (Saadat, 2004), the equation (4.41) is expressed to calculate the inductance in H/km and the capacitance in F/km with the equation (4.69) that will be used in the simulation in the present work. Currently students do not receive the methodologies that are applied in the processes of transposition of lines, but usually, if they are used at the level of companies dedicated to the ruble of design and construction of transmission lines.

In this research the use of the Matlab is proposed as a methodology, and under the Toolbox Simulink environment, there is the SimPowerSystems tool that allows building models that simulate an electrical power system (MatLab, 1996), and that in the particular case of this work, allows simulating the transposition in long electric lines, using the Pi model. An electrical power system combines electrical (electrical circuits) and electromechanical (generators and motors) elements, which greatly complicates its analysis without the help of computational tools. The objective of this research is to provide education to students using the Matlab, to understand the effects of transposition of transmission lines

2. Materials and Methods

As a simulation tool, Matlab was used, this software is basic for the students of the electrical engineering career, in the different processes of study and knowledge in the generation, transmission, and distribution of energy. A bibliographic search was carried out on the use of this instrument in teaching processes in higher education.

The *pi* model was used in a single-line model, applying 3 unilinear lines to build the three-phase system and simulate the respective transpositions; then the phase voltages are checked at effective values at the final end. In (Torrez & León, 2002), the unbalance index is estimated as the maximum deviation between the value of the line voltage and the average of the line voltages, divided by the average of the line voltages, where the subscripts i and j correspond to phases A, B, and C.

In the IEC standard (Caraballo & Bermudez, 2012), limits are recommended for the stress unbalance ratio defined by equation (1) of <2% for low and medium voltage systems , and <1% for high voltage, measured as values every 10 minutes, with an instantaneous maximum allowed of 4%. The reason for narrower limits in the case of high voltage systems is that they are designed to be operated at maximum capacity with a balanced three-phase load. In the case of distribution systems, whose main purpose is the feeding of single-phase loads, the lines and equipment installed are designed to operate with certain levels of imbalance.

$$U = 100 \cdot \max\left(\frac{U_{ij} - V_{pro}}{V_{pro}}\right) \quad (1)$$

Where:

U→ Online voltage

Vpro→ Average voltage in line

3. Results and Discussions

The structures of the transmission lines, cause different flow links per phase, and therefore different inductance, in Figure 1 the asymmetric arrangement of the conductors is shown. This results in unbalanced voltages at the receiving end of the line, even if the voltages at the emitting end and the line currents are balanced (Torrez & León, 2002).

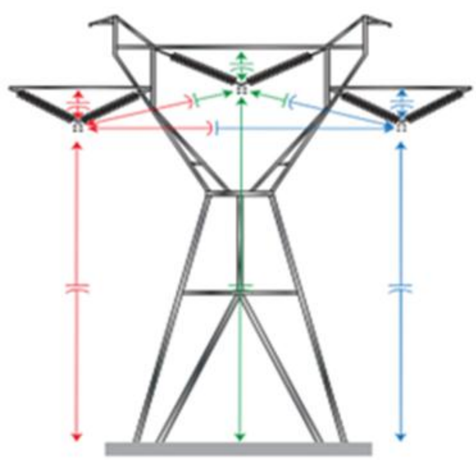

Figure 1. The geometry of the structure

The main causes for the existence of unbalanced voltages and/or currents in the three-phase power systems are the inequitable distribution of single-phase loads in the system, and the asymmetric impedances of the transmission lines, caused by the incomplete transposition of them.

A complete transposition is a physical rotation of the conductors in which each phase moves to occupy the next physical position sequentially; the common practice is to do it twice every 1/3 of the length of the line, to divide the line into three equal sections, eventually reaching three positions each phase. In figure 2, in (A) the position of the lines and structures is shown and in (B) the lines with transposition are observed

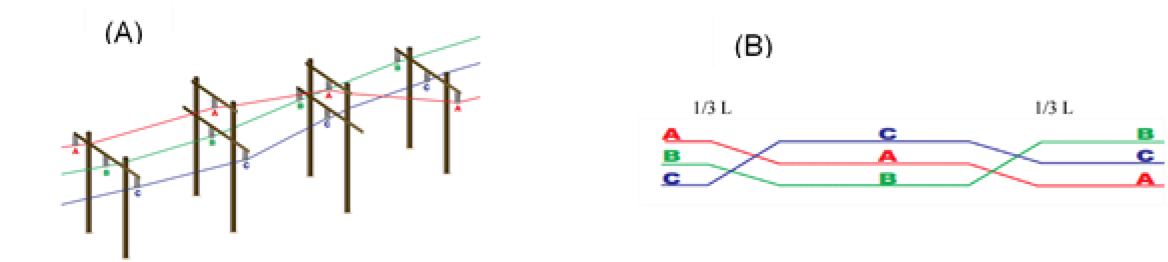

Figure 2. In (A) lines and structures and (B) lines with transposition

The result of the transposition is to balance the inductive coupling and the mutual capacitance between phases of the transmission line. That is to say, the mutual impedances between sequences are reduced to zero and when behaving as a symmetric circuit, the currents of each sequence produce only voltage drops of the same sequence (Viqueira, 1970). In a very general way, in power systems, the transmission lines must operate with balanced voltages.

Use of MatLab as a simulation tool

With Matlab as a didactic tool, it is possible to develop a simulation that allows identifying the voltage unbalances of the phases when the lines are not transposed and allowing comparison when transpositions are made.

The use of computational tools allows us to study didactic cases, citing among them (Caraballo & Bermúdez, 2012), where they monitor the stability of power systems at the point of operation, in the regions of voltage stability, which is useful for system analysts and network operators, is an input to identify unsafe or risky conditions for the stability of an electrical system, it is possible to predict network conditions and in turn take corrective actions.

In this field there are several didactic experiences (Colome *et al.,* 2001), then (Colome, 2013), focus on the teaching-learning process through computational tools, and successful learning so that students learn skills to pose, analyze and solve complex engineering problems.

In 2010, (Olarte & Díaz, 2010), made a programming in Matlab to identify the parameters of transmission lines (Pérez & Flórez, 2010), proposed an efficient alternative for fault simulation based on a cooperation strategy between Matlab and ATP (Hernández, 2012), under Matlab environment, developed a method to locate faults in transmission lines (Rossi & Baldini, 2008), have presented for teaching applications, routines developed in Matlab ™, for teaching the evaluation of the generated electric field by existing power lines in industrial facilities. In (Grainger, 2002), of the text Power Systems Analysis (Grainger, 2002), page 201 cites "from the previous example it is concluded that the nominal circuit π can represent long lines well enough if a high degree of accuracy (Piumeto *et al.,* 2014), analyzed the unbalance of stress introduced by non-transposed high-voltage asymmetric transmission lines, simulate and analyze the behavior of the lines under balanced supply and load conditions, in order to determine the individual contribution of them in the unbalance of tensions. In figure 3, a pi circuit of a medium length transmission line is shown, with the series impedance parameter and the admittance parameter in parallel distributed at the ends of the circuit.

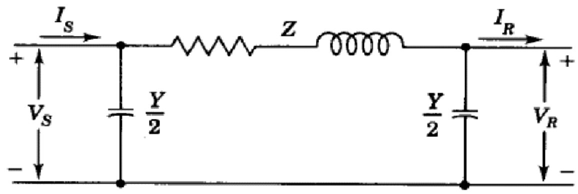

Figure 3. Nominal circuit π of a medium length transmission line (Grainger, 2002).

Where:

z⟶ Serial impedance per unit length (□/ km)

y⟶Admittance series per unit length per phase (Henry / km)

l⟶Line length (km)

Z⟶zl = Total series impedance per phase (□)

Y⟶yl = Admittance in parallel (or derivation) total per phase to neutral (Siemens)

Practical Example

For the present analysis, the real data of a project are taken. The data of the transmission line to be simulated are the following: AAAC-450 cable; diameter: 27.7 mm; R20 ° C: 0.0641 ohms/Km; load at the receiving end: 346 MW, line length: 60-180 km-300 km.; voltage in the load LL: 220 kV. The type structure is shown in Figure 4. The height from the ground to the lower crosshead is 24 meters in the simple circuit.

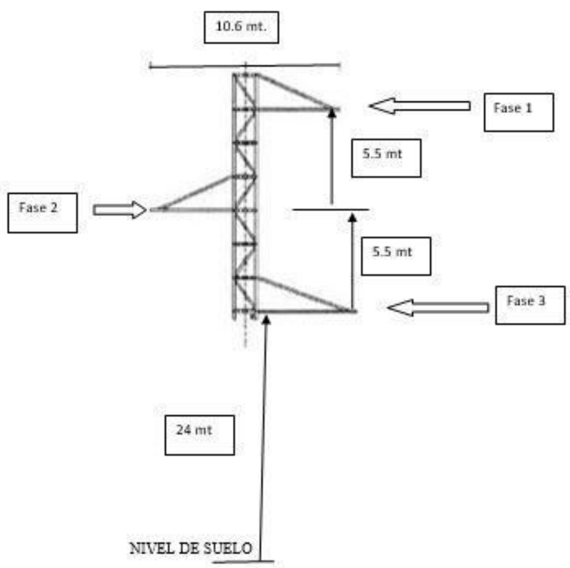

Figure 4. Geometric layout of the structure

Modeling the lines

To do the research, a pi line was created, first without transposition as shown in figure 5. The same model is then made, but with transposition, as shown in figure 6. The results of the effective line-to-ground voltage are reflected in table 1 of the results

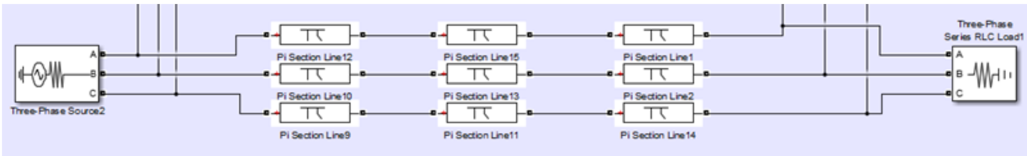

Figure 5. Model without transposition

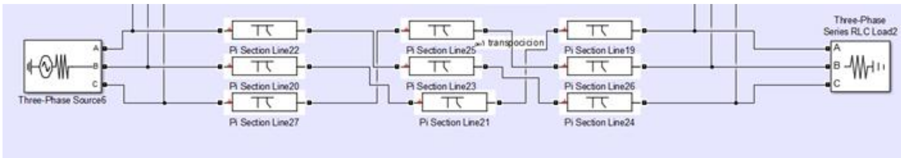

Figure 6. Model with transposition

Average transmission lines

This simulation was performed first with a distance of 180 kilometers, with 3 segments of 60 kilometers each; without transposition and then with transposition. Extreme receiver results: No transposition as shown in table 2 a.

Table 2a
Results of the tensions without transposition

Simple voltage of each phase	Value in kV.
V1n	126.30
V2n	127.22
V3n	128.32

Results at the receiver end: with transposition, it is observed in table 2b.

Table 2b
Results of transposition voltages

Simple voltage of each phase	Value in kV.
V1n	127.27
V2n	127.25
V3n	127.32

As observed in the voltage values, in both models, the results with transposition differ very little, but without transposition the unbalance value obtained is 0.8%.

Long

This simulation was done with a distance of 300 kilometers, with 3 segments of 100 kilometers each.
Results in extreme receiver: without transposition observed in table 3a.

Table 3a
Results of the voltages without transposition

Simple voltage of each phase	Value in kV.
V1n	125.74
V2n	127.28
V3n	129.18

Results at the receiver end: with transposition, it is observed in table 3 b.

Table 3b
Results of transposition voltages

Simple voltage of each phase	Value in kV.
V1n	127.38
V2n	127.33
V3n	127.47

The unbalance obtained in this case without transposition is 1.39%. As observed in the values of tension in both longline modeling, the results with transposition differ very little, but those without transposition have a deviation of 1.39%; which exceeds the maximum allowable unbalance value. Standard IEC-61003-3-13, admits values lower than 1% of unbalance of tensions (Grainger, 2002).

4. Conclusion

The tool was used under the Matlab Simulink environment to determine the behavior of short, medium and long transmission lines without transposition and with transposition; noticing that the line-to-neutral voltage imbalance becomes more noticeable, the longer the line is. It has been demonstrated with the results that it serves as a didactic tool for the students of the electrical engineering career. The software tool used facilitates, through graphics outputs, the conception of the mathematical model used for the analysis and understanding of the transpositions produced by long-length transmission lines.

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