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MATLAB APPLICATION FOR ANALYSIS AND EVALUATION OF ELECTRIC ENERGY TRANSMISSION STABILITY OF LONG TRANSMISSION LINES

Slobodan Bjelić
Faculty of Technical Sciences, Kosovska Mitrovica, Serbia

Nenad Marković
Higher Technical Professional School,
Urosevac, Leposavic, Serbia

Uroš Jakšić
Higher Technical Professional School
Zvecan, Serbia

Bojan Jovanović
Higher Technical Professional School,
Urosevac, Leposavic, Serbia

Bojan Prlinčević
Higher Technical Professional School,
Zvecan, Serbia

Abstract

The paper considers the possibility of applying formulas which include the wave character of the electromagnetic process in very high voltage lines on static stability of transmission system. Applied formulas are valid on the assumption that the frequency of alternating current generators connected to busbars is constant- standard. The procedure of validated simulation in the selected MATLAB program was used for verification and analysis. The obtained diagrams show that the better results are achieved using formulas that include wave character of electromagnetic process in lines.

Keywords: electromagnetic process, wave character, simulation, MATLAB.

INTRODUCTION

With voltage of 400(kV) and throughput of 500÷1500(MW), in the European Union the transmission of electric energy is achieved at the distances of 900÷1200(km). The limit of transmitted power with increasing length is related to the static stability of power plants in parallel operation and consumption of the system.

For the improvement of static stability of transmission grids connected through busbars to the infinite power system, the criteria defined in linear equations of electro-mechanical and electromagnetic transient processes of generators and synchronous machines connected to this system are used [2, 3, 9].

PARAMETERS OF BLOCK GENERATOR TRANSFORMER-BUSBARS SYSTEM

When synchronous turbogenerators (with cylindrical-shaped rotors) are connected through reactances of the block generator-transformer, according to Ben-Eichenburg diagram [6], the electromotive force depends on the value of the parameter of equivalent reactance x_e, i.e. according to relation:

$$E = \frac{U \cdot x_{G+T}}{x_l}\left[\sqrt{\left(\frac{x_e}{x_{G+T}}\right)^2\left(\frac{U_1}{U}\right)^2 - \sin^2\theta} - \cos\theta\right] \quad (1)$$

where: E is electromotive force of the generator, U is phase voltage of busbars on the output of the generator, θ is angle between vector of electromotive forces and busbars of synchronous generator, U_1 is phase voltage at the beginning of power line and x_e is equivalent reactance of power line in transmission system.

Natural power is transmitted by water provided that the end of the line is closed with characteristic impedance. If Z_c is real number and is Z_C=Z_2, then:

$$\bar{I}_2 = \frac{\overline{U}_2}{\overline{Z}_C},\ S = P = \frac{V_n^2}{Z_C} \tag{2}$$

Phase value of voltage at the end of the line is:

$$\overline{U}_2 = \overline{Z}_2 \bar{I}_2,\ \overline{U}_2 = U_2 \tag{3}$$

The amplitude values of voltages and currents of power line are equal to amplitudes at the end, and during the transmission of this power the power line behaves neutrally, does not lose nor does provide this power; the line supply itself in reactive power.

For classic lines it is (T_1 on fig. 1):

$$Z_C(\Omega) = 400,\ P(MW) = \frac{U_n^2}{400} \tag{4}$$

and for lines in bundle:

$$Z_C(\Omega) = 300,\ P(MW) = \frac{U_n^2}{300} \tag{5}$$

The parameters of power line are:

$$\begin{aligned} U_n &= 110(kV);\, P(MW) = 30 \\ U_n &= 220(kV);\, P(MW) = 120 \div 130 \\ U_n &= 400(kV);\, P(MW) = 530 \div 550 \end{aligned} \tag{6}$$

Power lines usually operate in the regime of transmission of powers approximately equal to apparent powers.

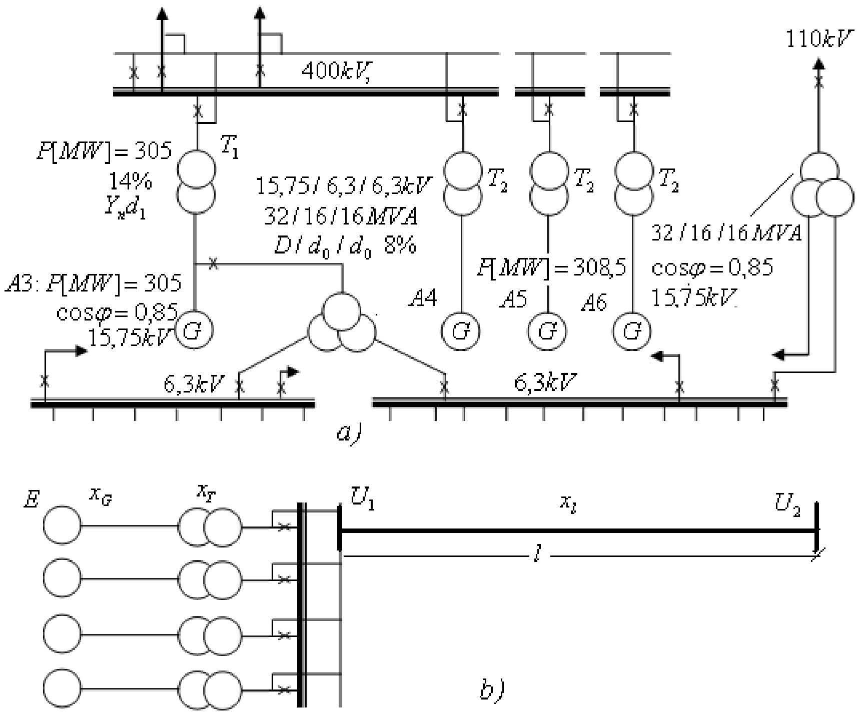


Fig. 1. *a) Scheme of the part of TE Nikola Tesla and very high voltage busbars*
b) Equivalent reactances of the part of the system with transmission line

This transmission lines have the following characteristics:

- Due to higher load currents 1000÷2000(A) the cross-sections of conductors are very large. Because of this but also because of the reduction of inductive reactance of losses, the constructions where phase lines are divided into two or more parallel conductors are designed.
- If the lengths of transmission lines are extremely large for compensation of higher capacitive currents of the line, the "shunt" reactors *R* are installed.
- Longitudinal capacitive compensation is sometimes used to increase throughput of transmission lines. Serial capacitors connected to phase line reduce

(compensate) inductive reactance in electric circuit.

- Parameters of lines with the voltage of 400(kV) affects the relay protection requirements and operating conditions.

400(kV) power lines operate at the limit of static and dynamic stability because based on economic criteria they are designed in relation to maximum load. Short circuit at any point must be switched off in the time less than 0,1÷0,12(s). Modern switches operate in 0,08(s) so their own protection time cannot be greater than 0,02÷0,04(s). Therefore, the relay protection of very high voltage power line requires high demand in relation to the speed of reaction.

Due to large lengths of lines and tolerable loads, currents and impedances in normal regimes and at short circuits are comparable values (approximately equal), which complicates protection and requires the use of special devices of increased sensitivity. Because of the higher value of capacitive susceptance ωC and the level of voltage V, the capacitive currents $I(\mathrm{A})=V\omega C$ of the lines with the voltage over 400(kV) considerably exceed the current values at 110(kV) and 220(kV). I_C currents per one kilometer correspond to the following voltage values: 1÷1,2(A) for 400(kV) of the grid, 0,34(A) for 220(kV) of the grid, and 0,2(A) for 110(kV) of the grid. Capacitive currents for transmission on voltages over 400(kV) in some cases have significant impact on protection operation.

In the analysis and calculation of short circuits and static or dynamic stability the Π or T schemes are used. In calculations or analyses, very important parameters are reactive resistances (reactances) of electric circuits that equate electric transmission system.

Values of reactances are predominantly calculated according to approximate formulas and do not take into account the wave character of electromagnetic processes in the power grids [1, 2, 4, 7, 8, 10, 11].

For all calculations and simulations the base value is apparent power and equivalent reactances of power system are calculated from the serial connection of the reactance of the block and transmission line:

$$x_e = x_{G+T} + x_l,\ x_l = x_1 l \qquad (7)$$

where: l(km) is the length of transmission line.

For calculation of static stability, the free element values of the characteristic equation obtained by the linearization of electromechanical and electromagnetic processes equation in synchronous machine, excitation and regulator of excitation. The per-unit value of the power in this case is [5]:

$$P[pu] = a = \frac{EU}{x_e} cos\,\theta \qquad (8)$$

If it is assumed that the transmission line of lengths l=300÷1000(km) does not have active losses, (ideal line r=0, g=0), and that is uses Π scheme, it is possible to implement correction factors that take into account the capacitance conductivity of lines b_1(S/km). The corrected formula (7) is then:

$$x_l = x_1 l\left[1 - \frac{l^2}{6} x_1 b_1\right] \qquad (9)$$

SIMULATION OF PROCESSES IN MATLAB AND ERROR ANALYSIS OF NEGLIGENCE OF ELECTROMAGNETIC PROCESSES

Instead of measuring the influence of parameters wave character, the simulation in MATLAB psbtriphaselineBG [5] and analysis of the impact of errors occurred due to negligence of electromagnetic processes in the calculation of stability in transmission grids were prepared and performed in this paper. The power plant TE Nikola Tesla with 4 power blocks was selected for simulation A3:P(MW)=305, $A4$=$A5$=$A6$:P(MW)=308,5.

The per-unit value of equivalent reactance of blocks generator transformer is x_{G+T}=1,45(Ω/km), and transmission line 400(kV):3x500(mm^2) from TE Nikola Tesla towards Kragujevac, Niš and Leskovac has inductive resistance (reactance) $x_1 = 0{,}2\ [\Omega / km]$ and capacitive conductivity (conductance) b_1=4,27(S/km).

The calculation of the system with the uniform distribution of parameters of equivalent reactance is carried out according to formulas (7, 8) and electromotive forces according to formula (1). Whereas it is assumed that the power transmission system operates continuously without voltage disruption, and power values are determined according to assumed angle θ=60^0. The values of phase voltages at the end of transmission line U_2=$U_{2(A,B,C)}$ are shown on the display. The calculation results are given in Table 1.

Figure 2 shows the simulation of the operation in the MATLAB psbtriphaselineBG program of one part of the power system and transmission line which is presented by Π scheme. The simulation parameters are calculated according to formulas (7) and (9), while other important parameters can be read from the presented schemes.

Tab. 1. *Table of important values of parameters in calculation and simulation*

	$x_e[pu]$			$x_e[pu]$	$E[pu]$	
$l[km]$	$x_l = x_1 l$	$x_l = x_1 l\left[1-\frac{l^2}{6}x_1 b_1\right]$	x_e, for. (7)	x_e, for. (9)	x_e, for. (7)	x_e, for. (9)
100	0,1115	0,111	1,5615	1,561	1,87	1,88
200	0,223	0,221	1,673	1,671	1,725	1,735
300	0,335	0,328	1,785	1,778	1,565	1,62
500	0,557	0,529	2,007	1,979	1,48	1,505
1000	1,115	0,862	2,565	2,310	1,35	1,37

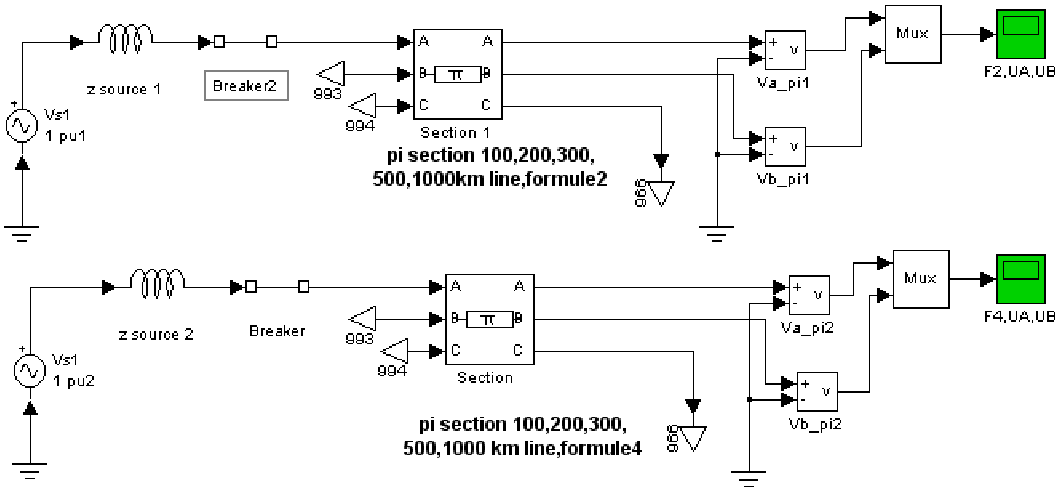
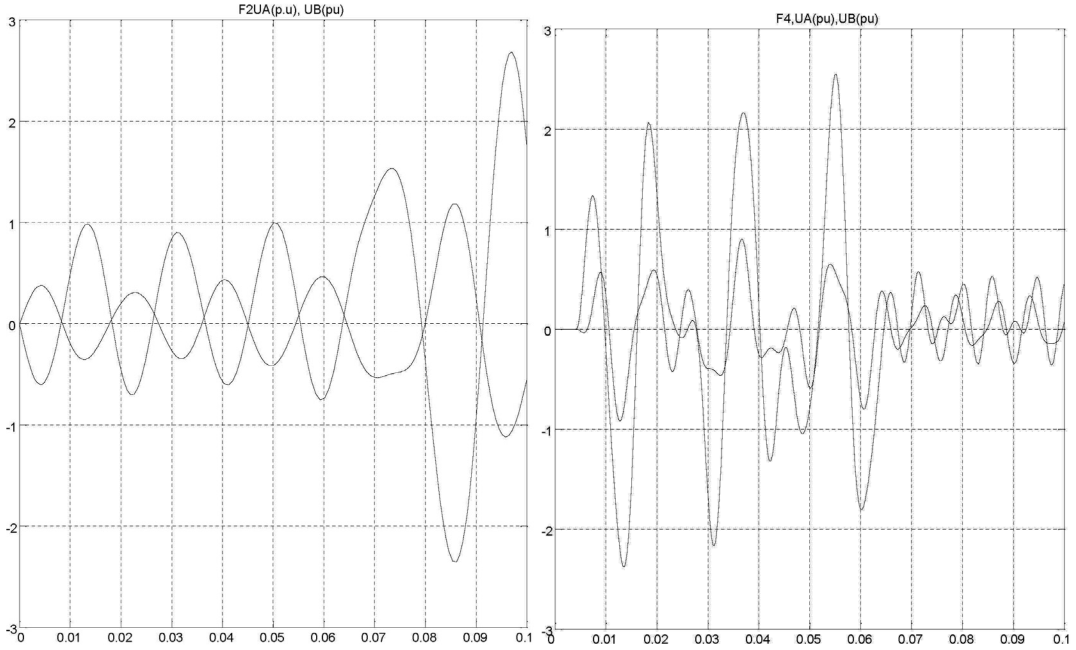


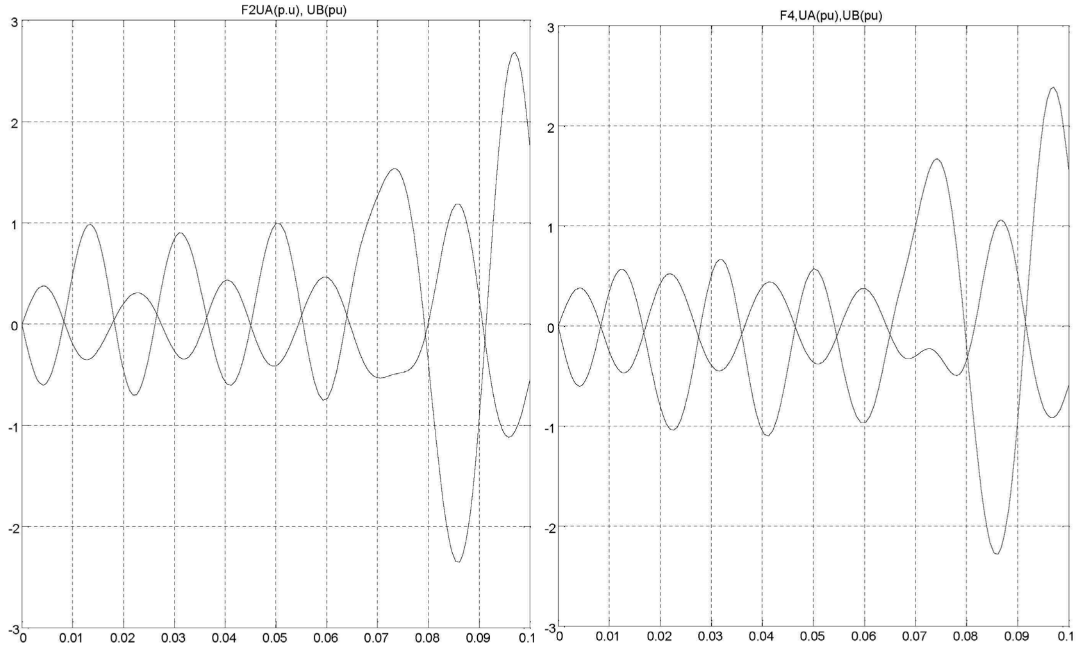
Fig. 2. *Simulation of operation process in MATLAB riphaselineBG program*

Fig. 3 and 4 show simulation diagrams of time flows of the voltages at the end of transmission lane 400(kV), in length of 100(km), made according to formulas (7, 9).



a) *b)*

Fig. 3. *Voltages time flows: a) voltages for transmission line 100(km), formula (7), b) voltages for transmission line 100(km), formula (9)*



a) *b)*

Fig. 4. *Voltage time flows: a) voltages for transmission line 500(km), formula (7), b) voltages for transmission line 100(km), formula (9)*

Based on diagrams on fig. 3 and 4 we can say that an increase of distance in transmission of electric power leads to a decrease of electromotive force of the generator *E* (pu), which means that ensuring static stability will be very difficult if there is no transverse inductive compensation that can only contribute to the growth of ems generators in order to maintain the nominal factor of the power $cos\varphi$.

CONCLUSION

In the case of equivalency of electric circuits of lines with distributed parameters and other elements with concentrated parameters (generators, transformers…), for the calculation of static stability the wave character of electromagnetic processes in transmission line must be taken into account, based on formula (7).

If quantity x_e, determined according to formula (7) for long lines l>500km is used for calculation of increased value of free element of characteristic equation obtained by linearizing of equation of electromechanical and electromagnetic processes in synchronous machine, excitation and regulator of excitation, i.e., equation of power value $a = P[pu] = a = \frac{EU}{x_e} cos\,\theta$. As the obtained diagrams show, in simulation for long lines the more accurate results are obtained if the values x_e determined according to formula (9) are used.

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