

Mathematical simulation application for research of nonuniform distributed-parameter circuit transients

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Abstract. This paper considers the simulation capability of nonuniform distributed-parameter circuit transients by using MatLab Simulink. This approach is capable of determining currents and voltages of nodes for power networks of any configurations and modes. The paper contains results of nonuniform line simulations in idle, short-circuit and load modes.

1. Introduction

The electric power system reliability during transients is one of the important problems since transient conditions are heavy-duty and result in overload of electrical grid elements and, consequently, power losses and equipment damages [1, 2]. It is necessary to take into account a set of nowadays electrical grid structure features for this problem solution, first of all, nonhomogeneity of power transmission lines on a great bulk of voltage classes.

The accurate information about distributed parameters is required to calculate the transmission line transients. A number of techniques are available to determine the transients in zero-loss circuits [3, 4]. Most of these techniques are based on the state variable approach. They are quite time-consuming in practice. The state variable approach allows obtaining good calculation results of a discrete time model [4-6]. However, it has such disadvantage as a difficulty of sample interval determination.

One of the options is mathematical modeling of the nonuniform distributed parameter circuit in the Matlab Simulink software.

2. A distributed parameters line model

Nonuniform line transients are described by the telegraph equations [5]:

$$\begin{aligned} \frac{\partial}{\partial x} u(x, t) &= -R(x)i(x, t) - L(x) \frac{\partial}{\partial t} i(x, t); \\ \frac{\partial}{\partial x} i(x, t) &= -G(x)u(x, t) - C(x) \frac{\partial}{\partial t} u(x, t), \end{aligned}$$

where $R(x)$, $L(x)$, $G(x)$ and $C(x)$ – parameters of a line length unit; x – coordinate of a selected point, measured from the line beginning.



The Target values will be voltage values $u_1(t), u_2(t), \dots, u_{N+1}(t)$ incase of $N+1$ points of the line and current values $i_1(t), i_2(t), \dots, i_N(t)$ in case of N points of the line. Voltage of the line beginning $u_0(t)$ and current at the line end $i_{N+1}(t)$ are known as boundary conditions.

In the next part of the paper the simulation data of the nonuniform circuit with distributed parameters are described (Figure 1).

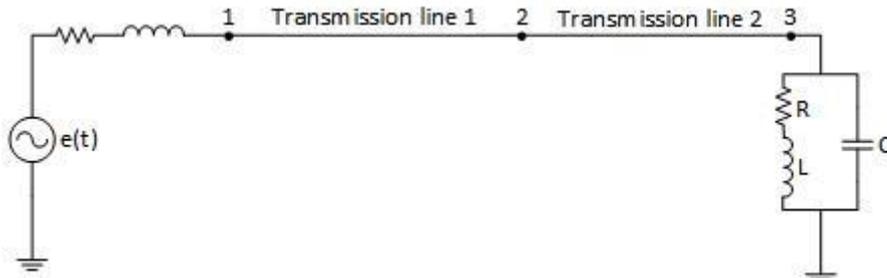


Figure 1. Transmission lines with terminations ($L_1 = 1.4$ mH, $R_1 = 0.42 \Omega$, $C_1 = 8.9$ nF, $L_2 = 1.33$ mH, $R_2 = 0.21 \Omega$, $C_2 = 8.5$ nF)

3. Nonuniform line simulation

In this part the simulation data of such transmission line modes as idle, short-circuit and load modes are obtained from experiments.

3.1. The idle mode

Here we will consider an open-ended nonuniform line of $l = 300$ km length, a sending end line breaker is normally opened and a switch is closed when $t = 0$ s. The voltage and current along the line are zero before the breaker is closed.

A simulation circuit diagram in Matlab Simulink for the idle mode is given in Figure 2. Breaker 1 and Breaker 2 are open (parameter ‘Switching times’ is significant).

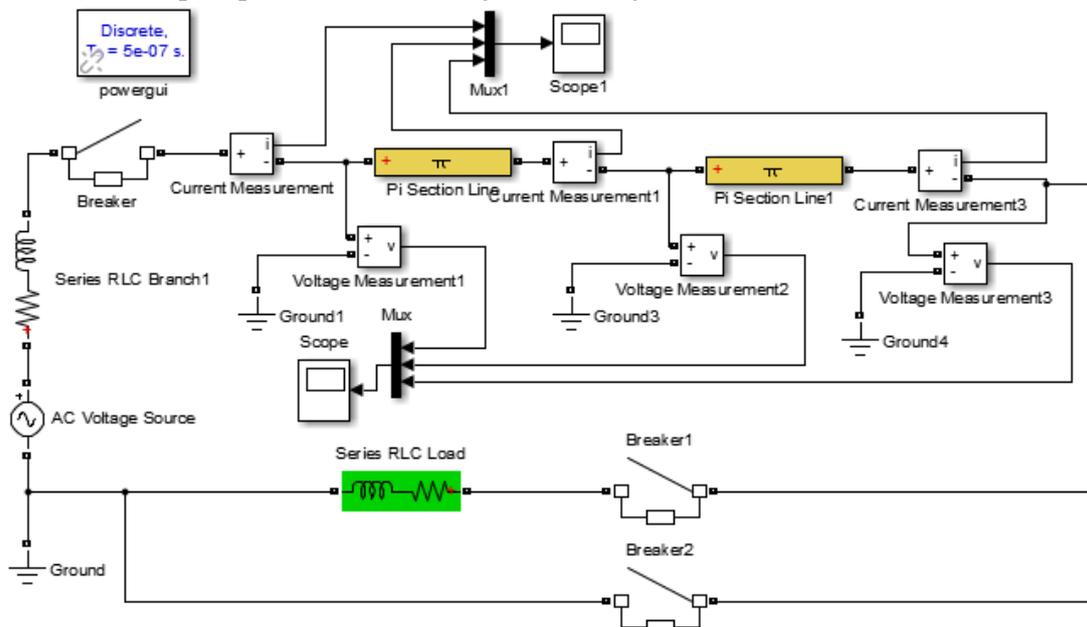


Figure 2. A Matlab Simulink circuit diagram.

The MatLab Simulink software package includes SimPowerSystems – a toolbox of blocks oriented at power systems. The simulation results for circuit diagram nodes 1-3 are shown in Figure 3.

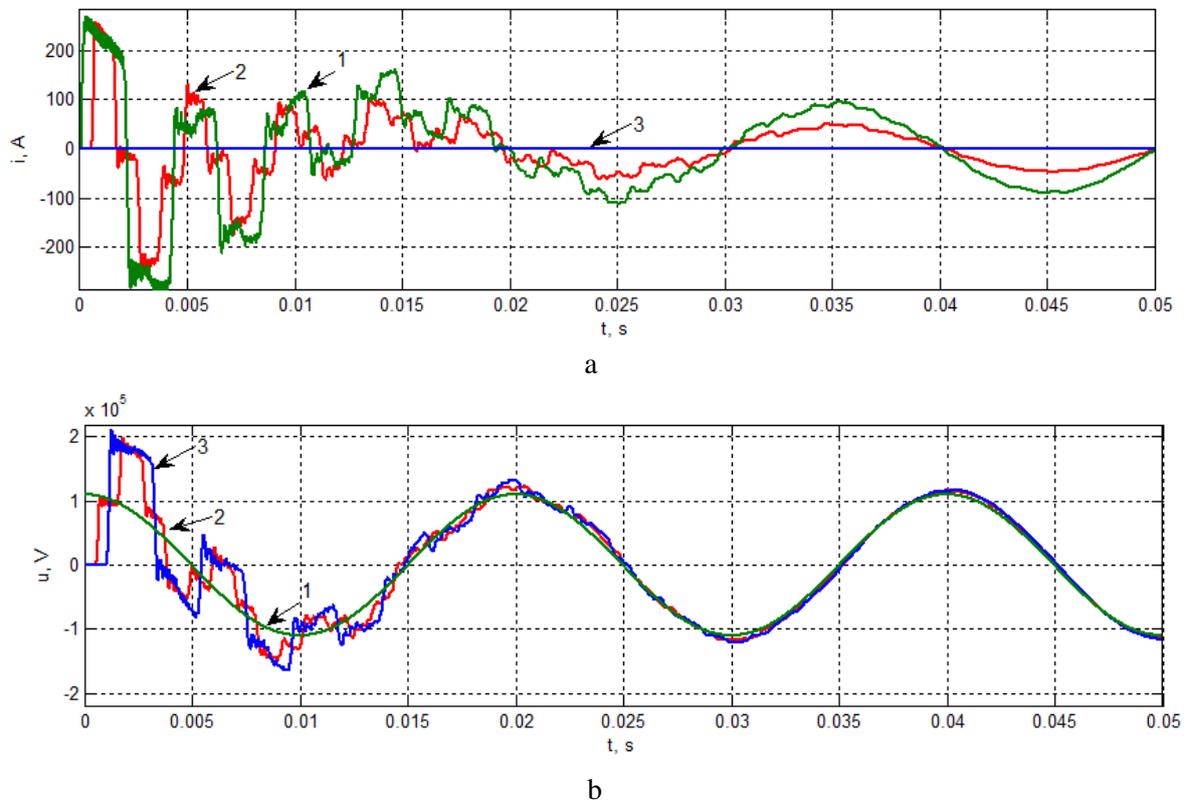


Figure 3. The transmission line parameters in the idle mode: *a* – currents of nodes 1-3; *b* – voltages of nodes 1-3

The diagrams show that when the breaker has been closed, the line has been put under alternating voltage. The current incident wave (IW) amplitude is 0.27 kA. When IW reaches node 2 in the time of 0.5 ms and splits from the obstacle into transmitted (TW) and reflected (RW) waves. Since the line characteristic impedance of the second half is less than that of the first, the current TW amplitude is higher and the current RW amplitude is lower than the IW amplitude. When current TW reaches the end, it reflects and changes the sign into the opposite. Therefore, the current of node 3 equals zero.

When voltage TW reaches the end, it is reflected with the same sign. Therefore, the voltage of node 3 is doubled. In a steady-state mode the voltage of node 3 is higher than the voltage of node 1.

3.2. The short-circuit mode

Now we will consider the same line closed at the end.

A simulation of the short-circuit diagram in Matlab Simulink is represented in Figure 2. Breaker 1 is opened, Breaker 2 is closed.

The simulation results for the circuit diagram are shown in Figure 4.

The diagrams make it evident that multiple reflectance overlapping provides multiple current surges. The current peak amplitude reaches almost 0.8 kA and is shaped by these surges. Also, it is obvious that the voltage of node 2 oscillates in between initial and zero values and tends to average out till the end of the transient. So, in a steady-state mode the current of node 2 is two times lower than the current of node 1.

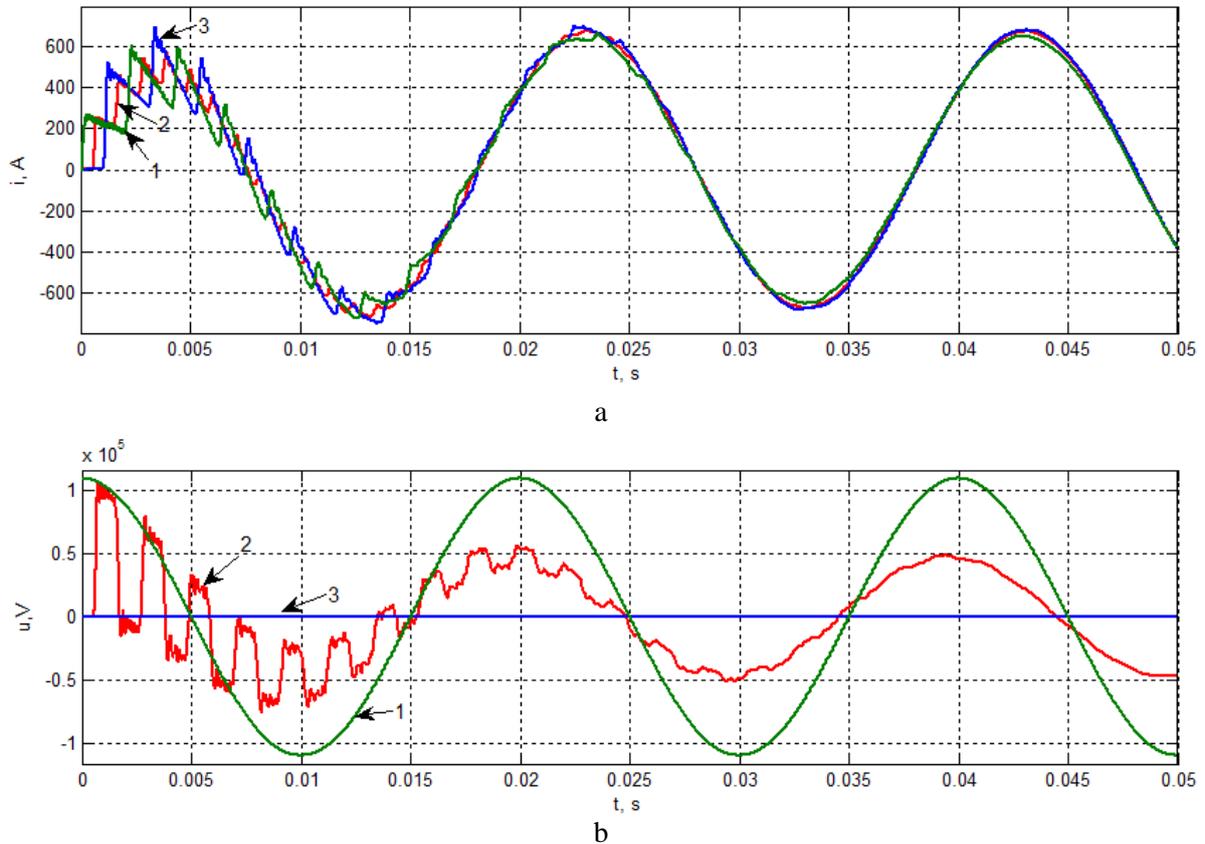


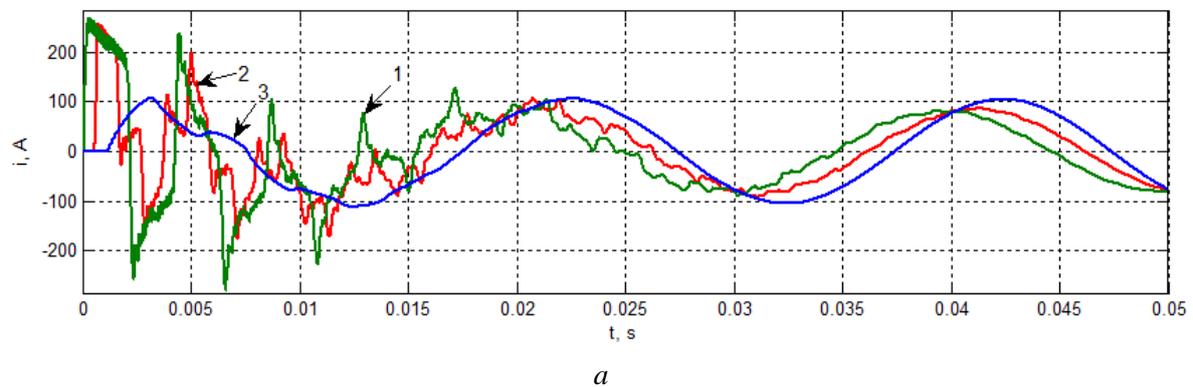
Figure 4. The transmission line parameters in the short-circuit mode:
a – currents of nodes 1-3; *b* – voltages of nodes 1-3

3.3. *The load mode*

Finally, we will consider the same line which is loaded at the end by $\underline{S} = 10 + j8$ MVA.

A simulation circuit diagram in Matlab Simulink for the load mode is given in Figure 2. Breaker 1 is closed, Breaker 2 is opened.

The simulation results for circuit diagram nodes 1-3 are shown in Figure 5.



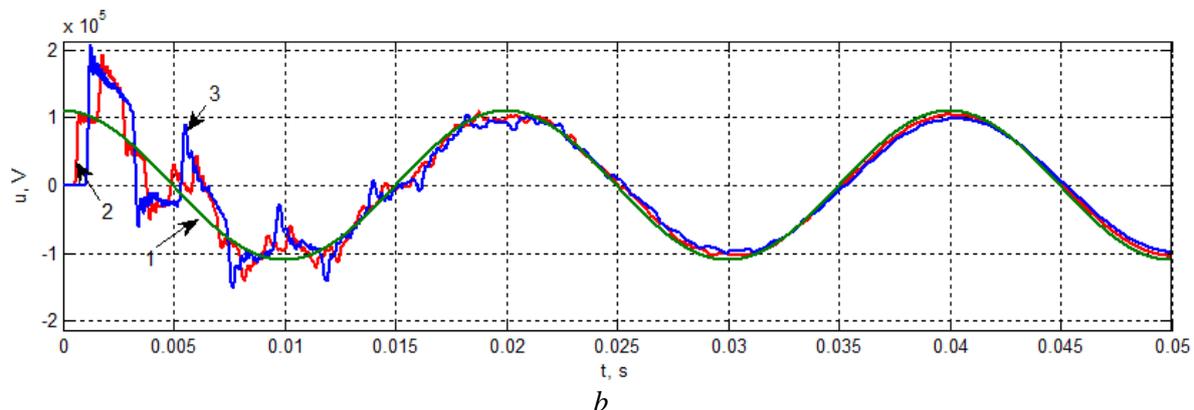


Figure 5. The transmission line parameters in the load mode: *a* – currents of nodes 1-3;
b – voltages of nodes 1-3

It can be seen from the diagrams that the current peak amplitude is 0.27 kA. During the transient current, the TW amplitude (in node 2) is higher than the IW amplitude. But after the transient ending the former is lower than the latter, and the current amplitude in node 3 tends to be a little higher than the amplitude in node 1.

When the TW voltage reaches the end, it is reflected with the same sign. That is why the voltage of node 3 is doubled. In the steady-state mode the voltage of node 3 is a little lower than the voltage of nodes 1 and 2.

4. Conclusions

The mathematical simulation in MatLab Simulink allows calculating the nonuniform distributed-parameter line transients not just in case of the power supply connection, but also during line parameters and load changes. The represented simulation results agree with those obtained in [4]. The capability of reducing the computation complexity for nonuniform distributed-parameter circuit transients by using MatLab Simulink has been shown.

References

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