Creation of a mathematical model to identify short circuits in power lines

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Abstract. We consider the issues of modeling power lines using a self-adjusting mathematical model which allows analyzing the lines operating modes while tracking instantaneous values of parameters. The obtained model can be used to build high-speed protection against phase-to-phase faults in power lines with a voltage of 10–35 kV, which have a small length.

1 Introduction

The relevance of the topic is explained by the fact that at present the operating conditions of electrical equipment are undergoing profound changes, constantly becoming more complex together with the technological processes in which they are used [1–6]. The modes of operation of electrical systems become more dynamic and diverse in nature, which leads to the need to increase the speed of protective equipment.

In most cases, the existing protection is based on the control, as a rule, of effective values of currents and voltages [7–10]. This requires a relatively long observation of signals in emergency situations to make the right decision, which leads to a decrease in performance.

In this regard, new approaches are required based on presentation of the protected objects by more complete and accurate mathematical models reflecting both static and dynamic properties of objects being protected.

The proposed method for detecting damage in power transmission lines (PTL) is based on the principle of the self-adjusting mathematical model of a controlled line. The method is valid for analyzing the modes of lines with a voltage of 10–35 kV.

2 Materials and methods

We will start the selection of mathematical model with representation of the power line in the form of a finite chain of RLC parameters, shown in Figure 1.

The figure shows: R_A, R_B, R_C are active resistances of phases A, B, C, respectively; L_A, L_B, L_C are inductance of phases A, B, C; C_A, C_B, C_C are capacities relative to the earth of phases A, B, C; C_{AB}, C_{BC}, C_{AC} are capacities between phases A, B, C.

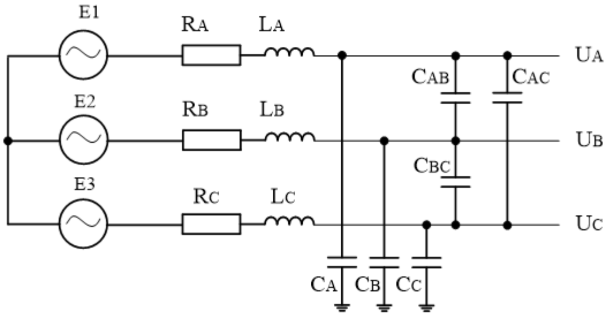

Fig. 1. Equivalent scheme of power lines in a form of RLC chain.

For lines of 10–35 kV interfacial capacitive components can be neglected, due to their insignificant influence on transient processes in the line.

Thus, the original equivalent circuit shown in Figure 1, takes the form presented in Figure 2.

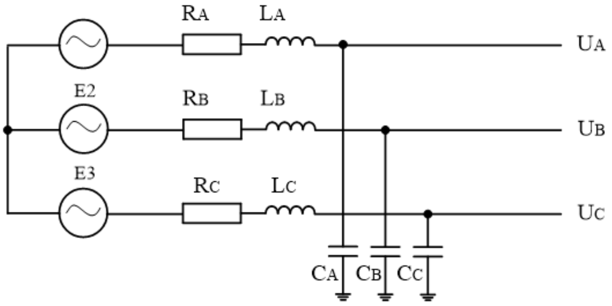

Fig. 2. Simplified equivalent scheme of PTL in a form of RLC chain.

The model for this equivalent circuit is the active-inductive-capacitive link shown in Figure 3 [11].

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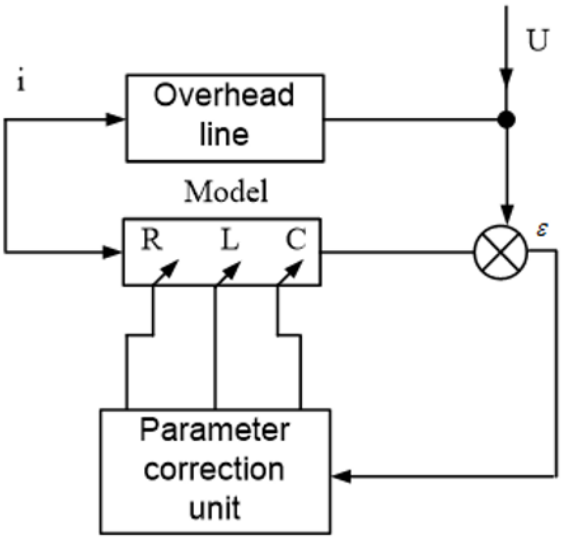

Fig. 3. RLC circuit model diagram.

This model is described by the equation of the Kirchhoff law in differential form [12]:

$$u = R_W i + L_W \frac{di}{dt} d + \frac{1}{C_W} \int i dt \tag{1}$$

where R_W, L_W and C_W are the resistance, inductance and capacitance of the line, respectively.

3 Results and discussions

Given the considerable complexity of the analytical analysis of such a system, as well as the difficulties of its modeling, we will prove the possibility of neglecting the capacitive component of a differential equation.

To prove this, we will present one of the phases of power transmission lines by a U-shaped equivalent circuit shown in Figure 4 [13].

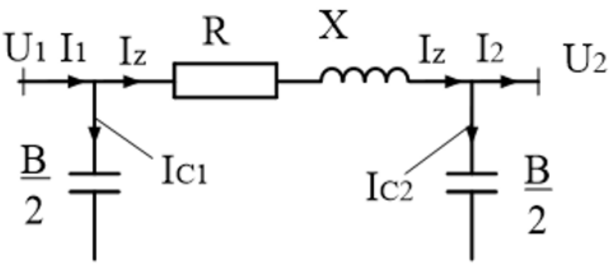

Fig. 4. U-shaped equivalent circuit of PTL.

The following notation is used in the figure: U_1, U_2, I_1, I_2 are the complex effective values of currents and voltages at the ends of the lines; I_z is current in the longitudinal resistance of the line; I_{C1}, I_{C2} are currents in transverse capacitive conductivities; B is capacitive conductivity.

According to the first Kirchhoff law, we have the following relations for currents in the equivalent circuit:

$$I_1 = I_Z + I_{C1};$$

$$I_Z = I_2 + I_{C2}.$$

According to the second Kirchhoff law

$$U_1 = U_2 + \Delta U,$$

where ΔU is voltage drop across the longitudinal resistance.

Taking into account the relationship between currents and voltages in power lines, we construct a diagram showing the ratio of currents and voltages, presented in Figure 5.

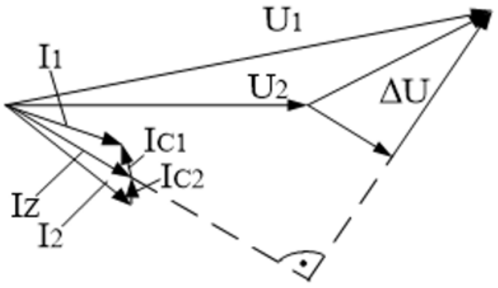

Fig. 5. Vector diagram of currents and voltages in power lines.

The diagram clearly indicates the fact that capacitive currents I_{C1}, I_{C2} are significantly less than current I_Z in the longitudinal resistance of the line, so when building a model the inductive component in differential equation (1) can be neglected.

Considering all the aforesaid, the equation describing the mathematical model of power lines, takes the form:

$$u = R_W i + L_W \frac{di}{dt} \tag{2}$$

However, it should be noted that such a simplification is unacceptable when considering single-phase and various other earth faults, since in this case the capacitive component of current prevails.

The final model of the line is shown in Figure 6.

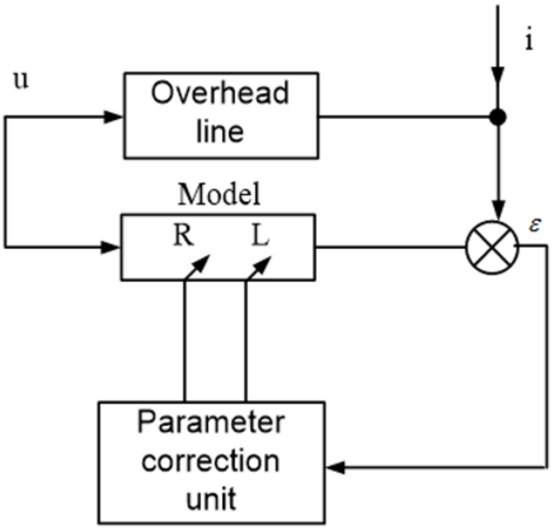

Fig. 6. Scheme of a simplified model of power lines.

4 Conclusions

Consequently, the resulting model can be used to build protection against phase-to-phase faults in power transmission lines with a voltage of 10–35 kV, which have a small length.

Despite all the above simplifications, which are aimed at improving the performance of the developed protection, we can talk about a slight decrease in the accuracy of the obtained results.

The considered model uses current and voltage as input signals, and at the output it allows analyzing the active and reactive (inductive) components of the resistance. Thus, the protection built on the basis of the proposed mathematical model will have greater accuracy than, for example, a resistance relay [14], which calculates impedance. The protection built on the basis of such a model can later be used as one of the channels of the existing digital protections [15].

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