# Influence of Synchronized Measurement Errors on the Results of Identification of the Transmission Line Parameters

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*Abstract* - **The parameters of transmission lines, as a rule, are determined by reference data, but during the operation, it might vary essentially from the actual data. There are noted the reasons for the parameters' modification. This paper explains the opportunity of parameter identification based on the synchronized measurements during the operation of the transmission line. The methods of parameter identification can be classified by various criteria. The diagram of classification was elaborated for the first time. Transmission lines can be represented in the form of quadripole and the T- and П-forms equivalent schemes, so, applying only the current and voltage synchronized measurement on both ends it is possible to obtain passive parameters of the line. There are presented final formula of six most effective methods for parameter identification of the transmission lines. All analyzed methods were verified with the models of real transmission line. There were compared the results of all proposed methods: the relative errors of calculation for all mentioned methods are less than 1%. The obtained results show the high accuracy of parameter identification for the proposed methods. The influence of measurement errors upon the values of parameters' results was analyzed in this work. The main contribution of this paper lies in the classification of the methods of transmission line parameters identification and in the research of influence of measurement errors on the results of the parameter identification for transmission lines.**

**Cuvinte cheie:** *linie electrică, măsurări sincronizate, parametrii schemelor echivalente în forma de П, coeficienții cuadripolului, bilanțul curenților, bilanțul puterilor.*

**Keywords:** *transmission line, synchronized measurements, parameters of equivalent circuit in П-form, quadripole coefficients, currents balance, powers balance.*

## I. INTRODUCTION

Transformers and transmission lines (TL) being the most used elements of transmission and distribution power systems have their own specific mathematical models, that take the form of equivalent schemes.

Solving the problems of the management of the different regimes of the electric power systems is performed with using mathematical models. Mathematical models are used for calculation permanent regime of the electric power systems, optimization regimes, static state estimation, reliability evaluation to small disturbances and short current calculation.

Basis of mathematical models is equivalent scheme of power system which is composed from equivalent circuits of basic elements connected between them according to real circuit of power system. Basic elements are electric line, two or three winding transformer, branch transformer (transformer with split winding), autotransformer, power sources, consumers, inductor, capacitor batteries. Parameters of equivalent schemes are determined from catalogue and are named catalogue data. This methodology is enough exact, but it doesn't consider all real circumstances as weather conditions, loading of basic elements and other factors. The difference between real values and those calculated with catalogue data might be considerable [1, 2].

Errors can take following values [3]:

- for active resistance $\Delta R = \pm 18\text{-}20\%$
- for reactance $\Delta X = \pm 10\%$
- for conductance $\Delta G$ and capacitive susceptance $\Delta B = \pm 25\%$.

Numerous applications in electrical power systems require the exact knowledge of the parameters of the equivalent schemes of transmission lines. These parameters are active resistance R, reactance X, conductance G and capacitive susceptance B, length of electric line. It is generally known, that some parameters for example active resistance varies due to both line's length and temperature; reactance varies only from function of line's length, but susceptance varies from function of line's length and ice accretions. In turn length of electric line is influenced not

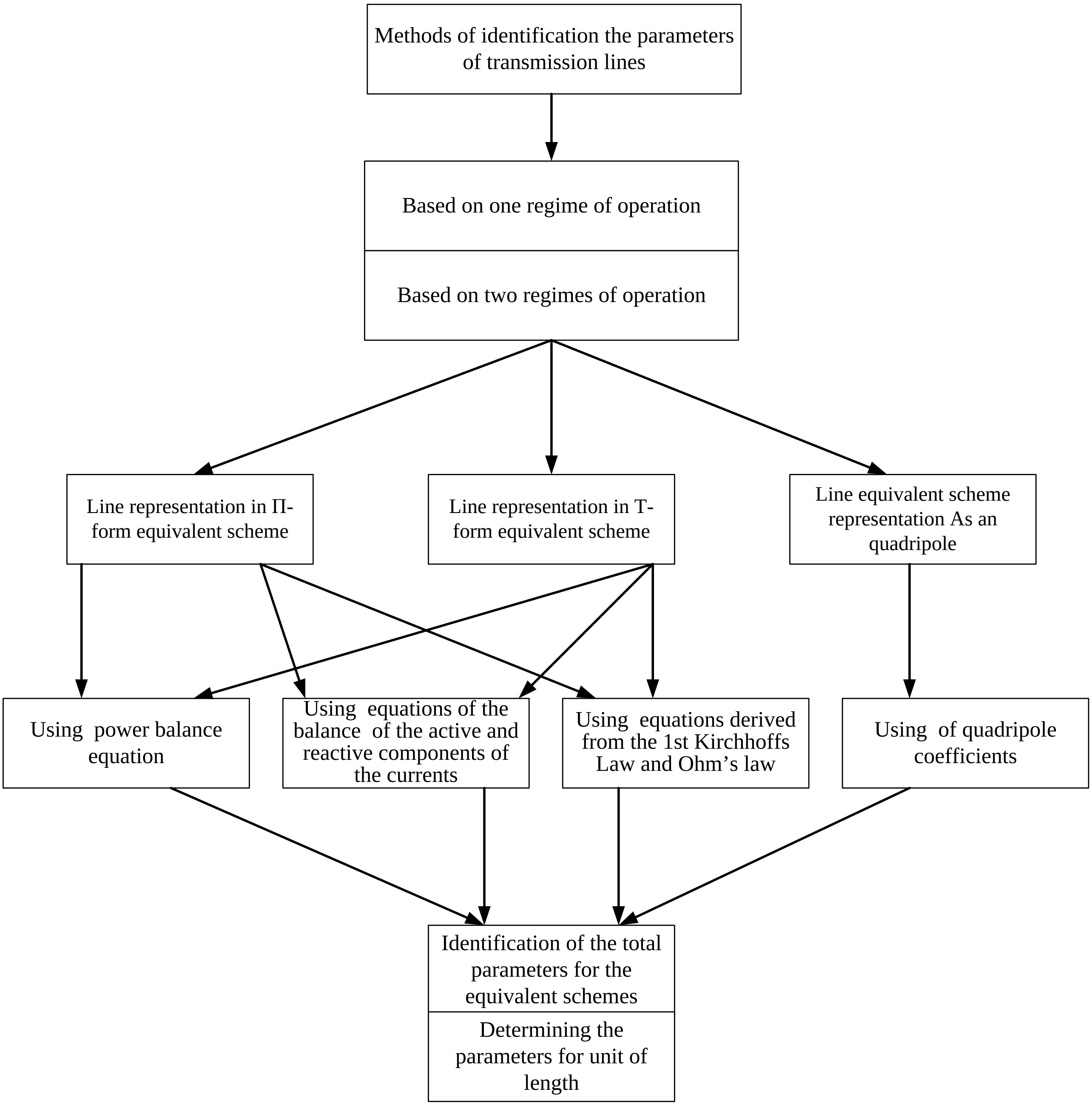


Fig. 1 Classification of the methods of parameter identification for transmission lines based on synchronized measurements.

only by weather conditions (temperature of environment, speed and direction of wind, presence of ice accretion), but also by power losses caused by effect Joule-Lenz.

Thus it is current to identify parameters of electric line using information about parameters of some regimes obtained from measurement systems' information. This information is provided by:

- data recorder of disturbances;
- phase measuring unit synchronized in time - PMU.

The resulting errors of the measured parameters are estimated at least [5]:

±0,1 for phase angle;
± 0,2 for voltages;
± 0,3 for currents;
± 0,4 for power.

## II. CLASSIFICATION OF METHODS FOR IDENTIFYING PARAMETERS OF EQUIVALENT CIRCUITS

Till now, there have been proposed in the literature various methods to identify the parameters of equivalent circuits of transmission line. Some methods are based on the set of measured phasors (the voltages $\underline{U}_1$ and $\underline{U}_2$ and currents $\underline{I}_1$ and $\underline{I}_2$ in nodes 1 and 2), obtained from PMU and other methods are based on the arrays of instantaneous values ($U_1(t_j),\ I_1(t_j),\ U_2(t_j),\ I_2(t_j)$) obtained from fault (disturbances) recorder, that are located on the both sides of the power line. The publication of the results of these works ensured the large volume of information, which is contained in magazines, articles, reports presented at scientific conferences and monographs. The study of the various suggestion, included in these publications, as well as their critical analysis can be made easier if a classification of these methods was established. Fig.1 shows a diagram, which illustrates a possible classification of methods for identification of the parameters of equivalent schemes of power lines. Classification is based on the following technical criteria:

- number of used regimes;
- type of the used informational measurement system;
- transmission line presentation models;
- the systems of equations used to describe the power line regime.

The methods of identification by the number of used regimes are divided into:

- methods with one set of measured values;
- methods with two sets of measured values.

Depending on the used measurement system information are divided into:

- methods based on the arrays of instantaneous values $(U_1(t_j),\ I_1(t_j),\ U_2(t_j),\ I_2(t_j))$, obtained from fault recorder, that are located on the both sides of the power line;
- methods based on the sets of synchronized measured phasors ($\underline{U}_1,\ \underline{U}_2$ and $\underline{I}_1,\ \underline{I}_2$), obtained from PMU, placed on the both sides of the power line.

There are used various mathematical models of transmission lines:

- bipole line representation;
- quadripole line representation;
- line representation in T-form equivalent scheme;
- line representation in Π-form equivalent scheme.

Also it might be mentioned that there are used various modes of regimes' description:

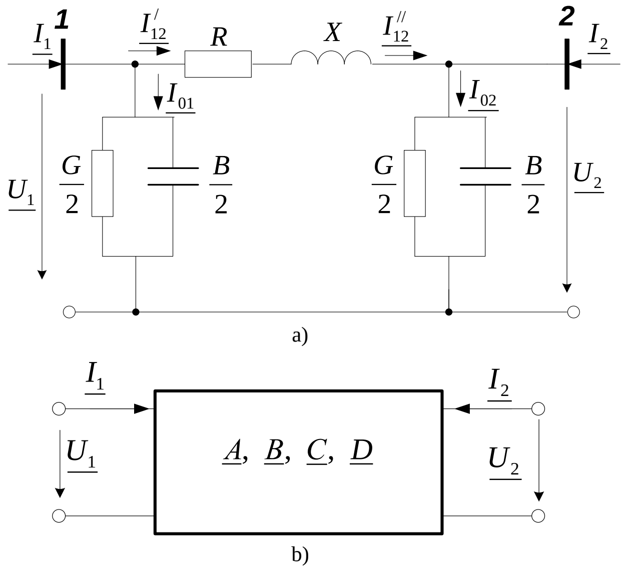
- equations derived from the 1st Kirchhoff's law;
- equations derived from the Ohm's law;
- different forms of equations derived from nodal analysis (balance of power in nodes, balance of active and reactive components of currents in nodes).

## III. SHORT METHOD DESCRIPTION

There are described below the final formulas of the methods that in previous studies [6] gave the best results. The below mentioned methods are performed with the use of equivalent scheme of transmission line in Π-form or quadripole form (Fig.2).

### A. Method 1: based on the equations derived from the 1st Kirchhoff's law with one set of measured values

The final formula of the method will be presented on the example of the Π-form equivalent circuit (Fig. 2 a). The measured values for this circuit are the voltages $\underline{U}_1$ and $\underline{U}_2$ and currents $\underline{I}_1$ and $\underline{I}_2$ in nodes 1 and 2.



a)

b)

Fig. 2 Equivalent scheme of the transmission line a) in Π-form and b) in quadripole form.

For node 1 it is obtained:

$$\underline{Z}_{12} = \frac{\underline{U}_1^2 - \underline{U}_2^2}{\left(\underline{I}_1\underline{U}_2 + \underline{I}_2\underline{U}_1\right)} \qquad (1)$$

$$\underline{Y} = \frac{2\cdot\left(\underline{I}_1 - \underline{I}_2\right)}{\underline{U}_2 + \underline{U}_1} \qquad (2)$$

### B. Method 2: powers balance method with one set of measured values

According to this method it is necessary to use measurements of currents and voltages in the single regime at the both ends of transmission line - $\underline{U}_1$, $\underline{I}_1$ and $\underline{U}_2$, $\underline{I}_2$ (otherwise set $\underline{U}_1$, $\underline{S}_1$ and $\underline{U}_2$, $\underline{S}_2$).

$$\begin{cases} P_1 = U_1^2 G_t - (U_1^2 - U_1 U_2 \cos\delta_{12})\cdot G_{12} + \\ \quad + U_1 U_2 \sin\delta_{12} B_{12} \\ Q_1 = -U_1 U_2 \cos\delta_{12} G_{12} - U_1^2 B_t + \\ \quad + (U_1^2 - U_1 U_2 \cos\delta_{12})\cdot B_{12} \\ P_2 = -U_2^2 G_t + (U_1 U_2 \cos\delta_2 - U_2^2)\cdot G_{12} - \\ \quad - U_1 U_2 \sin\delta_2 B_{12} \\ Q_2 = U_1 U_2 \sin\delta_2 G_{12} + U_2^2 B_t + \\ \quad + (U_1 U_2 \cos\delta_2 - U_2^2)\cdot B_{12} \end{cases} \qquad (3).$$

By solving linear system of equations (3) the values of longitudinal $(G_{12},\ B_{12})$ and transversal $(G_t,\ B_t)$ admittances are obtained. Thus, the transmission line parameters are calculated by following formula:

$$\underline{Z}_{12} = R_{12} + jX_{12} = \frac{G_{12}}{G_{12}^2 + B_{12}^2} + j\frac{B_{12}}{G_{12}^2 + B_{12}^2}. \qquad (4)$$

and

$$\underline{Y} = G_t + jB_t \qquad (5)$$

### *C. Method 3: powers balance method with two sets of measured values*

There are used measurements of currents and voltages in two operating regimes at the both ends of transmission line. Values $\underline{U_1}^{(1)}$, $\underline{I_1}^{(1)}$ and $\underline{U_2}^{(1)}$, $\underline{I_2}^{(1)}$ (otherwise set $\underline{U_1}^{(1)}$, $\underline{S_1}^{(1)}$ and $\underline{U_2}^{(1)}$, $\underline{S_2}^{(1)}$) are obtained from the 1st set of measurement parameters, and $\underline{U_1}^{(2)}$, $\underline{I_1}^{(2)}$ and $\underline{U_2}^{(2)}$, $\underline{I_2}^{(2)}$ (otherwise set $\underline{U_1}^{(2)}$, $\underline{S_1}^{(2)}$ and $\underline{U_2}^{(2)}$, $\underline{S_2}^{(2)}$) – from the 2nd one.

$$\begin{cases} P_2^{(1)} = -U_2^{2(1)}G_t + (U_1^{(1)}U_2^{(1)}\cos\delta_2 - U_2^{2(1)})\cdot G_{12} - \\ -U_1^{(1)}U_2^{(1)}\sin\delta_2^{(1)}B_{12} \\ Q_2^{(1)} = U_1^{(1)}U_2^{(1)}\sin\delta_2^{(1)}G_{12} + U_2^{2(1)}B_t + \\ +(U_1^{(1)}U_2^{(1)}\cos\delta_2^{(1)} - U_2^{2(1)})\cdot B_{12} \\ P_2^{(2)} = -U_2^{2(2)}G_t + (U_1^{(2)}U_2^{(2)}\cos\delta_2^{(2)} - U_2^{2(2)})\cdot G_{12} - \\ -U_1^{(2)}U_2^{(2)}\sin\delta_2^{(2)}B_{12} \\ Q_2^{(2)} = U_1^{(2)}U_2^{(2)}\sin\delta_2^{(2)}G_{12} + U_2^{2(2)}B_t + \\ +(U_1^{(2)}U_2^{(2)}\cos\delta_2^{(2)} - U_2^{2(2)})\cdot B_{12} \end{cases} \quad (6)$$

Passive parameters of the transmission line are found with the help of expressions (4) and (5).

### *D. Method 4: currents balance method with one set of measured values*

There is derived the balance of active and reactive currents for the nodes 1 and 2 of transmission line equivalent scheme:

$$\begin{cases} I_{1a} = U_1 G_t - (U_1 - U_2\cos\delta_{12})\cdot G_{12} + U_2\sin\delta_{12}B_{12} \\ I_{1r} = -U_2\cos\delta_{12}G_{12} - U_1 B_t + (U_1 - U_2\cos\delta_{12})\cdot B_{1} \\ I_{2a} = -U_2 G_t + (U_1\cos\delta_2 - U_2)\cdot G_{12} - U_1\sin\delta_2 B_{12} \\ I_{2r} = U_1\sin\delta_2 G_{12} + U_2 B_t + (U_1\cos\delta_2 - U_2)\cdot B_{12} \end{cases} \quad (7)$$

By solving linear system of equations (7) the values of longitudinal ($G_{12}$, $B_{12}$) and transversal ($G_t$, $B_t$) admittances are obtained. Then, the transmission line parameters are determined by expressions (4) and (5).

### *E. Method 5: currents balance method with two sets of measured values*

This method applies values from two sets of measured parameters.

Passive parameters of the transmission line are found with the help of expressions (4) and (5).

$$\begin{cases} I_{2a}^{(1)} = -U_2^{(1)}G_t + (U_2^{(1)}\cos\delta_2 - U_2^{(1)})\cdot G_{12} - \\ -U_2^{(1)}\sin\delta_2^{(1)}B_{12} \\ I_{2r}^{(1)} = U_2^{(1)}\sin\delta_2^{(1)}G_{12} + U_2^{(1)}B_t + \\ +(U_2^{(1)}\cos\delta_2^{(1)} - U_2^{(1)})\cdot B_{12} \\ I_{2a}^{(2)} = -U_2^{(2)}G_t + (U_1^{(2)}\cos\delta_2^{(2)} - U_2^{(2)})\cdot G_{12} - \\ -U_1^{(2)}\sin\delta_2^{(2)}B_{12} \\ I_{2r}^{(2)} = U_1^{(2)}\sin\delta_2^{(2)}G_{12} + U_2^{(2)}B_t + \\ +(U_1^{(2)}\cos\delta_2^{(2)} - U_2^{(2)})\cdot B_{12} \end{cases} \quad (8)$$

### *F. Method 6: quadripole coefficients*

Due to the fact that transmission line is represented as passive quadripole ($\underline{A} = \underline{D}$), there are obtained coefficients from one set of measured values.

$$\underline{A} = \frac{\underline{U_1}\cdot\underline{I_1} + \underline{U_2}\cdot\underline{I_2}}{\underline{I_2}\cdot\underline{U_1} + \underline{U_2}\cdot\underline{I_1}}. \quad (9)$$

$$\underline{B} = \frac{\underline{U_1}^2 - \underline{U_2}^2}{\underline{I_2}\cdot\underline{U_1} + \underline{I_1}\cdot\underline{U_2}}. \quad (10)$$

$$\underline{C} = \frac{\underline{I_1}^2 - \underline{I_2}^2}{\underline{I_2}\cdot\underline{U_1} + \underline{I_1}\cdot\underline{U_2}}. \quad (11)$$

So, the transmission line parameters are determined from the expressions:

$$\underline{Z}_{12} = \underline{B}. \quad (12)$$

$$\underline{Y} = \frac{2(\underline{A} - 1)}{\underline{B}}. \quad (13)$$

In order to compare the results of the proposed methods with the passive parameters obtained from catalogue data it is necessary to evaluate the measurement errors which appear during parameter identification. There are known random and systemic measurement errors. The random errors as a rule are not considerable, and the nature of their appearance cannot be predicted. Instead, the systemic errors are caused by instrumental current and voltage transformers, has permanent nature. Development of Smart Grid networks and digital substations leads to the replacement of analogue measuring systems (CT and VT) with digital ones, combined in a WAMS type system. In such a system, PMUs are connected to optical current and voltage transformers (OCT, OVT) [7]. The main advantages of optical transformers are high accuracy class (0.2, 0.2s) and high resistance to weather conditions. Thus in this paper there was analyzed the influence of measurement errors upon the results of parameter identification methods for the range of errors 0.04-0.2%.

## IV. CASE STUDIES

In this section there are represented some case studies to demonstrate accuracy of the obtained results and the effectiveness of proposed methods. The calculations were performed with the help of software complex RastrWin, which ensured the measured values of currents and voltages at both ends of transmission line. For verifying the accuracy of results obtained by the above proposed methods it was used the equivalent scheme of real power line Chishinau-Strasheni 330 kV with the following parameters: conductor 2xACO-300/39, pylon’s type – П-330-2б length 41 km.

The parameters calculated from catalogue data of studied line are:

$$R = 2.214\ Ohms,\ X = 13.079\ Ohms,$$

$$G = 1.242\ \mu Sm,\ B = 141.04\ \mu Sm.$$

There are obtained the results of high accuracy, when transmission line parameters are calculated in accordance with the formula shown in the section “Short methods description”. The percent relative errors are shown in the TABLE I.

TABLE I.

RELATIVE ERROR OF THE RESULTS OBTAINED BY THE METHODS M1-M6

| **Method** | **Realtive error of** | | | |
|---|---|---|---|---|
| | $\varepsilon_R$, % | $\varepsilon_X$, % | $\varepsilon_G$, % | $\varepsilon_B$, % |
| M1 | 0.017 | 0.002 | 0.201 | 0.106 |
| M2 | 0.017 | 0.002 | 0.193 | 0.099 |
| M3 | 0.001 | 0.003 | 0.193 | 0.071 |
| M4 | 0.017 | 0.002 | 0.193 | 0.099 |
| M5 | 0.001 | 0.003 | 0.193 | 0.071 |
| M6 | 0.017 | 0.002 | 0.201 | 0.106 |

TABLE II shows the percentage change in relative error versus measurement uncertainty.

TABLE II.

RELATIVE ERRORS OF THE RESULTS UPON THE INFLUENCE OF THE MEASUREMENT ERRORS

| **Method** | | **Δε%** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *+0,04* | *+0,1* | *+0,16* | *+0,2* | *-0,04* | *-0,1* | *-0,16* | *-0,2* |
| **M1** | *R* | 2,98 | 7,44 | 11,89 | 14,87 | 2,98 | 7,44 | 11,91 | 14,89 |
| | *X* | 1,01 | 2,52 | 4,04 | 5,06 | 1,01 | 2,52 | 4,03 | 5,03 |
| | *G* | 0,07 | 0,18 | 0,29 | 0,36 | 0,07 | 0,18 | 0,29 | 0,36 |
| | *B* | 0,01 | 0,04 | 0,06 | 0,07 | 0,01 | 0,04 | 0,06 | 0,07 |
| **M2** | *R* | 3,11 | 7,79 | 12,48 | 15,61 | 3,11 | 7,76 | 12,4 | 15,48 |
| | *X* | 1,05 | 2,64 | 4,23 | 5,29 | 1,05 | 2,63 | 4,2 | 5,25 |
| | *G* | 0,82 | 2,06 | 3,29 | 4,11 | 0,83 | 2,07 | 3,31 | 4,14 |
| | *B* | 1,36 | 3,39 | 5,42 | 6,77 | 1,37 | 3,41 | 5,46 | 6,83 |
| **M3** | *R* | 3,2 | 7,99 | 12,76 | 15,94 | 3,2 | 8,02 | 12,85 | 16,07 |
| | *X* | 1,05 | 2,63 | 4,21 | 5,27 | 1,05 | 2,61 | 4,18 | 5,22 |
| | *G* | 0,84 | 2,11 | 3,36 | 4,19 | 0,84 | 2,12 | 3,41 | 4,28 |
| | *B* | 1,33 | 3,34 | 5,34 | 6,68 | 1,33 | 3,34 | 5,34 | 6,68 |
| **M4** | *R* | 3,15 | 7,88 | 12,62 | 15,78 | 3,15 | 7,87 | 12,58 | 15,71 |
| | *X* | 1,01 | 2,54 | 4,06 | 5,08 | 1,01 | 2,53 | 4,05 | 5,06 |
| | *G* | 0,86 | 2,15 | 3,45 | 4,31 | 0,87 | 2,16 | 3,46 | 4,33 |
| | *B* | 1,40 | 3,49 | 5,59 | 6,98 | 1,40 | 3,51 | 5,61 | 7,02 |
| **M5** | *R* | 3,24 | 8,08 | 12,90 | 16,11 | 3,24 | 8,13 | 13,03 | 16,31 |
| | *X* | 1,01 | 2,52 | 4,04 | 5,06 | 1,01 | 2,52 | 4,02 | 5,03 |
| | *G* | 0,88 | 2,21 | 3,52 | 4,40 | 0,88 | 2,22 | 3,57 | 4,46 |
| | *B* | 1,38 | 3,44 | 5,51 | 6,89 | 1,38 | 3,43 | 5,49 | 6,87 |
| **M6** | *R* | 2,98 | 7,44 | 11,89 | 14,87 | 2,98 | 7,44 | 11,91 | 14,89 |
| | *X* | 1,01 | 2,52 | 4,04 | 5,06 | 1,01 | 2,52 | 4,03 | 5,03 |
| | *G* | 0,07 | 0,18 | 0,29 | 0,36 | 0,07 | 0,18 | 0,29 | 0,36 |
| | *B* | 0,01 | 0,04 | 0,06 | 0,07 | 0,01 | 0,04 | 0,06 | 0,07 |

Note: relative errors are calculated in relation to the initial value of the result for each method

In order to compensate errors from current and voltage transformers it is necessary to introduce into the methods of parameter identification the error compensation factor.

## V. CONCLUSIONS

This paper demonstrates the classification of the methods of parameter identification for transmission lines based on synchronized measurements obtained in the operation mode. There were represented the most reliable methods with high accuracy results. Although all methods ensure the percent relative errors less than 1%, methods based on the powers and currents balances are more accurate both in impedance and admittance results of transmission line. Analysis of the change in the calculation results under the influence of the measuring error shows that current and voltage transformers errors can affect considerably the results of calculation. For all methods the active resistance is the most sensitive parameter to measurement errors. The most accurate results are obtained for line admittance when the method of quadripole is used. For the future development and application of the proposed methods it is necessary to introduce in the calculations the compensation factor of measurement error.

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