E3S Web of Conferences **216**, 01042 (2020) https://doi.org/10.1051/e3sconf/202021601042
RSES 2020

For the construction of subsystem for power line diagnostic states of distribution networks as a part of AMRCS

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Abstract. At present, in order to automate and informative processes in distribution zones (DZ) with a voltage of 0.4 kV, new technologies have found wide application in the form of automated meter reading and control system (AMRCS). However, as part of these information systems, there are no technologies focused on solving diagnostic problems. The report proposes methodological and algorithmic foundations for constructing a subsystem for diagnosing the states of wires of the main lines of DZ. Diagnostic criteria are formulated based on the assessment of the level of their run-out. The research results are aimed at improving the existing AMRCS and increasing the reliability of distribution networks.

1 Introduction

At present, automated meter reading and control system (AMRCS) [1] are being actively implemented for the purpose of comprehensive automation of 0.4 kV electrical distribution networks (DZ), the hierarchy of which mainly consists of two levels. The structure of the lower level includes a group of meters (Сч) installed at network customers' site and a data concentrator (DC), which is built on the basis of a microprocessor controller and installed in a transformer substation.

The concentrator remotely collects data from the meters in an automatic mode, stores them and, after preliminary processing, transfers the required data to the top-level central computer located in the supervisory control centre. Data exchange between the structural elements of the automated system is carried out via communication channels. The main function of traditional AMRCS is the automation of commercial metering of electricity. At the same time, in distribution networks, the most important task is to automate the processes of diagnosing the states of its functional elements [2-5]. At the same time, part of the problem is associated with diagnostics of the states of phase and neutral wires of a three-phase distribution network in conditions of asymmetry of currents and voltages [6-9]. The analysis shows that the formalization and algorithmization of this problem requires the development of an appropriate mathematical model and a method for identifying the parameters of the electronic equipment, such as the resistance of interpersonal sections (IS), in real time. As you know, during the operation of radio electronic devices, these parameters change in time randomly, depending on the state of the external environment, which leads to certain difficulties in the development of models of physical processes in radio electronic devices and algorithms for parametric identification. The known methods of parametric identification [10-13] are not sufficiently adapted for their application in real time. One of the possible approaches in this direction is the problem of identifying the parameters of distribution networks based on numerical methods [14-16]. The report proposes algorithmic foundations for constructing a subsystem for diagnosing the states of wires of distribution networks as part of the AMRCS. In this case, the method described in [17] is used to identify the current parameters (resistances) of the interpersonal sections (IS) of DZ.

2 Problem statement

As an object four-wire DZ of 0.4 kV is considered, the settlement scheme of which is shown in fig. 1.

Designations make the following sense: k, ν - the index variables designating respectively number of phases A, B, C $(k = \overline{1.3})$and electric outlines of network $(\nu = \overline{1, n})$; $\tilde{E}_{0k} - EMF$ k- phase; $\tilde{U}_{0k}$, $\tilde{I}_{0k} = \tilde{\imath}_{1k}$ $-$instantaneous sinusoidal voltages and currents respectively on inputs of the corresponding phases$\tilde{I}_{\nu k}$, $\tilde{U}_{\nu k}, Z_{\nu k}-$ sinusoidal instantaneous current, voltage and resistance of loading (electro receiver) with coordinate (ν, k); $\tilde{\imath}_{\nu k}$, $z_{\nu k}-$ an instantaneous current and complex resistance of ν interpersonal section (IS) k $-$phases; $\tilde{u}_{\nu k}$, $\tilde{u}_{\nu}-$ voltage respectively on ν- of IS k- phase and neutral wire; $\tilde{J}_{\nu}, z_{\nu 0}-$ an instantaneous current and complex resistance ν- section of a neutral wire.

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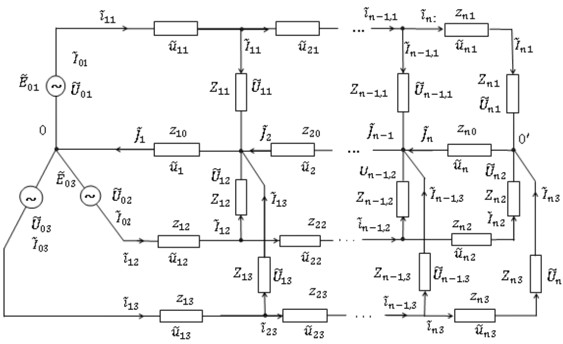

Fig. 1. Settlement scheme of three-phase network

It is further assumed that the following conditions are met:

1) the three-phase network is a linear system;

2) the system uses technical means to suppress the higher harmonic components of currents and voltages in the network;

3) from electricity meters ($Сч_{\nu k}$) installed at network subscribers and in a transformer substation, to the AMRCS database via communication channels at discrete times $t \in [t_\xi, t_{\xi+1}]$ with a sampling step $\Delta t_\xi = t_{\xi+1} - t_\xi$ $(\xi = 1,2,\dots)$ the following data is received:

effective values of currents $I_{\nu k}$ and voltages $U_{\nu k}$ at the phase inputs and network loads;

power factors $F_{\nu k} = cos\varphi_{\nu k}$,, determined by phase shifts $\varphi_{\nu k}$ between the corresponding voltages $\widetilde{U}_{\nu k}$ and currents $\tilde{I}_{\nu k}$ $(k = \overline{1,3},\ \nu = \overline{0,n})$

The task is to determine the diagnostic algorithm and the structure of the subsystem for diagnosing the states of IS of the distribution network as part of udes the following main stages:

Identification of IS parameters (resistances).

Formulation of the diagnostic criterion.

Algorithmization of solving the diagnostic problem.

3 Identification of the MAU parameters

The basic data for the solution of the formulated task in the form of the following matrixes and vectors are provided below:

$$I = \begin{bmatrix} I_{11} & I_{21} & \cdots & I_{n1} \\ I_{12} & I_{22} & \cdots & I_{n2} \\ I_{13} & I_{23} & \cdots & I_{n3} \end{bmatrix}; U = \begin{bmatrix} U_{11} & U_{21} & \cdots & U_{n1} \\ U_{12} & U_{22} & \cdots & U_{n2} \\ U_{13} & U_{23} & \cdots & I_{n3} \end{bmatrix};$$

$$F = \begin{bmatrix} F_{11} & F_{21} & \cdots & F_{n1} \\ F_{21} & F_{22} & \cdots & F_{n2} \\ F_{13} & F_{23} & \cdots & F_{n3} \end{bmatrix};$$

$$I_0 = [I_{01},\ I_{02},\ I_{03}]; \quad U_0 = [U_{01},\ U_{02},\ U_{03}];$$

$$F_o = [F_{01},\ F_{02},\ F_{03}].$$

As is known, in traditional AMRCS, interpersonal complex currents $i_{\nu k}, \dot{J}_\nu$and voltages $\dot{u}_{\nu k}$, $\dot{u}_\nu$are not identified and controlled. At the same time, AMRCS has the ability to determine them from data from the system's electricity meters, which allows solving a number of important functional tasks, such as identifying uncontrolled electricity consumption [18-20] and balancing the distribution network [8, 21-23]. In this case, the instantaneous sinusoidal currents $\tilde{I}_{\nu k}$, voltages $\widetilde{U}_{\nu k}$on the corresponding loads and their resistance $Z_{\nu k}$ in the steady state can be represented in a complex form [24]:

$$\dot{I}_{\nu k} = I^{e}_{\nu k} + jI^{M}_{\nu k} = I_{\nu k}e^{j(\beta_k + \alpha_{\nu k})}, \quad (1)$$

$$\dot{U}_{\nu k} = U^{e}_{\nu k} + jU^{M}_{\nu k} = U_{\nu k}e^{j(\beta_k + \psi_{\nu k})},$$

$$Z_{\nu k} = Z^{e}_{\nu k} + jZ^{M}_{\nu k} = \bar{Z}_{\nu k}e^{j\varphi_{\nu k}},\ \nu = \overline{1,n},\quad k = \overline{1,3}, (2)$$

where "B" and "M" characters designate material and imaginary parts of the corresponding complex variables; $I_{\nu k},\ U_{\nu k},\ \bar{Z}_{\nu k}$modules of these variables. At the same time

$$\varphi_{\nu k} = \psi_{\nu k} - \alpha_{\nu k}, \qquad \beta_k = 2(k-1)\pi/3,$$

where $\alpha_{\nu k}$, $\psi_{\nu k}$– increments of phase shifts concerning their nominal values $\beta_k$caused by asymmetry of currents and voltage in network. In case the model of loadings in the set mode in the form (1) and (2) interpersonal currents is constructed and voltage can be evaluated on the basis of the known laws of electrical equipment [24] (fig. 1), i.e.:

$$i_{\nu k} = \sum_{l=\nu}^{n} \dot{I}_{lk} = \sum_{l=\nu}^{n} (I^{e}_{lk} + jI^{M}_{lk}) = l_{\nu k}e^{j(\beta_k + \tilde{\alpha}_{\nu k})}, (3)$$

$$\dot{J}_\nu = i_{\nu 1} + i_{\nu 2} + i_{\nu 3}, \dot{u}_\nu = \dot{J}_\nu z_\nu,$$

$$\nu = \overline{1,n}, \quad k = \overline{1,3}, \qquad (4)$$

$l_{\nu k}$, $\tilde{\alpha}_{\nu k}$ –effective value and increment of phase shift of interpersonal complex current $of i_{\nu k}$ respectively.

Further, we will assume that on the basis of the method proposed in [17], a model of the distribution network was built in a complex form (1) - (4) and on its basis the current values of the resistances of the interpersonal sections of the phase wires $z_{\nu k}$and the neutral wire $z_{\nu 0}$of the three-phase network were identified.

4 Criterion of diagnostics

Let us introduce the vectors Z_0, Z_1, Z_2, Z_3, composed of the current values of the parameters of the interpersonal sections of the phase and neutral wires at the time moment $t \in t\xi$:

$$Z_0 = [z_{10},\ z_{20}, \dots,\ z_{n0}],$$

$$Z_1 = [z_{11},\ z_{21}, \dots,\ z_{n1}],$$

$$Z_2 = [z_{12},\ z_{22}, \dots,\ z_{n2}],$$

$$Z_3 = [z_{13},\ z_{23}, \dots,\ z_{n3}].$$

On the basis of the specified vectors we make Z matrix:

$$Z = \begin{bmatrix} Z_0 \\ Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} = \begin{bmatrix} z_{10} & z_{20} & \cdots & z_{n0} \\ z_{11} & z_{21} & \cdots & z_{n1} \\ z_{12} & z_{22} & \cdots & z_{n2} \\ z_{13} & z_{23} & \cdots & z_{n3} \end{bmatrix}.$$

It can be noted that the elements of the matrix Z are found as a result of solving the problem of identifying the parameters of the distribution network.

Further, we will assume that, according to the passport data, the basic matrix Z is preliminarily determined and recorded in the concentrator database (DC), composed, respectively, of the nominal values of the network parameters $z^*_{\nu\rho}$and$z^*_{\nu 0}$:

$$Z^* = \begin{bmatrix} Z^*_0 \\ Z^*_1 \\ Z^*_2 \\ Z^*_3 \end{bmatrix} = \begin{bmatrix} z^*_{10} & z^*_{20} & \dots & z^*_{n0} \\ z^*_{11} & z^*_{21} & \dots & z^*_{n1} \\ z^*_{12} & z^*_{22} & \dots & z^*_{n2} \\ z^*_{13} & z^*_{23} & \dots & z^*_{n3} \end{bmatrix}.$$

To diagnose the states of the interpersonal sections of the backbone line, the identification data of the current parameters of DZ are used, represented by the matrix Z and the components of the base matrix Z^*

In the general case, to assess the level of run-out of power lines of interpersonal network sections, you can proceed as follows. First, the relative deviations of the current values of the network parameters from their nominal values are calculated: $\Delta z_{\nu\rho} = (|z_{\nu\rho} - z^*_{\nu\rho}|)/z^*_{\nu\rho}, \ \nu = \overline{1,n}, \ \rho = \overline{0,3},$ (5)
where ρ – the index variable which designates numbers zero and phase wires of three-phase network.

It is known that technical losses of the electric power in the respective sections of network increase if the found estimates $\Delta z_{\nu\rho}$exceed their critical values. Therefore, the criterion for the normal state of DZ power lines can be taken to meet the following conditions:

$$\Delta z_{\nu\rho} \le \Delta z^{max}_{\nu\rho}, \nu = \overline{1,n}, \quad \rho = \overline{0,3} \quad (6)$$

where $\Delta z^{max}_{\nu\rho}$ –the maximum allowed relative levels of run-out of the respective lines of power supply.

5 Algorithmization of solving the diagnostic problem

In order to algorithmize the solution of the problem of diagnosing the states of wires of interpersonal sections of the main line of the distribution network, we introduce into consideration the matrix $D = \{d_{\nu\rho}\}_{n\times 4}$, which has the same dimension as the matrix Z, i.e. $\rho = \overline{0,3}\nu = \overline{1,n}$. In this case, the first line corresponds to the states of the interpersonal sections (IS) of the neutral (zero) wire, and the remaining three lines correspond to the states of IS of the three phase wires of the network. The components of this matrix $d_{\nu\rho}$are determined by the following rule:

$$d_{\nu\rho} = \begin{cases} 0, if \Delta z_{\nu\rho} \le \Delta z^*_{\nu\rho}, \\ 1, \ if \Delta z_{\nu\rho} > \Delta z^*_{\nu\rho}, \end{cases} \rho = \overline{0,3}, \quad \nu = \overline{1,n}.$$

Forming of a matrix D is carried out on the basis of criteria conditions (6), i.e. if the status of the corresponding wire with coordinate (ν, ρ) meets the set requirements, then $d_{\nu\rho} = 0$,, otherwise $d_{\nu\rho} = 1$.

The algorithm of diagnostics of IS statuses of three-phase network received on the basis of criteria conditions (6) is given in fig. 2.

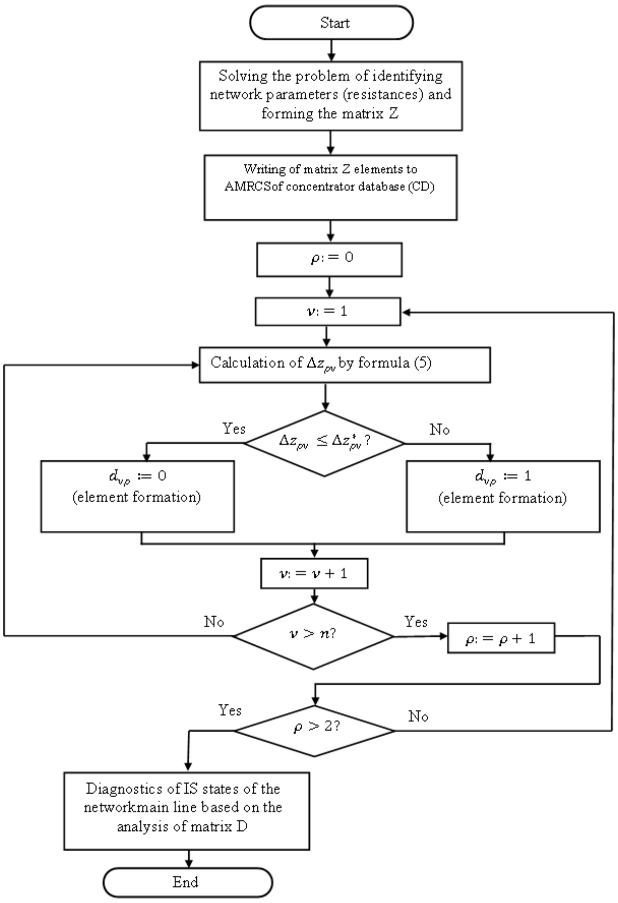

Fig. 2. Algorithm of diagnostics of statuses of interpersonal sections of a backbone line of three-phase network

6 Diagnostic subsystem software structure

The generalized structure of the software package of the diagnostic subsystem is shown in Fig. 3, which includes the following software modules:
1. The module for generating initial data (MGID).
2. Module for identification of current parameters (resistances) of IS network (MIP).
3. The module for the formation of basic values of parameters (MFBP).
4. Diagnostic module (DM).

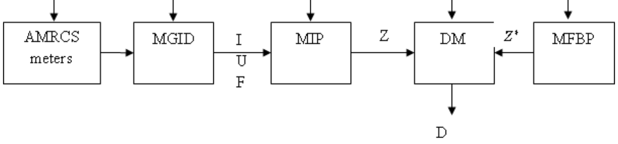

Fig. 3 The structure of subsystem software complex for diagnostics of the IS distribution network wires state

In the process of distribution network functioning, by data extraction from AMRCS meters, the corresponding data enter the concentrator database (DC). On their basis, the MGID software module forms a matrix I, U, F and vectors I_0, U_0, F_0.

Further, these data are sent to the MIP module, which in turn identifies the matrix Z.

In the software module of the MFBP, the elements of the base matrix Z^* are calculated. Further, on the basis of the matrix components Z and Z^* in the DM software module, based on criterion (6) and the analysis of the matrix D, diagnostics of the states of IS wires of the distribution network is carried out.

7 Conclusion

Algorithmic foundations for constructing a subsystem for diagnosing the states of phase and neutral wires of a three-phase distribution network with a voltage of 0.4 kV, functioning under conditions of asymmetry of currents and voltages, are proposed. The initial data are the measurement data of AMRCS received from a group of meters installed at sites of customers' network and in a transformer substation. The computational procedure of the method is based on the idea of comparing the current values of the resistances (parameters) of the interpersonal network sections with their basic values obtained on the basis of the passport data of the wires of the main line, which are preliminarily determined and recorded in the database of the automated system. For the purpose of diagnostics, a criterion has been proposed that determines the critical level of wear of the distribution network wires. On its basis, an algorithm for diagnosing the states of wires of a three-phase distribution network has been developed, which is focused on creating a diagnostic subsystem as part of a traditional AMRCS, which allows distribution companies to take prompt measures to maintain electrical wires of the distribution network in the required state.

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