IMPROVE ACCURACY OF LINE SECTIONS PARAMETERS OF MEDIUM VOLTAGE NETWORK ACCORDING SYNCHRONOUS MEASUREMENT

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1. INTRODUCTION

The aim of this work was to investigate the errors in determining the parameters of the real parts of lines 10 kV feeder according synchronized measurements from the experimental IEDs installed in the center of the power feeder and buses 0.4 kV transformer substations (TS) fed by them.

Section 2 contains a description of the technique developed by the authors for determining the active and reactive resistances of sections of the feeder main line from vector measurements of currents and voltages. Descriptions of the investigated feeder and measuring systems are given in Section 3. The results of calculations and their analysis are presented in Section 4. Section 5 contains conclusions and discussion of directions for improving the proposed method.

2. PROPOSED METHODOLOGY

The methodology for identifying the parameters of individual ultra-high voltage lines, according to PMU data, established at the ends of the line, has been worked out in sufficient detail in the works of many authors. In most works, a preliminary transition from phase measurements to a direct sequence of currents and voltages is made, on the basis of which the parameters of the P-shaped circuit replacement circuit for the direct sequence of the fundamental harmonic of the network frequency are calculated.

If transverse conductances are not taken into account (this assumption is valid for the sections of overhead lines of the distribution network), the calculation of the longitudinal resistance of the replacement circuit i-j of the line segment for the direct sequence of the fundamental harmonic is performed in accordance with Ohm's law as follows:

$$\underline{Z}_{ij} = \frac{\underline{U}_i - \underline{U}_j}{\sqrt{3}\underline{I}_{ij}} \tag{1}$$

where $\underline{U}_i, \underline{U}_j$ – the stress vector at the beginning and end of the i-j section of the line;

$\underline{I}_{ij}$ – current vector in the i-j portion of the line.

The calculation of line section resistances in accordance with (1) can be performed independently for each time point over which phasor measurements are available.

In the presence of synchronized measurements at the ends of the sections of the lines of medium voltage distribution networks, this methodology can also be applied. It should be expected that, due to small voltage drops on the sections of the medium voltage distribution network lines, the error in determining the resistance in this way can be significantly higher compared to the ultra-high voltage lines. To reduce it, it is necessary to compensate for the systematic errors of the measuring systems used.

An additional problem in solving the problem under consideration is that in many cases the medium voltage feeder has a branched structure and measurements are made only at the power center and on low-voltage buses of the lowering transformer substations. With the main circuit of the feeder and known parameters of power transformers, the measured currents and voltages on the LV side of the transformers can be brought to the high voltage winding and then used to calculate the parameters of the trunk sections. An important factor in such a reduction is the accuracy of setting the transformer ratio $n_т$. The conventional method for determining $n_т$ through the voltage of the control tapping U_{tap} and the rated voltage of the winding U_{lv} leads to some systematic error associated with the difficulty of accurately performing the relation

$$W_{tap}/W_{lv}=U_{tap}/U_{lv}, \tag{2}$$

where W_{tap}, W_{lv} – number of turns in the upper and lower voltage windings at the current position of the control tap of the transformer.

The proposed methodology implies the simultaneous identification of parameters of line sections and systematic errors in measuring systems (IED, VT). The technique is based on solving the optimization problem of minimizing the root-mean-square (RMS) deviation of the inductive resistance of a line section in a given time interval. The independent variables are the optimization of systematic errors in the VT at the center of power supply (CPS) feeder and IEDs.

Mathematically, the problem of simultaneous identification of line parameters and determination of correction coefficients compensating for systematic errors is formulated as follows.

It is necessary to minimize the objective function F

$$F(n_т, \delta\theta, \delta t) = \sigma_X \to 0, \tag{3}$$

where $n_т$ – the transformer ratio of a 10 / 0.4 kV step-down transformer mounted on a tap of a feeder fed from the end of a section of the main line whose parameters are identified;

$\delta\theta$ – a correction factor that takes into account the systematic angular errors of the voltage transformer in the CPS and IEDs;

δt – a correction factor that takes into account the effect of temperature on the systematic error in measuring the voltage in the feeder CPS;

σ_X – the RMS deviation of the inductive resistance of the line segment, equal to:

$$\sigma_X = \sqrt{\frac{\sum_{i=1}^{N_M}(X_{i\text{calc}} - M_X)^2}{N_M - 1}}, \tag{4}$$

where M_X – the mathematical expectation of the inductive resistance of the line segment, equal to:

$$M_X = \frac{\sum_{i=1}^{N_M} X_{i\text{calc}}}{N_M}, \tag{5}$$

where N_M – number of points in the time interval for which synchronized measurements are performed.

The choice of the objective function of the inductive resistance is due to the fact that the active resistance is subject to more abrupt changes due to the influence of temperature.

The calculation of the active and inductive resistances of the i-j section of the line for the direct sequence of the fundamental harmonic was performed in accordance with expression (1).

The voltage vector at the beginning of the head section of the feeder was calculated taking into account the correction factors $\delta\theta$ and δt:

$$\underline{U}_{MS,M} = \left|\underline{U}_{MS,M}\right| \cdot (1 + \delta t \cdot t) \cdot e^{j(\varphi_{MS,M} + \delta\theta)}, \tag{6}$$

where $U_{MS,M}$, $\varphi_{MS,M}$ – measured values of the module and the angle of the voltage vector in the CPS;

t – air temperature, taken from the weather server for the area of passage of the feeder.

Calculation of voltage vectors at the end of sections of the feeder main was performed in accordance with known values of the parameters of transformers and taps according to the IED established on 0.4 kV busbars of the transformer substation in accordance with the laws of Ohm and Kirchhoff. As a design scheme of the transformer taken T-shaped circuit comprising an ideal transformer with transformation ratio $n_т$.

To solve the optimization problem in this formulation, we used the method of coordinate descent in this paper.

After performing the optimization calculation and determining the resistances of the head section of the feeder, the stress vectors for each measurement point at the end of this section were calculated. The current vector for the second section of the main was determined in accordance with the first Kirchhoff law based on the current of the head section of the feeder and the design value of the winding current of the HV transformer.

Calculation of the resistance of the second section of the highway was carried out according to a similar procedure.

3. DESCRIPTION OF THE SCHEME OF A SEARCHED FEDER AND MEASURING SYSTEMS

The field measurements have been fulfilled with an operating 10 kV feeder owned by the municipal networks of the town of Mikhailovsky, Stavropol Territory, Russia. The single-line feeder circuit is shown in Figure 1.

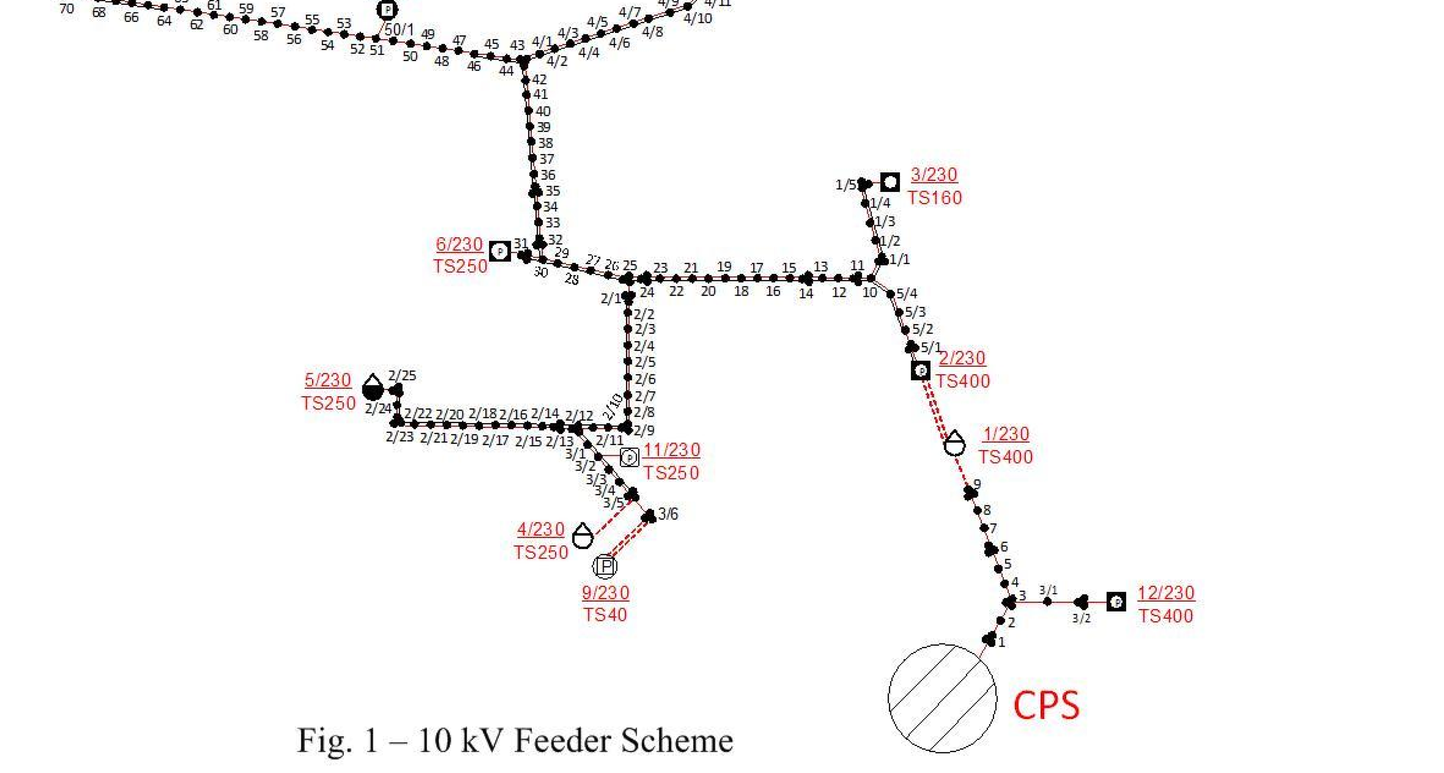

Fig. 1 – 10 kV Feeder Scheme

Most of the feeder lines are made in air design by aluminum and steel-aluminum wires. An exception is the portion between TS1 and TS2, and tap to TS2 and TS9, cable lines made with aluminum conductors (in the scheme shown in phantom). The feeder supplies 12 10.0/0.4 kV single-transformer substations under the normal mode. All transformer substations except TS-12 are fitted with Y/Yн-12 winding connection circuit. The TS-12 transformer features Δ/Yн-11 circuit. The power feeder is supplied by 10 kV 35/10 kV buses. For the research, experimental three-phase IEDs manufactured by Energomera and installed at all 12 TS and in CPS were used.

The measuring module of the IED is based on ADS131E08 microcircuit, incorporating a 24-bit sigma-delta ADC produced by Texas Instruments. A GPS/GLONASS module receiving is used to synchronize measurements and AD9548 the phase-locked loop chip by Analog Devices.

The samples of the phase voltages and currents being measured in the range of 20 ms (corresponds to one period of the rated frequency of the network of 50 Hz) with a preset schedule (with interval Ti = 600 seconds) have been transmitted to the AMI data collection server via GSM modems.

4. RESULTS

Identification of the parameters was carried out for the two main sections of the investigated feeder. The choice of these sections was due to the fact that the transformers on TS12 and TS1 connected to these sections operated in a mode close to idling.

As a starting point, measurements were made of the current and voltage vectors from the IED installed in the CPS and on TS12 and TS1 for the period from November 11 to 27 2016.

The results of identifying the parameters of the main sections of the line and the systematic errors of the measuring systems are given in the table 6. The calculated values of the correction factors in the table 7.

Table 6. The results of identifying the parameters of the main sections of the line and the systematic errors of the measuring systems

Section Number	Calculated Values			Measured Values	Absolute error			Relative error		
	R, Ω	X, Ω	l, m	l, m	R, Ω	X, Ω	l, m	R, %	X, %	l, %
CPS-2	0,071	0,031	84,8	68,7	0,029	0,06	16,1	73	23	23
2-4	0,122	0,084	229,7	222,7	-0,011	0,002	7	-9,0	2,4	3,1

Table 7. The calculated values of the correction factors

Section Number	The calculated values of the correction factors		Measured Values
	$\delta\theta$, degree	δt, kV/?C	$n_т$, p.u.
CPS-2	-0,0100	0,000073	25,6875
2-4	-0,0011	0,000073	26,1444

As follows from the obtained results, the error in determining active resistances varies from -9% to 73%, inductive resistances from 2,4 to 23%, lengths of main sections of lines 3,1% to 23%.

5. CONCLUSIONS

1. A technique for identifying the parameters of the main sections of the lines of open medium-voltage networks is proposed, which will increase the accuracy of identification by compensating for the systematic errors of VT and IED.
2. Approbation of the technique using the example of two main sections of a real feeder of 10 kV has shown that the error in identifying active resistances is 73% and -9%, inductive resistances 23 and 2.4%, line sections - 23% and 3.1% respectively for the head section of the feeder 68.7 m long and the second section of the highway 222.7 m long.
3. To improve the accuracy of identifying the parameters of the sections of the lines, it is justified to select the modes with the maximum load of sections that can be provided in the Smart Grid conditions by reconfiguring the network. Research deserves particular attention to identifying the parameters of network elements in emergency modes.