Asymmetric power consumption in rural electric networks

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Abstract. Study of changes in quality indicators and an increase in additional losses of electrical energy in rural distribution networks of 0.38 kV in the village (Vishnyakovo, Irkutsk region). The measurements were carried out by a certified device “Resource-UF2M”, which records changes in the quality indicators of energy efficiency, but does not record additional losses of electrical energy associated with this changed quality. Therefore, based on the obtained measurement data, we used the developed computer program “Asymmetry” to calculate the required power quality indicators, as well as additional electrical energy losses caused by a change in these indicators. Based on the results of measurements and calculations, time diagrams were built, and an analysis was made of quality indicators and additional losses of electric energy in the existing 0.38 kV networks.

1. Introduction
In rural low-voltage electrical distribution networks, there is a significant deterioration in the quality of electrical energy, especially when it comes to indicators characterizing the asymmetry of a three-phase voltage system. There are a number of standards that regulate compliance with the quality criteria for electrical energy. It should be noted that the issues of improving the quality of electrical energy were little considered and were reduced to fixing changes in indicators and a number of recommendations, mainly related to the redistribution of electrical loads over the phases of a three-phase system. Now, in addition to this, we are considering the possibility of using special technical means that allow intelligently control changing indicators of energy quality in automatic mode, using the minimum power of balancing means. The purpose of this study is to conduct experimental studies of the quality and energy losses in operating electrical networks with a voltage of 0.38 kV, as well as to analyze the results of these studies. It is no secret that rural distribution electric networks of low (0.38 kV) voltage are most susceptible to changes in energy quality. And if the indicators associated with the non-sinusoidality of the three-phase voltage system for networks of this level are not sufficiently significant, the issues related to the asymmetry of the three-phase voltage system are more relevant. Therefore, we have defined the following as the research objectives:
• Conducting research on energy quality indicators in existing rural electrical networks.
• Calculation of the required coefficients and construction of timing diagrams.
• Analysis of changes in the corresponding indicators, as well as the accompanying additional losses of electrical energy.
• Recommendations for the use of measures to minimize the impact of the changed EE quality on the elements of the electrical network and the operation of other electrical consumers.

2. Research result
The studies were carried out in several districts of the Irkutsk region, in particular in the village Vishnyakovo, pos. Petropavlovsk, pos. Brewer of the Irkutsk region. The studies were conducted from August 17 to December 13, 2019. Therefore, we focused our attention on the asymmetry of the three-phase voltage system. The calculation of the required indicators of energy quality, as well as additional losses of power and electrical energy caused by changes in these indicators, was carried out using the program "Asymmetry" [1], based on the modular method proposed in [2].
We have carried out similar research at various times in various regions of our country and abroad [3-5].

We carried out measurements in accordance with the current Standard with GOST 308.4.4.30-2013. The sample of the weighted average values of the measured values was made during 1008 ten-minute intervals per week, in accordance with GOST-32144-2013.

In this article, we present the research results for the Vishnyakovo transformer substation No. 120203 10 / 0.4 kV. From the 0.4 kV buses of this substation there are 4 feeder power lines made with a 50mm² SIP wire. The total length of the power transmission line was 1.333 km. The specific active resistance of the transmission line is 0.641 Ohm / km. The load connected to these power lines is public utility consumers (mainly one- and two-family residential buildings).

Based on the measurements, we have built time diagrams of currents, voltages, as well as the coefficients of voltage unbalance in reverse and zero sequences and the power loss factor.

As can be seen from the analysis of measurement results (figure 1), the most loaded is phase "A", the least loaded is phase "B". In percentage terms, the currents flowing in the phases have the following values. The current in phase "C" is 77.68% (72.84A) of the value of the current flowing in phase "A" (93.77A). The current flowing in the least loaded phase "B" is 50.84% (47.67A) of the current of phase "A".

Analysis of the calculation results (figure 2) showed that the average value of the power loss factor (Kp) was 1.4. This means the following. The real losses of electrical energy due to the asymmetry of the phase currents are, on average, over the studied period of time:

\[ \Delta W = (I_A^2 + I_B^2 + I_C^2) r_0 l \cdot T \]  

where \( r_0 \)-specific active resistance of the phase conductor, Ohm/km; \( l \)-length of power distribution lines, km; \( T \)-experiment time, hours.
Therefore, the average power loss is 13988 Watt (13.988 kW). If the existing level of phase current unbalance remains unchanged throughout the year, then the electric loss will be: 122535 kW·h. In the case of complete balancing of the operating mode of rural electrical distribution network, the annual electrical losses will be: 87525 kW·h. Accordingly, the annual reduction in electrical losses will be: 35010 kW·h. Now, the cost of electricity for rural areas of the Irkutsk region is 1.17 rubles/kWh, the cost of energy saved for the year would be: 45708 rubles.

Analysis of changes in power quality indicators characterizing the asymmetry of the three-phase voltage system for the entire study period (7 days) showed that the change in the voltage unbalance coefficients in the reverse and zero sequences are within the permissible limits established by GOST 32144-2013 (figure 3, 4).
Figure 3. Dynamics of average values of voltages (phase – A, B, C) in lines (0.38 kV).

Figure 4. Dynamics of average values of currents

3. Conclusions
The conducted research of asymmetric operating modes of the 0.38 kV electrical distribution network showed the following:

- In this electrical network, the phase current asymmetry is significant.
- The most expedient technical means for balancing the operating modes in the studied electrical network is a special balancing device with automatic regulation of its parameters.
- The use of such a device will save 45708 rubles per year.
- The level of voltage unbalance on the 0.4 kV buses (quality indicators - coefficients of voltage unbalance in reverse and zero sequence) meets the requirements of the State Standard (GOST 32144-2013).
- It is possible to balance the operating modes of rural distribution networks and reduce the corresponding additional losses of electrical energy by using special balancing devices with minimal zero-sequence resistance and automatic power control [6-8].
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