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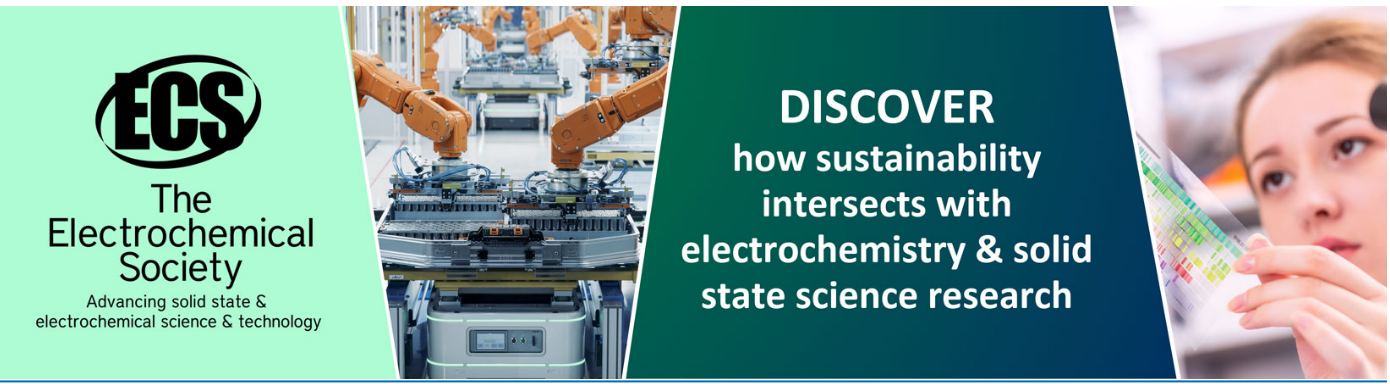

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Green technologies in rural electric powerindustry

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Abstract. The article examines the indicators of the quality of electric energy and additional power losses due to the asymmetry of the three-phase voltage system in rural distribution electric networks 0.38 kV. Violation the symmetrical mode operation of the electrical network causes a deterioration the power quality and can lead to fire-hazardous situations. The proposed method of using the means of balancing the modes of operation electric networks is considered as a scenario for the introduction of "green" technologies to improve the efficiency of electricity supply in rural areas. The connection of balancing devices (BD) and various types of three-phase symmetric and unbalanced loads, as well as their combinations are considered on the model of the electric network at various points of power consumption. The parameters of the electrical network and BD are modeled and calculated by the computer complex "Asymmetry-2". The programs for the *Matlab* graphic editor are compiled and diagrams of changes the indicators characterizing the quality and additional losses of electricity from the changing unbalanced load are constructed. A numerical analysis is carried out on the basis of the performed calculation and recommendations are given for determining the most appropriate place for connecting the BD in the electrical network.

1. Introduction

Grid construction in rural power supply systems does not fully correspond to the progressive development of electricity consumption. Over the past decade, the growth of electric power receivers (PR) in the household load of consumers has significantly outstripped the "safety margin" of the elements of electric networks, through which electricity is delivered to individual consumers in rural localities. The "safety margin" should be understood as the possibility of normal operation of all network elements, which does not allow them to wear out prematurely. Currently, in all aspects of ensuring the normal life of people and improving environmental safety, the dominant attention is paid to the development of "green technologies" (GT). These technologies are aimed at creating comfortable conditions for the existence of humanity in a favorable unity with the Nature of our planet. In this regard, there is a need for a detailed study of the operating modes of electric networks, as links of electric power systems, in order to introduce GT in the processes of production, transport and consumption of electric energy. A large number of publications are devoted to the analysis of changes the power quality in rural power supply systems [1; 3- 5]. To a greater extent, this is due with the unbalanced operating modes. Such modes lead to deterioration of the operation and failure of the PR in rural networks [6-15] and causes significant overheating of the main elements of the network, which often leads to fires in domestic and industrial premises [16]. Thus, the unbalanced operation modes of the networks, the premature failure of the elements of these networks, as well as the threat to the safety of people's lives are a kind of "triad", which is a cause-and-effect area that forms a number of tasks aimed at creating a GT in the electricity supply of rural areas.

The purpose of the article is to study the technical possibilities of using special balancing devices in 0.38 kV electrical networks, as one of the options for GT in rural power supply systems.

2. Materials and methods

The asymmetry of currents in the network, created by various types of unbalanced load, leads to additional power losses, characterized by a loss coefficient K_P [16]:

$$K_P = \Delta P_H / \Delta P_C = 1 + K_{2I}^2 + K_{0I}^2 (r_0 / r_1) \quad (1)$$

where: ΔP_H - power losses in the network under unbalanced conditions; ΔP_C - power losses in the network, caused by positive-sequence currents; K_{2I} - negative-sequence current unbalance factor; K_{0I} - zero-sequence current unbalance factor; r_0, r_1 – zero-sequence resistance and positive-sequence resistance, respective.

The conductor cross-section is selected by operating current and is checked for heating in order for this current not to exceed the admissible value for this cross-section. This means that the cross-section is selected with an assumption that factor K_P =1. At the same time, the cross-section is always selected disregarding the zero-sequence flows in the neutral conductor in the 0.38 kV network. Since the cross-section of neutral conductor is not larger (and sometimes even smaller) than the cross-section of phase conductor, the flowing three zero-sequence currents overheat the insulation which results in its melting and causes a single-phase short circuit. In the event that automatic circuit breaker in the main section of the network is selected inappropriately (i.e. it is not checked for operation sensitivity under minimum short circuit conditions), the protection device fails to operate in case of a short circuit in some remote part of the network. As a result, fires take place in both individual houses in rural populated settlements, cottage areas, urban flats, and in some agricultural and industrial premises [7-8].

The most effective means of balancing the operating modes of electrical networks is the use of special balancing devices (BD) with a minimum zero-sequence resistance and automatically controlled power [16-24]. Figure 1 shows the functional diagram of the mathematical model of the electrical network under study.

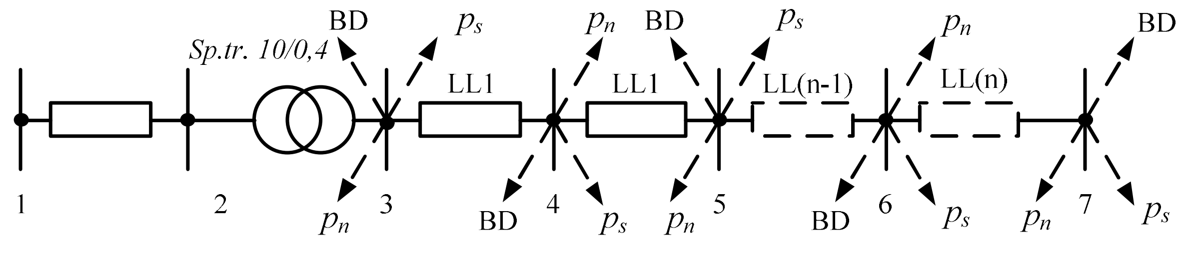

Figure 1. Mathematical model of the system.

The system includes the following elements: **1-2** - medium voltage overhead power line. The length of the 10 kV overhead line is adopted according to the standards of reliability of power supply and is equal to 16.7 km. The complex resistance of the positive and negative sequences of this line, made by the AC 35 wire, is reduced to a voltage of 0.4 kV and is equal to: $Z_{HV1} = Z_{HV2} = 0,0243 + j0,01 = 0,0263 e^{j22,37}$, *Ohms;* **2-3** - 10/0.4 kV power transformer with *"Y/Y-n"* winding connection scheme. The complex resistance of the positive, negative and zero sequences of the transformer depends on the rated power of the transformer. Consider the case when a transformer with a rated power of $S_{nom.} = 100$ *kVA* is used. For him, complex resistances positive and negative sequences are: $Z_{T1}=Z_{T2}=0,032+j0,065=0,072e^{j64,}$ *Ohms*, complex resistance of the zero sequences is $Z_{T0}=0,254+j0,582= 0,635e^{\ j66,4}$ *Ohms.*; **3** – 0, 4 kV transformer busbars; **3 - 7** – 0.38 kV line, 1 km long, made of self-supporting insulated wire SIP 1, with a cross section of 3x50+1x70 mm^2. The line is divided into 4 equal sections of 0.25 km each. The resistances of each section of the positive (negative) sequence are equal: $Z_1=Z_2 = 0,641+j0.0790 = 0.6458\ e^{\ j7.0295}$, *Ohms*; complex resistance of the zero sequences – $Z_0= 0,493 +j0.0685 = 0.4977e^{\ j7.914}$ *Ohms.* In each of the nodes: **4**, **5**, **6** and 7, a three-phase unbalanced load: p_a, p_b, p_c and a three-phase symmetric load p_s, are connected, whose value modules change in accordance with table 1.

Table 1. Changes the modules of three-phase unbalanced and symmetric loads.

p_a	$p_в$	p_c	p_s	$p_н = p_a + p_в + p_c$
0.0177	0.00425	0.0030	0.225	0.025
0.0355	0.00850	0.0060	0.200	0.050
0.0532	0.00850	0.0091	0.175	0.075
0.0709	0.01700	0.0121	0.150	0.100
0.0887	0.02125	0.0151	0.125	0.125
0.1064	0.02550	0.0181	0.100	0.150
0.1241	0.02980	0.0211	0.075	0.175
0.1419	0.04000	0.0241	0.050	0.200
0.1596	0.03830	0.0272	0.025	0.225
0.1773	0.04250	0.0302	0.000	0.250

It should be noted that the modules of p_a, p_b, p_c are the ratio of capacity of single-phase loads in phases to the average full rated power three-phase unbalanced load and module p_s – the ratio of active power symmetric load to its full capacity. The complexes of these values are given by using the arguments: $\varphi_a= \varphi_b= \varphi_c=25,24^0$; $\varphi_s=36.87^0$. $p_a + p_b + p_c =p_n$; $p_n + p_s =1$ - every time when the load are changes. Since the resistance of the negative sequence of a three-phase symmetric load (asynchronous motor) differs from the resistance of the positive sequence, a complex coefficient is used to determine it: $K_{2s}=0,17 + j0,24 = 0,0735e^{j54,689}$ [1]. To each of the nodes (4, 5, 6, 7), and on the transformer busbars also (node 3), a BD can be connected. The BD parameters are defined in accordance with [4] and equal: $Y_{BD1}= Y_{BD2} = 0,0791e^{j90}$; $Y_{BD0} = 0,475e^{j0}$.

3. Results and Discussion

The values of the power loss coefficient in each of the load nodes were obtained using the computer program "Asymmetry-2". The algorithm of this program is based on the method described in [5].

To compare the effect of BD on additional power losses, consider figure 2. The analysis of the diagrams (figure 2) showed the following. In the absence of SU in all load nodes, but with the inclusion of a three-phase symmetric load in them, the average value of the loss coefficient for the considered 1, 2, 3 and 4 nodes is, respectively:1.2231; 1.1706; 1.0996 and 1.1034. When the BD was turned on in the first load node, their values were distributed as follows: in the first node, the loss factor decreased by 18.3%, in the second – by 2%, in the third it increased by 0.016%, in the fourth – by 0.07%. If the BD is enabled in the second load node, then, compared to the option when the BD is not in the first node, the loss coefficient will remain unchanged; in the second node it will increase by 38.6%, in the third it will increase from 1.18%, in the fourth-by 0.21%. When enabling the BD in the third node: in the first node, the coefficient decreased by 2.56%; in the second case, the coefficient value did not change, in the third, its value increased by 29.95%, in the fourth-by 1.08%. If the database is enabled in the fourth node: in the first, second, and third nodes, the loss factor value does not change, and only in the fourth node, its value increases by 20.69%. On the other hand, the average value of the loss coefficient for all nodes of the electrical network without BD is 1.15. If the database is included in 2, 3 and 4 load nodes, the increase in the loss factor will be 4.15%, 6.04% and 4.67%, respectively. And only if the BD is enabled in the first load node, the loss factor is reduced by almost 2%. Figure 2 shows that the power loss factor increases markedly at the last points of load changes. This is due to the fact that as the power of the three-phase unbalanced load increases, the power of the symmetric load decreases accordingly. Let's build diagrams of loss coefficients that show the symmetric effect of a three-phase symmetric load (figure 3). Consider the following combinations: BD and p_s are absent; DB is enabled, p_s is absent; p_s is enabled, BD is absent, and BD and p_s are enabled in the node. In figure 3 shows diagrams of changes in the power loss factor for various combinations of BD and three-phase symmetric load. The analysis of the presented diagrams showed the following. The average value of the loss factor in the absence of both BD and p_s in the node is 1.9452. Its reduction occurs when: the node includes a BD and a p_s - on 34.42%; if the node has only a p_s - on 59.04% and when the node includes only one DB - on 63.03%. Thus, the inclusion of the BD in the load node significantly reduces the loss of electrical energy, even in the absence of a three-phase symmetric load.

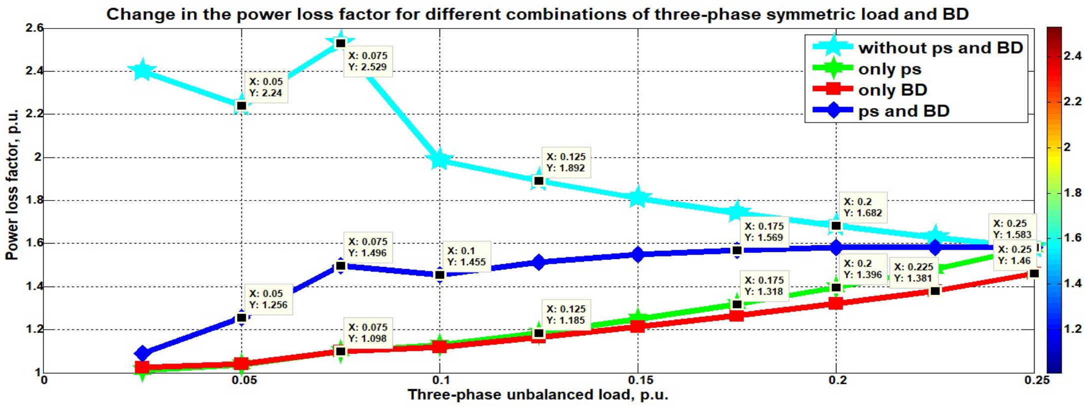

Figure 2. Change in the power loss factor when switching on the balancing device in different load nodes.

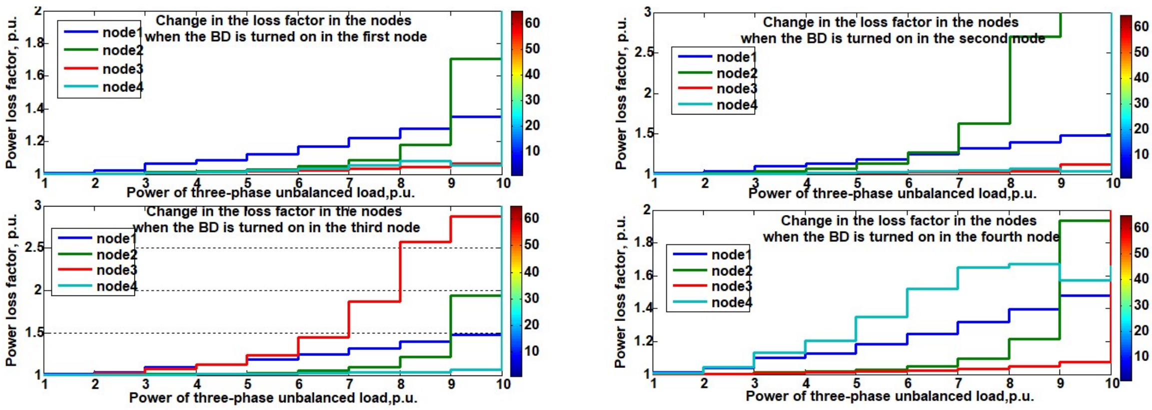

Figure 3. Change in the power loss factor for the following combinations BD and p_s.

4. Conclusion

- The balancing device, has a significant effect on reducing the power loss factor in the electrical network.
- The power loss factor in an electrical network with three-phase unbalanced and three-phase symmetric loads included in different nodes has the greatest reduction when the balancing device is connected to the load node closest to the buses of the transformer substation. This reduces additional heat loss and reduces the risk of fires.

- The use of a balancing device in rural networks that feed the household load of consumers can be considered as a scenario for the use of green technologies in the rural electric power industry.

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