Method of manual symmetrication of electric networks

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Abstract. The article describes a method of reducing asymmetry in the electrical network supplying the utility load. The essence of the method lies in the uniform distribution of loads by switching branches. The results of experimental studies are presented, confirming that the proposed method actually reduces the asymmetry of the network, and also reduces power loss and voltage loss during the transmission of electricity. A comparison with the existing method of uniform distribution given, the high efficiency of the proposed method has been experimentally proven.

1. Introduction

The asymmetry of the currents and voltages of electric networks causes additional losses in the transmission of electricity, and is also one of the reasons for the decrease in voltage at consumers with distance from the power source. Without the use of baluns, thereby avoiding significant capital expenditures, it is possible to conduct balancing by uniform distribution of network loads [1].

2. Formulation of the problem

Existing methods suggest measuring the results of switching from the more loaded phase to the less loaded phase [2], [3]. Mathematically determining the probability of reducing asymmetry in a network with arbitrary parameters, the following conclusion was made. The probability that the reduction of asymmetry will be provided in the interval [0%, 50%) will be 67.28%, and in the interval [50%, 87.5%] – 25.86%. In addition, there is a probability equal to 6.87%, that as a result of balancing, asymmetry, on the contrary, will increase by an amount from 14.29% to 300% [4]. Therefore, there is a need to create a method in which the final value of asymmetry will be predictable, and the amount of reduction of asymmetry, and, consequently, the effect of balancing, will be significant. Also, when creating a method, it should be taken into account that manual balancing performed by the operatively-mobile team cannot be carried out more often than 1-2 times a year.

3. Description of the method and mathematical model

Baseline data for the calculations are formed using current and voltage sensors installed in the head section of the electric network to be symmetric [1]. The data are collected for a long period, and taking into account the collected data, the optimal variant of switching the branches is calculated. To perform the calculation, it is necessary to create a mathematical model of the electrical network, including network parameters and describing the balancing process. Directly switching branches, that is, reattachment the branch from phase A, for example, to phase B, is performed by an on-site field crew of electricians.

It is required to measure the currents of outgoing connections, enter data into the automated system using terminals and obtain the proposed switching solution.

The data of the measurements taken will correspond to the data obtained using an automated data collection system, since the sum of the current values of all measured connections is equal to the current flowing in the head section of the network as in equation (1).

$$I = I_{№1,ф.A} + I_{№1,ф.B} + ... + I_{№n,ф.C}\,, \tag{1}$$

where is n – the number of level connections.

Assuming that the equality of equations (2) during the entire observation period is preserved, the results of the measurement can be used to calculate the current of all phases of all connections at any time.

$$\left.\begin{aligned} &\frac{I_{№1,ф.A}}{I} = const, \\ &\frac{I_{№1,ф.B}}{I} = const, \\ &... \\ &\frac{I_{№n,ф.C}}{I} = const, \end{aligned}\right\} \tag{2}$$

According to the known values of current and voltage for each phase of connection at each time point, network parameters are calculated. For the entire observation period, the total phase resistance for each possible switch is theoretically calculated. From the proposed options, the option with the smallest asymmetry coefficient value is selected, which is the total power deviation (3).

$$k_{несим.} = \left|P_A - P_{ср}\right| + \left|P_B - P_{ср}\right| + \left|P_C - P_{ср}\right| \tag{3}$$

Over the entire observation period for each switching option, we obtain sets of asymmetry coefficients (3). Summing over the entire period, we obtain the total coefficient (4). From the total coefficients for each switching option, choose the smallest one.

$$\sum k_{несим.} = \left|P_{A1} - P_{ср1}\right| + \left|P_{B1} - P_{ср1}\right| + \left|P_{C1} - P_{ср1}\right| + \left|P_{A2} - P_{ср2}\right| + \left|P_{B2} - P_{ср2}\right| + \left|P_{C2} - P_{ср2}\right| + \ldots + \left|P_{An} - P_{срn}\right| + \left|P_{Bn} - P_{срn}\right| + \left|P_{Cn} - P_{срn}\right| \tag{4}$$

Thus, we obtain the switching variant, the total deviation in power over the entire observation period of which is minimal. In accordance with the theoretically determined switching option, the operatively-mobile team performs re-interconnections of wires of outgoing connections. After the balancing is completed, the data will continue to flow, and on the basis of the new data obtained, it will be possible to evaluate the beneficial effect of balancing.

4. The work of the method on the example and comparison with the existing option

Suppose we have a network with 4 connections, shown in figure 1. At the initial moment of time, the network has certain resistance values representing the resistance of the wires of the phases and the neutral wire and the resistance of the loads of each phase (see table 1). At the moment of time t=15min. there is a change in the resistance of loads multiply existing - resistance increases by 300 ± 10% (see table 1).

Currents $I_A = 301mA,\ I_B = 255mA,\ I_C = 721mA,\ I_N = 402mA$ flow in the head section of the network at the moment of time t=0. The absolute value of the asymmetry factor in the form of the average deviation in power is $\Sigma k = 135{,}2$ (see table 2). At the moment of time t=15min., the load resistances have changed and currents $I_A = 74mA,\ I_B = 64mA,\ I_C = 207mA,\ I_N = 133mA$ flow before balancing asymmetry factor is $\Sigma k = 38{,}8$ (see table 2).

Suppose that at the moment of time t=0 measurements of outgoing connections were taken. For the available version, before the network is balancing, the total asymmetry factor is $\Sigma k = 174{,}0$. Assuming that relation (2) is also preserved for all other moments of time, we calculate the total asymmetry coefficient for all variants. The minimum total asymmetry factor is $\Sigma k = 43{,}3$ for option number 8. We perform balancing, switching branches in accordance with option number 8. As a result of switching, currents $I_A = 451mA$, $I_B = 410mA$, $I_C = 455mA$, $I_N = 26mA$ began to flow in the head section of the network for t=0 asymmetry factor is $\Sigma k = 11{,}2$. For the moment of time t=15min. we have the currents $I_A = 122mA$, $I_B = 107mA$, $I_C = 117mA$, $I_N = 12mA$, asymmetry coefficient is $\Sigma k = 4{,}5$ (see table 2).

Table 1. Values of resistance of phase conductors, neutral wires and load connections.

t, min.	No. connections	$R_{phase\ wire\ .A}$,Ohm	$R_{phase\ wire\ .B}$,Ohm	$R_{phase\ wire\ .C}$,Ohm	$R_{zeros\ wire}$, Ohm	$R_{phase\ wire\ .A,No.n}$,Ohm	$R_{phase\ wire\ .B,No.n}$, Ohm	$R_{phase\ wire\ .C,No.n}$, Ohm	$R_{zeros\ wire,No.n}$, Ohm	$R_{A,№n}$, Ohm	$R_{B,№n}$, Ohm	$R_{C,№n}$, Ohm
0	1	20,3	20,1	20,2	30,0	49,5	43,8	46,7	65,6	∞	1920	2390
	2					55,5	42,9	48,5	65,5	1520	∞	980
	3					48,1	47,8	48,5	69,4	2400	3960	850
	4					45,0	45,1	45,6	66,8	3040	2680	700
15	1	20,3	20,1	20,2	30,0	49,5	43,8	46,7	65,6	∞	7640	9500
	2					55,5	42,9	48,5	65,5	6010	∞	3900
	3					48,1	47,8	48,5	69,4	9840	15880	3470
	4					45,0	45,1	45,6	66,8	12170	10590	2820

Table 2. Phase currents, phase voltages and asymmetry factor before and after symmetrization.

Symmetrization	The moment of time t, min	I_A,mA	I_B, mA	I_C, mA	I_N, mA	U_A,V	U_B,V	U_C,V	k
Before symmetrization	0	301	255	721	402	230	235	202	135,2
	15	74	64	207	133	227	234	221	38,8
After symmetrization	0	451	410	455	26	220	2247	221	11,2
	15	122	107	117	12	225	227	225	4,5

Thus, the voltage loss decreased from 21.3% and 5.0% for option No. 1 to 14.8% and 2.7% for option No. 8. The total power loss decreased from 33.8W and 3.0W for option No. 1 to 29.7W and 2.3W for option No. 8. The additional losses of the symmetrized area decreased from 7.7W and 1.0W for option No. 1 and from 0.83W to 0.05W for option No. 8.

Taking into account that the experimental model of the power line is built on a 1:100 scale of power, the total electric power losses for two periods of time from t=0 to t=15min. and from t=15min. to t=30min. for option No. 1, it will be 0.92 kWh, for option No. 8, it will be 0.80 kWh.

Additional losses of electricity from the area to be symmetric will be 0.22 kWh for option No. 1 and 0.02 kWh for option No. 8 (see table 3).

Table 3. The maximum voltage losses on the load, the total losses, including losses in the wires of the symmetrized section, the asymmetry coefficients of currents and voltages for the reverse and zero sequences.

Symmetrization	The moment of time t, min	k	$\Delta U_{макс}$,%	∑ΔP Common	∑ΔP Additional in the symmetrized area	k_{U2},%	k_{U0},%	k_{I2},%	k_{I0},%	Option number
Before symmetrization	0	135,2	21,3	33,8	7,7	1,35	6,20	38,01	31,83	1
	15	38,8	5,0	3,0	0,83	1,51	2,44	40,97	39,22	1
After symmetrization	0	11,2	14,8	29,7	1,0	0,13	1,99	4,27	3,18	8
	15	4,5	2,7	2,3	0,05	0,30	0,30	6,18	8,84	8

When trying to balance the network in the existing way, i.e. switching phases from more loaded to less loaded will be obtained the following option. In accordance with [3], the phases with the highest current value are connected to the phase of the network with the lowest effective value of the phase voltage and vice versa, and with the phases occupying an intermediate position, switching is not performed.

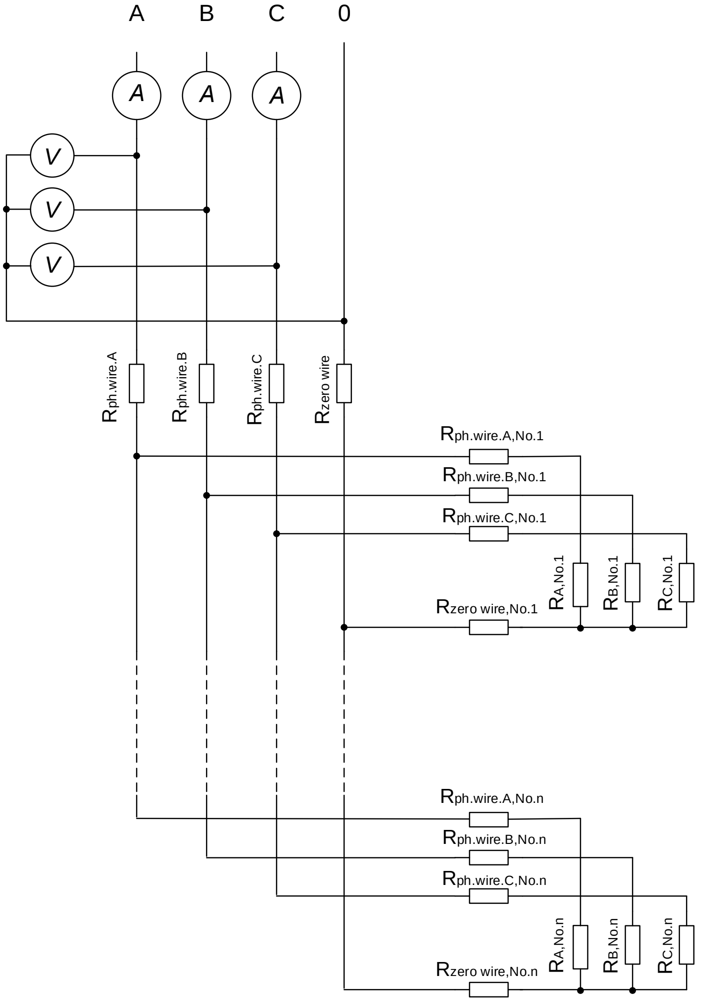

Figure 1. Electric network.

Let switching in this way will affect half of the connections, otherwise, if all connections are involved, the least loaded phases will become the most loaded and vice versa, which will not affect or worsen the situation. For example, performing switchings for all connections as a result of calculations using a mathematical model, we obtain an increase in the total power loss from 33.8W to 38.1W, i.e. by 12.7%.

Performing switching with half of the connections, we obtain for the time point t = 0 a decrease in total losses from 33.8W to 32.1W, which is 5.0%. In the proposed method is 12.1%. The largest voltage deviation is 15.0%, in the proposed method it is 14.8%. For the moment of time t = 15min. we have a decrease in total losses from 3.0W to 2.5W, which is 16.6%. The decrease in the proposed method is 23.3%. The largest voltage deviation is 3.8%, in the proposed method it is 2.7%.

5. Findings

The proposed method provides a more efficient balancing, in which power loss and voltage loss is less. The efficiency of balancing the proposed method experimentally confirmed.

The possibility of calculating network parameters and create a mathematical model for determining the option with the least asymmetry confirmed.

6. References

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