

Power quality and losses in 0.38 kV rural distribution networks

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Abstract. The guidelines for the design of rural and urban power supply systems do not consider the issues of reactive power compensation and reduction in additional losses due to unbalanced and non-sinusoidal conditions. At the same time, today's rural power consumers have a great number of non-linear loads in their residential premises. Moreover, the unbalanced phase currents and voltages are an established fact. The paper aims to demonstrate the extent to which power quality and losses vary in real rural 0.38 kV networks. To this end, the objectives were posed to study the operation of two facilities: 1- switchgear at the cottage (with an installed capacity of 15 kW); 2 - switchgear at the communal entrance hallway for 60 apartments in an apartment building (with an installed capacity of 75 kW).

Introduction

Numerous studies on the improvement in power quality and the reduction in power losses [1-8] indicate that solving these problems can significantly improve the efficiency of power supply to various household and non-household consumers. Nowadays, the ever-increasing number of different loads in residential premises has changed greatly the nature of electricity consumption, consequently, the need arises to revise some guidelines for the design of their power supply systems. In this regard, we have conducted a study on low-voltage electrical networks that power residential premises in rural areas.

The measurements were carried out in accordance with the current State standard 308.4.4.30-2013. The weighted average values of measured characteristics were sampled over 1008 ten-minute intervals per week, in accordance with the State standard 32144-2013 (hereinafter, the Standard). A certified instrument used for measurement was "Resurs-UF2-M". Based on the measurement results, we obtained time diagrams of changes in the mean daily values of voltage deviation, negative-sequence, and zero-sequence voltage unbalance ratio, coefficients characterizing non-sinusoidal voltage, and calculated additional power losses due to unbalance, non-sinusoidality and reactive power flow.

Research into the steady-state voltage deviation

This section of the article describes steady-state voltage deviation.

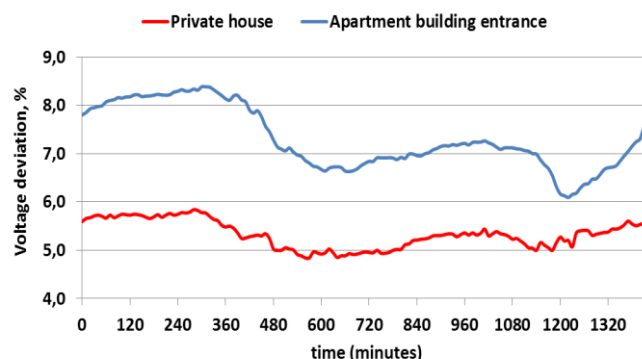


Fig. 1 - Change of a deviation of voltage on input of an apartment house and private house

Table 1 - Estimated data for minimizing the reactive power

Title	Private house	Apartment house
Length of line, km	0,03	0,05
Average current phases, A	9,88	21,8

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The average value of the voltage, V	231,1	235,47
Consumed active power, kW	3,57	7,99
Consumed reactive power, kVar	1,71	3,83
Power compensating device, kVar	0,46	1,038
Ctive power losses prior to the installation of devices of compensating, W (for 168 hours)	3,2	14,7
Ctive power losses after installation of compensating device, W (for 168 hours)	$1,58 \cdot 10^{-4}$	$12,57 \cdot 10^{-4}$

An analysis of the calculated data on this characteristic revealed the following.

1) An average steady-state δU_u at the point of consumer connection to the 0.38 kV network is 5.3% for the cottage and 7.3% for the 60 apartments in the apartment building. As is seen, these values exceed the values established by the Standard by 1.06 and 1.46 times respectively.

2) Power losses due to reactive power flows are small, however, they will become even less if compensators are installed.

The study on the harmonic content of voltage

The findings of the studies have shown the following. In a cottage, where the installed capacity and, correspondingly, the calculated load are much less than those in the apartment building, the values of the coefficients characterizing the non-sinusoidal phase and phase-to-phase voltages do not exceed the limits set by the Standard during the entire measurement interval. In the apartment building, in two cases, the harmonic components of the phase voltage exceed the established values, namely: at the 15th harmonic, in phase "A" - by 36% (1.4 times), in phase "B" - by 33% (1.33 times); in phase "C" - by 43% (1.43 times); and at the 21st harmonic, in phase "A" - by 75% (1.75 times), in phase "B" - by 65% (1.65 times), in phase "C" the results are similar to those in phase "B". It is worth noting that these results correspond to the value of the harmonic factor in 95% of the one-week time interval. The results of the study on the value of this factor in 100% of the one-week time interval are almost the same. The studies on the harmonic content of the phase-to-phase voltage did not reveal any violations.

Let us determine power losses due to non-sinusoidal current for 60 apartments of the apartment building.

$$\Delta P_N = I_1^2 r_0 l + I_{15}^2 r_0 l + I_{21}^2 r_0 l \quad (1)$$

$$I_n = I_1 \cdot k_n$$

$$I_1 = \frac{P}{\sqrt{3} \times U} \quad (2)$$

where I_1 – the fundamental frequency current; I_{15} and I_{21} – the 15th and 21st harmonic current, respectively; k_n – the n-th harmonic factor.

$$\Delta P_N = 114,1^2 \cdot 0,05 \cdot 1,91 + 136,92^2 \cdot 0,05 \cdot 1,91 + 99,27^2 \cdot 0,05 \cdot 1,91 = 3974,7 \text{ kW}$$

Thus, the greater the consumer load, the greater the probability of changes in the harmonic content of the supply voltage, especially at the triplen harmonics. Therefore, to improve the harmonic content of voltage, it is recommended to use appropriate narrow-band resonant filters with an automatic control system capable to automatically change their parameters

Unbalanced operation

The calculations of unbalanced operating conditions in three-phase circuits involved the method of symmetrical components which suggests the representation of any three-phase unbalanced system of magnitudes (currents, voltages) as a sum of three balanced systems of magnitudes.

The time diagrams of changes in phase currents at the input to a cottage are shown in Fig. A5, and at the input to an apartment building - Fig. A6. The average values of currents in phases "A", "B" and "C" for the studied period of time are 4, 18 and 8 A for the cottage and 22, 23 and 17 A for the apartment building. As is seen from the graphs, the most loaded phase in the cottage is phase "B", and the least loaded phase in the apartment building is phase "C". The current in the apartment building in phase "A" does not differ much from the current in phase "B".

According to the Standard, the value of the negative- and zero-sequence voltage coefficients should not exceed 2% in 95% of a week-long time interval, and 4% in 5% of the same time interval.

As is evidenced by the results obtained by measuring with a certified device, the power quality at the connection point of the consumer (both the cottage and the apartment building) is within the permissible limits of the Standard.

Let us see how the uneven load of the three-phase system phases affects the increase in power losses. Uneven distribution of currents in the phases of a three-phase network leads to additional balanced (negative-sequence and zero - sequence) components of the currents which increase power losses in the network.

Power losses that occur during unbalanced conditions are estimated by the loss factor K_p .

$$K_p = 1 + K_{21}^2 + 4K_{01}^2 \quad (3)$$

An analysis indicates that the average values of negative-sequence (K_{21}) and zero-sequence (K_{01}) currents (Figs. A12, A13) are $K_{21}=0,504$ and $K_{01}=0,505$ for the cottage, and $K_{21}=0,21$, and $K_{01}=0,17$ for the apartment building, respectively. Thus, the calculated average value K_p is 2.3 - for the cottage and 1.17 for the apartment building. Consequently, power losses under unbalanced conditions exceed the losses under balanced conditions by

2.3 times for the cottage and by 1.17 times – for the apartment building.

As can be seen from the measurements and calculations made, the power losses due to phase current unbalance are insignificant at the 60 apartments of the apartment house. This is because each apartment is powered by a single-phase system, and there are no unbalanced currents and voltages.

Additional power losses in the unbalanced conditions contribute to an increase in the cost of electricity. Let us calculate power losses for the period at issue, the time of power loss τ is assumed to be 168 hours.

Then the total power losses in the considered line, given unbalanced currents in each of the phases, will be:

$$\Delta W = lr_0\tau(I_A^2 + I_B^2 + I_C^2) \quad (4)$$

where l – the length of the considered line (0.03 km);
 r_0 – resistance of 1 km wire, equal to 1.91 Ohm/km;

I_A, I_B, I_C – average values of phase currents over the studied period, respectively (average currents in phases over the period of measurements were 4A, 18A, and 8A, respectively).

Then, we determine power losses after a reduction in the unbalanced currents. Power loss factor K_p is assumed to be equal to 1.2 since according to the published data, the balancing devices can reduce K_p to 1.1-1.3 on average.

The cost of electricity for rural electrical networks is 0.7546 rubles/kWh. The cost of power losses in the unbalanced conditions is 2934.68 rubles for the considered period. Reduction in the unbalanced voltage and current could reduce the cost of power losses to 727.61 rubles.

The average value of the power loss factor in the apartment building for the measurement period is 1.24. According to the calculations, given the additional losses due to unbalanced currents, power losses in the apartment building amounted to 21545.50 kWh with a total cost of 16258.23 rubles. This fact, however, is related to the technical losses caused by working currents. Losses due to unbalanced currents at the switchgear for the considered 60 apartments (in which the three-phase assembly is located) are caused by the negative-sequence and zero-sequence currents that flow in the cable from the transformer substation to this switchgear. Therefore, if a balancing device is installed at this switchgear, for example [9], then these losses will be reduced to the required level.

Conclusions

The findings indicate the following:

1) Rural 0.38 kV distribution networks, which are equipped with the minimum number of control devices and supply power to various types of electrical loads, are in rather poor conditions and, which is most important, have high power losses.

2) For apartment buildings, where each apartment has a single-phase input, the balancing devices should be installed either at the switchgear of each communal entrance hallway (for 60 apartments) or at the 0.4 kV buses of 10/0.4 kV power transformer.

3) For cottages, however, it is advisable to install the complete small-sized technical facilities integrating reactive power compensators, devices for the improvement in harmonic content of voltage, and balancing devices equipped with automatic control systems capable to automatically improve power quality by changing power of these devices up to their complete shutdown, in the case of their minimum power consumption.

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Appendix A

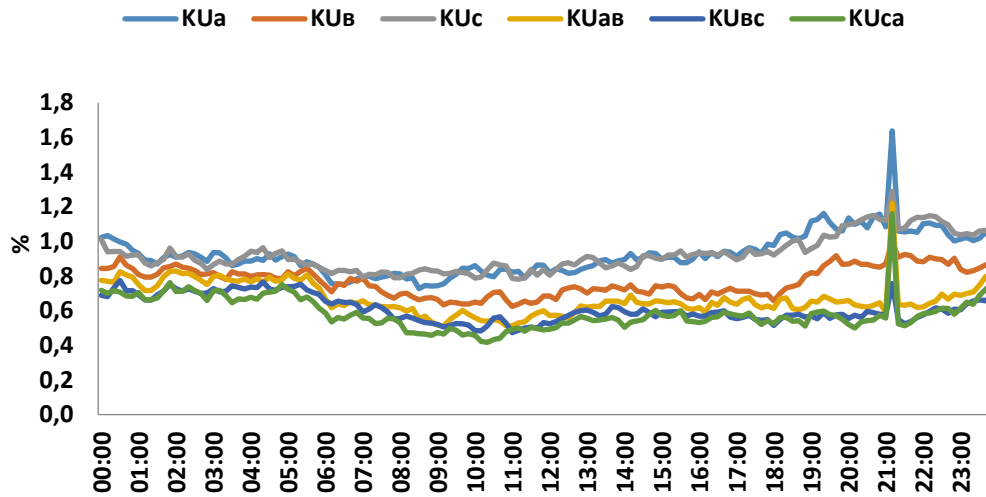


Fig. A1 - Change of voltage variation coefficient nonsinusoidality (private house)

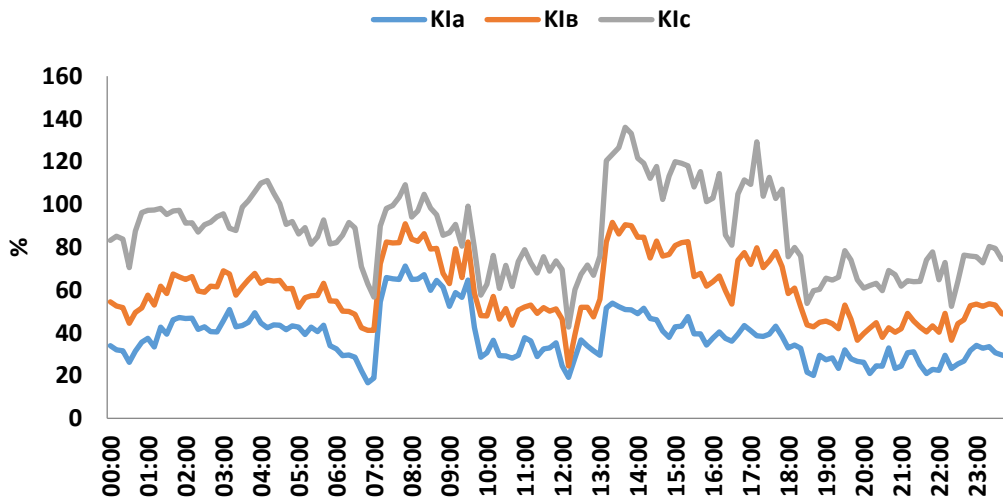


Fig. A2 - Change of current change coefficient nonsinusoidality (private house)

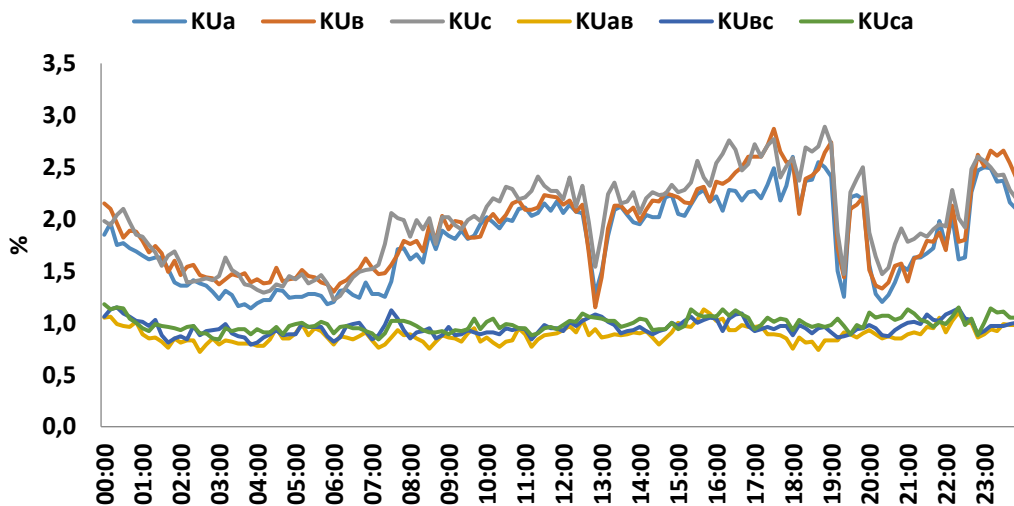


Fig. A3 - Change of coefficient non-sinusoidality of voltage (apartment house)

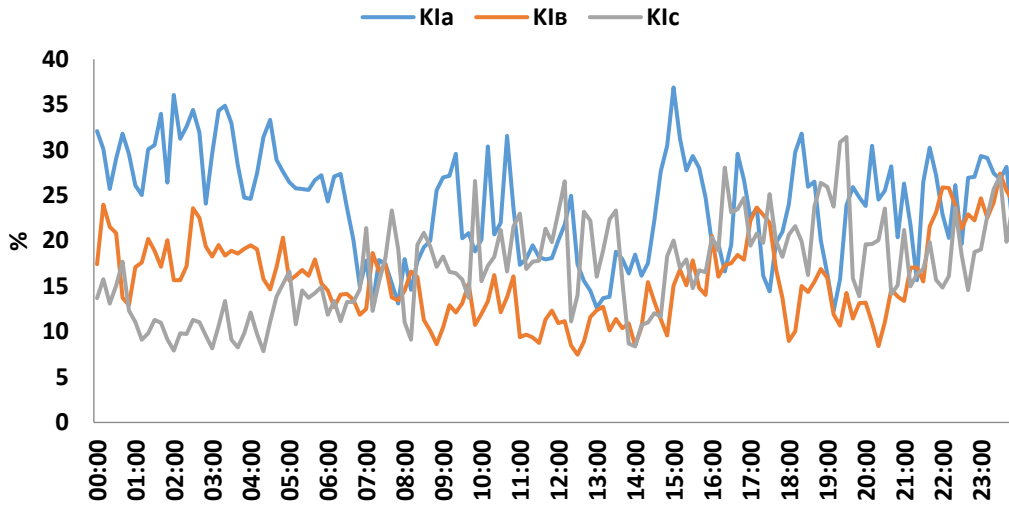


Fig. A4 - Change of coefficient non-sinusoidality of the current (apartment house)

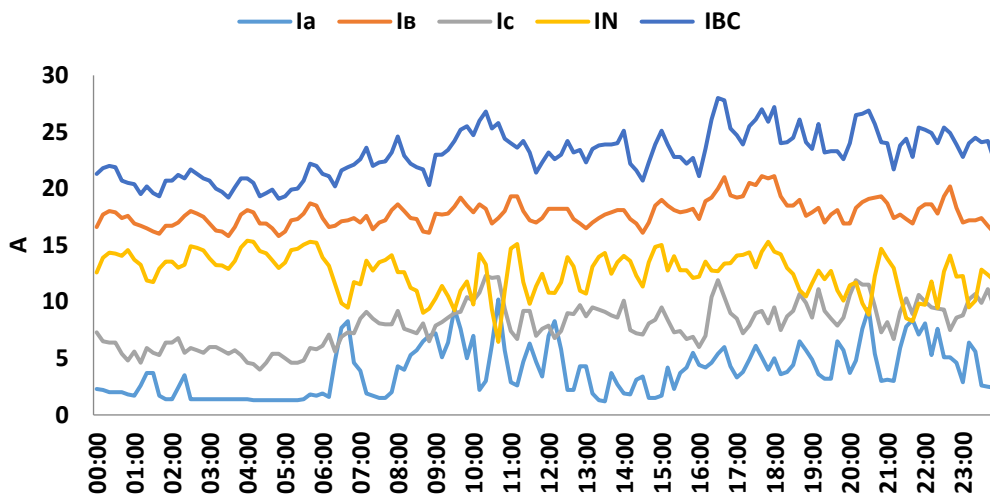


Fig. A5 - Change of the phase currents on input of the private house

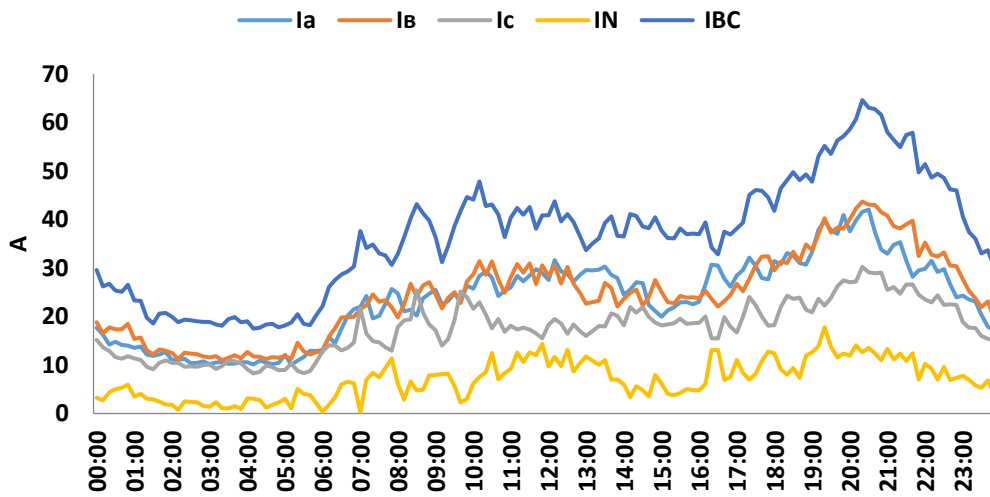


Fig. A6 - Change of the phase currents on input of the apartment house

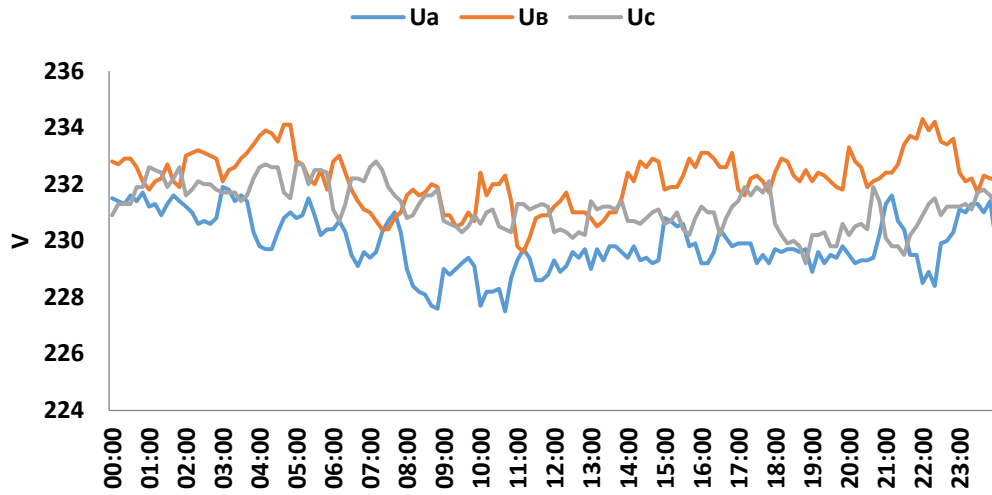


Fig. A7 - Change of the phase voltages on input of the private house

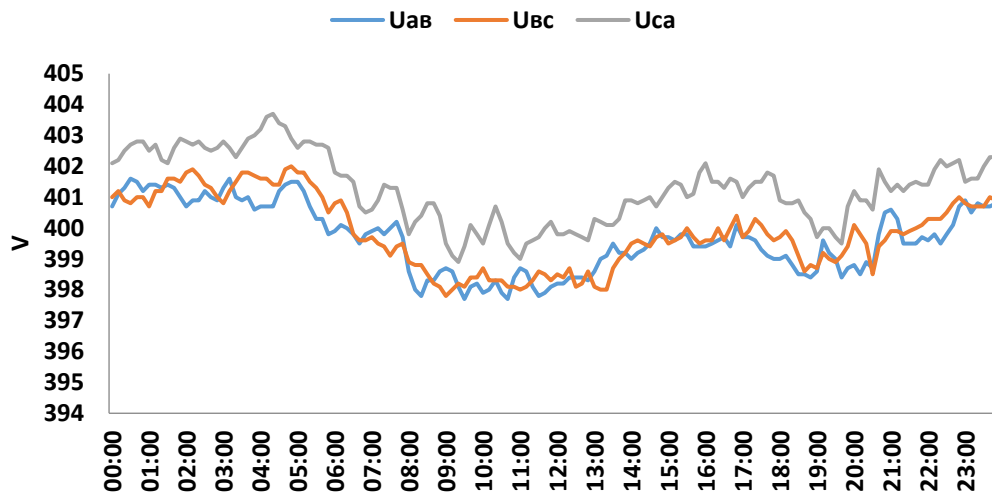


Fig. A8 - Change of interphase voltages on input of the private house

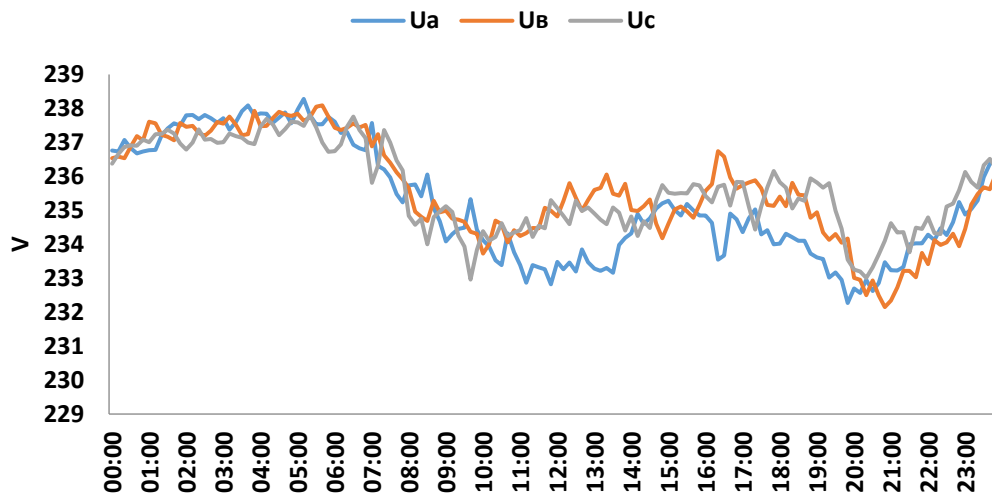


Fig. A9 - Change of phase voltages on input of the apartment house

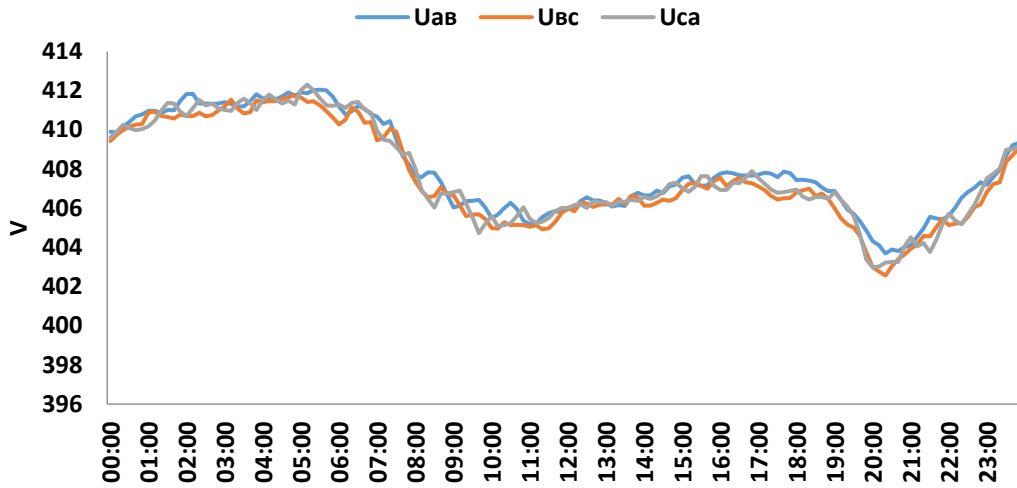


Figure A10 – Change of interphase voltages on input of the apartment house

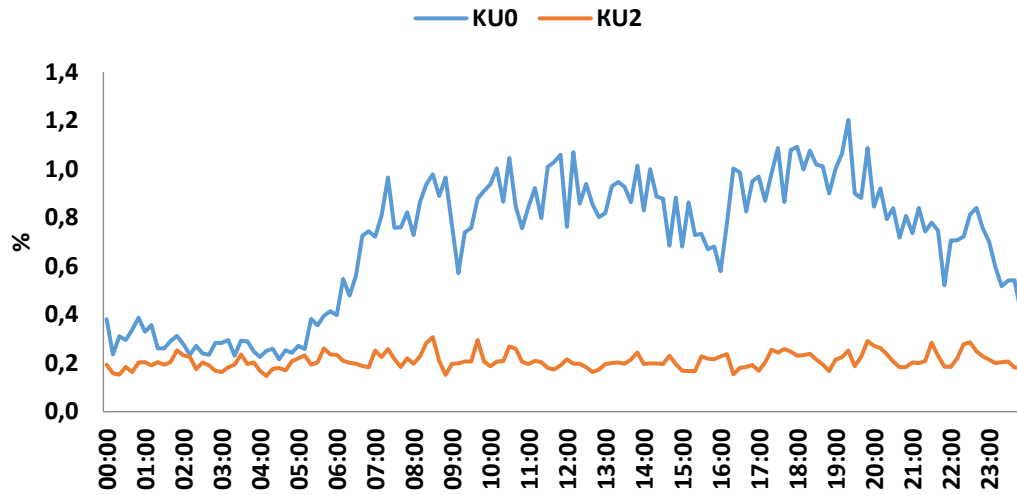


Fig. A11 – Change of coefficients of asymmetry of voltages on the negative and zero sequences of the apartment house

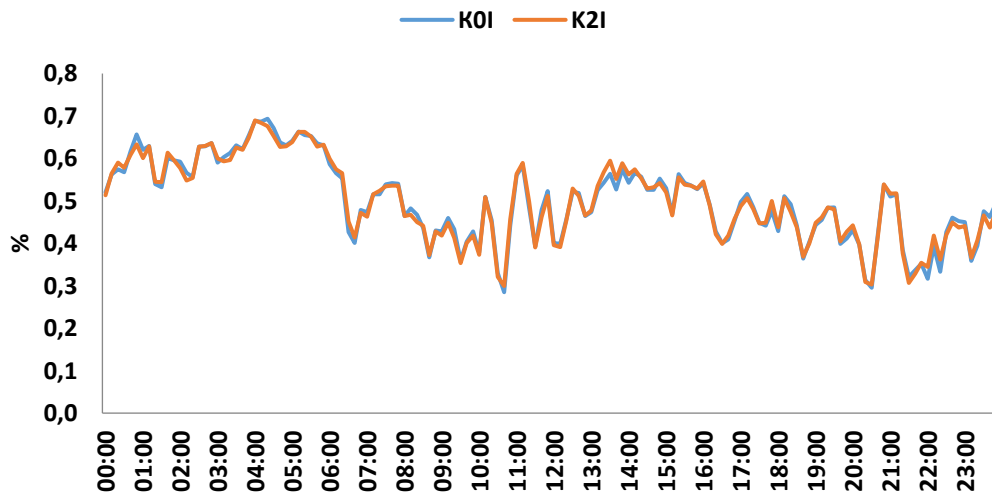


Fig. A12 – Change of coefficients of asymmetry of currents on the negative and zero sequences of the private house

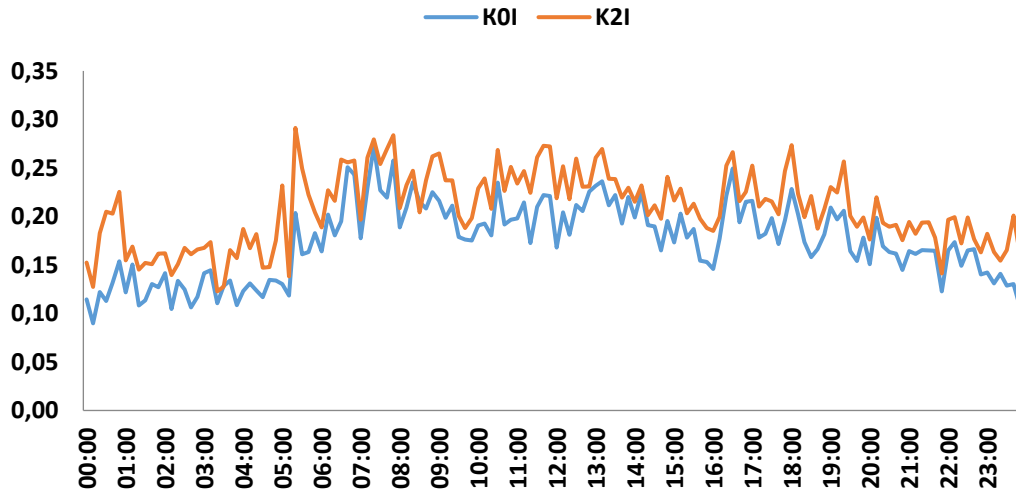


Fig. A13 - Change of coefficients of asymmetry of currents on the negative and zero sequences of the apartment house