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Statistical analysis of supply voltage levels for rural customers

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Abstract. In the elaboration, levels of supply voltage at the ends of loaded low-voltage lines were statistically evaluated, describing them using basic statistical measures and examining the frequency distributions. Levels of voltages and time of their occurrence on the background of current regulations were also assessed. It was found out that in spite of the fulfilment of statutory requirements electricity consumers complained about the poor, in their opinion, quality of the voltage.

Key words: low voltage networks, supply voltage quality

INTRODUCTION

Among the parameters characterizing the quality of the electric power supply the value of the supply voltage has the basic impact on the work of electric receivers. Too low voltage level translates to malfunctioning of most electronic devices, deterioration of lighting conditions, problems with the operation of induction motors, heating, etc.

Receivers most sensitive to voltage deviations include a electric light sources. For bulbs changing of this parameter affects, among others, the value of the luminous flux (the relationship of the power of 3.5), efficiency (the relationship in the power of 2), changes in power consumption (the relationship in the power of 1.6), and with the rapid changes can cause flickering lights [1 - 4].

The second group of receivers very sensitive to the value of the supply voltage is IT equipment, including control systems. Lowering of the supply voltage may lead to malfunctions, commonly used to control, microprocessors and uncontrolled interruption of the process and even damage the equipment. Microprocessor systems after return of the voltage to the rated value are unable very often to continue working because of lost or erroneous data, and they must be reprogrammed [5 - 9].

The switchgear is also sensitive on the supply voltage value, in particular contactors and relays, which, when the voltage drops, can switch off the controlled device in an uncontrolled manner [8, 9].

Another group consists of induction motors whose the main parameter, which is the torque, is dependent on the square of the supply voltage. So, reducing the supply voltage by 10% means that torque will be only ~80% of its value occurring at the nominal voltage. With a significant voltage drops may even unplanned stop it. The reduced supply voltage results also in a reduction in engine speed and increasing the value of the input current, which in extreme conditions, through a significant increase in operating temperature, will shorten the life of the winding insulation and the insulation between the sheets of magnetic circuits [3, 8 -11].

The reduction of the supply voltage adversely affects also the performance of the heating units and prolongs its work, thus increasing costs [10, 12, 13].

Fluctuations in voltage supply work negatively not only on the work of receivers, but also on the distribution network, from which they are powered. In power lines voltage variations affect the present in them power losses and voltage drops. In the case of transformers, voltage deviations increases the risk of damage to the insulation and can cause an unfavourable change in the operating point of the transformer, as well as the impact on the increase of losses for the idle state [14 -15].

On the level of voltage in the power network technical characteristics (mainly the length and cross-sections of the line) have decisive influence, in addition to the load by apparent power. It is therefore recommended that the length of low voltage circuits leaded from transformer stations will not exceed 500 m, and in exceptional situations 1000 m. Unfortunately in distribution networks, especially in rural areas, often there are circuits of considerable length and small cross-section wires [16 - 20]. In this situation ensuring the legally required level of the supply voltage is very difficult. Costs of poor power quality, which can be a big, burden for both suppliers and consumers of electricity.

OBJECTIVES

The purpose of the elaboration was to evaluate the statistical levels of voltage at the ends of loaded low-voltage lines. In particular, basic statistical parameters were designated and frequency distributions were analysed for the tested variable. In the elaboration levels of voltages and time of their occurrence on the background of current regulations were also assessed.

TEST METHOD

Studies of the voltage quality were performed on rural areas of the South Poland. They consist of the registration of voltage levels in the three transformer stations selected and at ends of the loaded low-voltage lines leaded out from these stations. Tested transformer stations were columnar stations, equipped with transformers having power ratings from 100 kVA to 160 kVA. Low voltage lines leaded from these stations are made of AL cables (flat) and AsXSn (twist) with a diameter of 25 - 70 mm^2, and their average length is 530 m. In contrast, measurements of supply voltages are limited only to the beginnings and ends of the longest circuits whose length contained in the range of 1550 to 2250 m.

Own studies were conducted in the winter period not less than one week using the network analyser REM-370. This analyser recorded, among others, momentary and averaged 1 and 10-minute supply voltage.

RESEARCH RESULTS

The effective value of the voltage is the main parameter that characterizes the quality of the supply voltage. According to the regulations being in force in Poland, every week 95% of a set of 10-minute averages of effective voltage at the point of delivery of electricity from the low-voltage network must be within the tolerance band of ± 10% of rated voltage [21, 22].

The supply voltage level in the power network is subject to change. These changes may be the nature of the planned (deterministic) or random changes. The first are the result of the voltage adjustment using the transformer, aiming to provide appropriate voltages for receivers, the second - random power flow as a consequence of random changes of the power consumed by receivers. The value of the current flowing in networks is related with the size of the consumed power. The current flowing in the network causes voltage drops. The voltage value supplied the recipient at any time is dependent on the voltage value in the power source and the total voltage drop across all components of the supply network. Lowest supply voltages are present at the ends of circuits, so for the purpose of assessing the quality of power supply voltage measurements are performed in these places.

Figure 1 shows waveforms of changes for the 10-minute effective values of the voltage recorded at the end of the longest circuits leaded out from the tested transformer stations. For purposes of statistical analysis parameters describing these voltages in a systematic way were determined [23], and in particular the calculated measures of association, dispersion, asymmetry and concentration, the size of some of which are presented in Table 1. In addition, Figure 2 shows the frequency distributions of voltage levels at the ends of analysed lines.

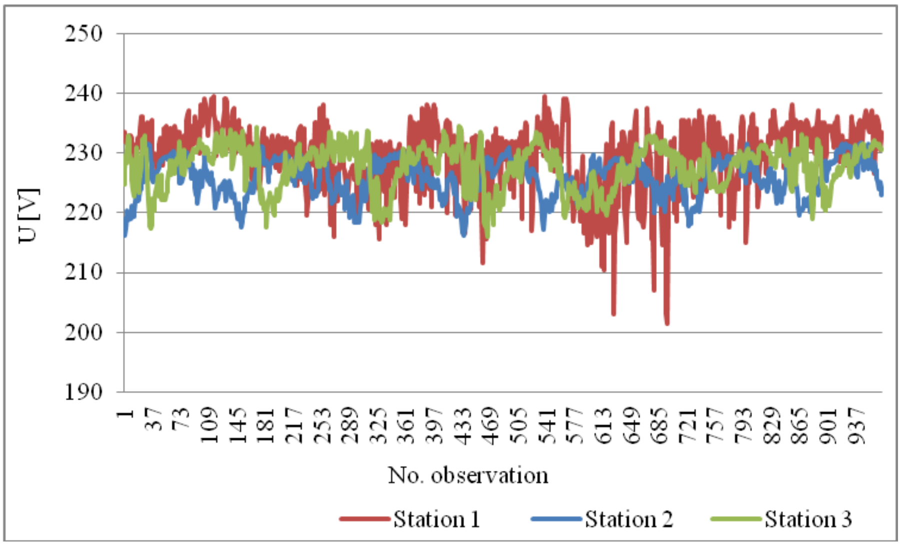

Fig. 1. Waveforms of average 10-minute voltage values at ends of the low-voltage lines

Table 1. Statistical parameters describing average 10-minute supply voltage values at ends of the low-voltage lines

Specification	Parameter			
	U_a [V]	V [%]	A	K
Station 1	235.88	64.78	-0.15	-0.68
Station 2	234.42	58.87	- 0.15	-0.67
Station 3	237.80	59.95	-0.16	-0.24

where: U_a - average value, V - coefficient of variation, A - skewness, K - kurtosis

Histograms shown in Figure 2 illustrate the qualitative properties of the actual distribution of voltage levels at the end of low-voltage lines, taking into account the adjustment of voltages using the transformer, and the asymmetry of the phase currents and voltage drops in the low-voltage lines. Voltage drops in low-voltage lines causes the asymmetry of distribution of voltage levels at the end of the line. As is apparent from Figure 2 and Table 1 this is the negative asymmetry. Distributions for the negative asymmetry are less researched than those with the positive asymmetry, however, in the analysis of voltage levels at the end of low-voltage lines the distribution of the right-hand skewness can be obtained through a simple linear transformation [24].

Having regard to the distributions shown in Figure 2 that the normal distribution is the best suited for the description of information on the change of the voltage at the ends of low-voltage lines, the distribution of the analysed variable gets closer to normal when moving from the ends to the beginnings of low-voltage lines.

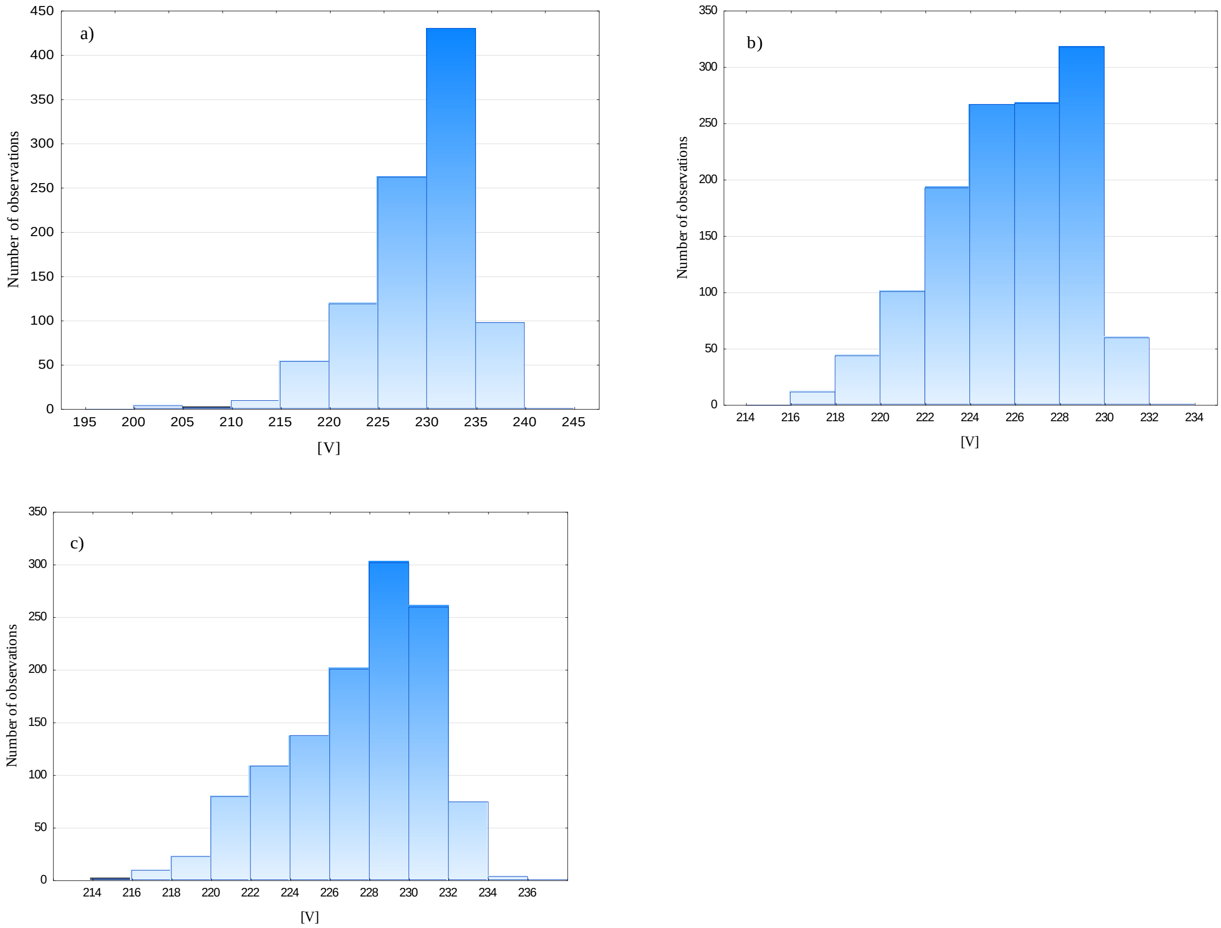

Fig. 2. The frequency distribution of voltage levels at ends of the low-voltage line leaded out from transformer stations: a) 1, b) 2, c) 3

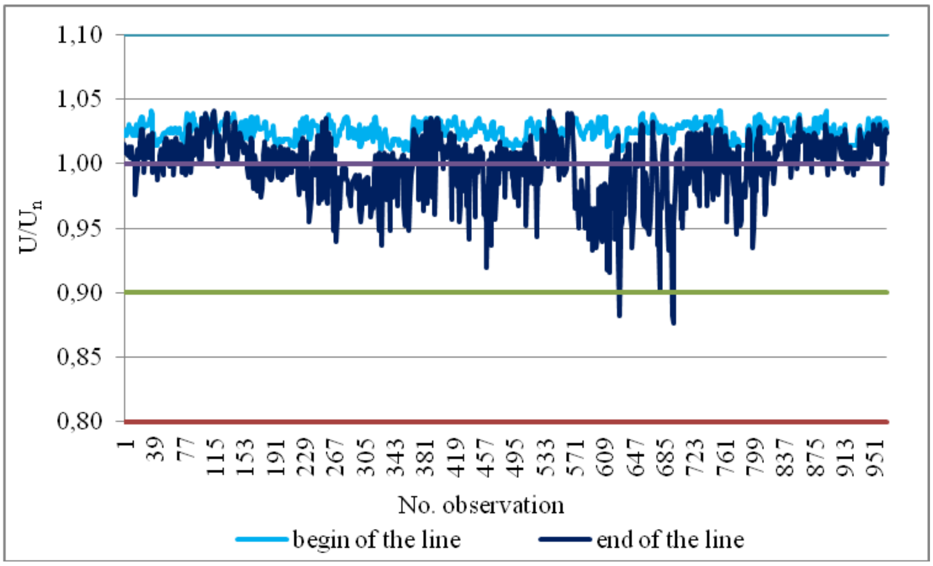

Fig. 3. Waveforms of average 10-minute voltage values at the begin and end of the longest low-voltage line; where: U_n - nominal voltage

For the analysis of the quality of the power voltage the knowledge not only waveform at the end, but also at the beginning of the circuit is needed. Figure 3 shows such waveforms for the line having the worst voltage conditions. From Figure 3 it shows that the recipients exceeded the lower allowable voltage range. However, it also can be seen that the exceedances could not might be for the suitable adjustment of the voltage under the load using transformers.

The evaluation of the voltage quality in terms of its effective values at the point of supply of the electricity (Table 2) were carried out separately for each phase of the tested circuits, taking into account also, according to current requirements, time in which the voltage is within the specified range.

Table 2. The statistics of average 10-minutes voltage values at ends of the low-voltage line in measuring periods

Specification	Parameter	Voltage [V]		
		L1	L2	L3
Station 1	Minimum (95% of week)	214.0	219.0	221.0
	Maximum (95% of week)	237.0	236.0	238.0
	Minimum (100% of week)	186.0	201.5	206.0
	Maximum (100% of week)	244.0	239.5	243.0
Station 2	Minimum (95% of week)	216.7	207.1	228.2
	Maximum (95% of week)	229.1	227.5	239.5
	Minimum (100% of week)	210.1	197.2	220.3
	Maximum (100% of week)	232.1	234.9	244.9
Station 3	Minimum (95% of week)	217.8	213.6	224.6
	Maximum (95% of week)	233.4	231.6	239.9
	Minimum (100% of week)	203.4	205.4	212.0
	Maximum (100% of week)	240.0	235.2	244.3

As can be seen from the Table 2 requirements for voltage levels at receiving points of the electricity and time of their occurrence are met. Despite that electricity consumers have complained about the poor quality of power supply and the associated nuisance and incurred losses. This is because the majority of the currently operated electricity receivers is apparently sensitive to even short-term reduction of the supply voltage exceeding the limits by law. So it seems that being in force in the assessment of the quality of electricity, a 10-minute period of voltage averaging is too long.

In power quality analysers commonly available on the market one minute is the shortest possible averaging time. The Table 3 compares the results of the voltage measurement at the end of the longest low-voltage line at various averaging. Taking into account the average 1-minute supply voltage it can be seen that the number of registered exceedances of the allowable voltage range in the L2 phase is over 100 times higher than for 10-minute averaging.

Table 3. Number of observations exceeding by ± 10% the nominal supply voltage at the end of the longest line leaded out from the station 2, depending on the measurement averaging time

Phase	For supply voltage value	Number of observations
L1	average 10-minute	0
	average 1-minute	6
L2	average 10-minute	57
	average 1-minute	600
L3	average 10-minute	0
	average 1-minute	0

Customer complaints on the poor quality of power, despite the fulfilment of statutory requirements, however, should encourage distribution companies to take measures to improve the voltage conditions of their clients. The modernization of the network which consists of increasing cross-section of power cables, leading the additional track or shorter circuit by mounting a transformer station is the typical way to solve problems of voltage drops [25, 26]. Commercially available voltage adjusters of the low-voltage network can be also used [27, 28]. The latter solution is much cheaper than actions of modernizing of the network. Since the voltage adjustment by means of these devices is carried out independently for each phase, voltage adjusters symetrise simultaneously the distribution of phase voltages.

CONCLUSIONS

Distributions of voltage levels at ends of loaded low-voltage lines is characterized by negative asymmetry, and for the description of this variable, from well-studied theoretical distributions, the normal distribution is best suited. The distribution of supply voltage levels for receivers gets closer to normal when moving from the end of the line to buses of the transformer station.

The fulfilment of statutory requirements in relation to the effective values of the voltage at the point of delivery of electricity from the low-voltage network is not the same with the satisfactory, perceived by receivers, quality of the voltage. Most electric receivers currently in use is in fact sensitive to even short-term reduction of the voltage exceeding 10% of the nominal value. So it seems that being in force in the assessment of the quality of electricity, a 10-minute period of voltage averaging is too long.

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