Optimization of losses by switching to higher voltage in distribution networks

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Abstract. The article considers the basis of scientific research in the field of electric power industry the issues of transition to 20 kV voltage in the distribution power grids of Uzbekistan. The main advantages of this method are analysed, as well as the factors affecting power and energy losses in electrical systems and networks. The paper presents a schematic diagram of an electric network section, on which a comparative calculation and analysis of voltage, energy and power losses in 6/10/20 kV networks is carried out. Special attention is paid to the peculiarities of calculation of these parameters, as well as the basic expressions for their calculation and the resulting graphical relationships. From the analysis it can be concluded that it is reasonable to use 20 kV voltage in distribution networks. It allows to reduce power and energy losses, which is an important factor in the efficient operation of electric power systems, to increase line capacity and service range. However, when selecting the optimal voltage for certain conditions, it is necessary to take into account a number of factors, such as the length of transmission lines, the type of wires and transformers used, and the load level of the network.

1 Introduction

Energy saving is a complex implementation of legal, organizational, scientific, scientific, production, technical and economic measures aimed at optimal use of energy resources. Increasing attention to the problem of energy saving is associated with increasing losses in electric power systems and networks. One of the possible ways to solve this problem is the modernization of distribution networks, which allows to reduce power losses and increase the efficiency of its use. This can be achieved by introducing new technologies for transmission and distribution of electricity, as well as by optimizing the processes of management and monitoring of energy consumption. In addition, research in electrical and energy engineering should be conducted to develop more efficient methods of power generation and transmission. In general, energy saving is an important task that requires joint efforts of the state, scientific and industrial organizations, and the whole society [1].

Modernization of distribution networks is one of the main directions. At present, the situation in electric distribution networks is difficult:

- High physical wear and tear of electrical equipment;

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- Significant power losses (up to 15% of power losses);
- Low level of automation.

The increase in electric load often leads to technical limitations in the use of existing networks. In addition, new generation resources are being introduced [2].

Supply electricity to new consumers. However, these approaches do not solve the problem of providing industrial enterprises and cities with the necessary quantity and quality of electricity. One of the ways to reduce electric losses in the electric network is the use of 20 kV voltage instead of 6-10 kV. establishes the priority of transition from 6 (10) kV to 20 kV voltage as a promising and necessary direction for the development of a set of regulatory documents. 20 kV was introduced as a standard in Russia in the early 1960s, but historically it has not been widely used. Currently, dozens of countries and regions of the world use 20 kV medium voltage. In 1948, parts of these voltage networks were first used in the United States, France, and Germany. Many countries in Europe - Italy, Austria, Bulgaria, Poland, Hungary, etc. (80% of the territory of Europe) started Since the 60s of the 20th century, there was a transition to 20 kV voltage. Currently, networks of such voltage are widely used in Asian countries, including China, Korea, Taiwan, Singapore and others. The 20 kV voltage is used throughout Finland and Estonia [3].

2 Materials and methods

Technical measures to save energy and improve the energy efficiency of the electric grid should be aimed at reducing electricity losses, modernizing the systems of commercial and technical accounting of electricity in distribution and transit electric networks and consumers. The structure of losses in electrical networks is shown in Table 1.

Table 1. The structure of losses in electrical networks.

Technological losses of electrical energy				
		Technical losses		
		Losses independent of load		**Load losses**
		Idling losses	**Climatic losses**	
Electricity consumption substation for own needs	Losses due to errors in the metering system electricity	- in power transformers - in compensating devices - in shunt reactors - in cable lines - in voltage transformer and electric meters	- there is an airline to the crown - the airline is protected from leakage currents - electricity consumption for melting ice	- in power transmission lines - in power transformers - in current limiting reactors - in high-frequency communication barriers

The expert assessment was carried out taking into account the following factors affecting electric power losses in electric power systems and grids:

1. Service life of lines and equipment, which is an important parameter affecting electric losses. Studies show that as the service life of lines and equipment increases, their technical characteristics deteriorate, which leads to an increase in energy losses.
2. Accidents in power systems and networks also have a significant impact on power losses. Frequent accidents lead to outages and repairs, which increases the downtime of lines and equipment and, consequently, to power losses.

3. The voltage class of transmission lines is also an important factor affecting power losses. Studies show that high voltage lines have lower power losses than low and medium voltage lines.
4. Load losses also have a significant impact on electrical losses in electric power systems and grids. Electrical losses increase with increasing load on transmission lines.
5. Commercial losses due to imperfections in computing systems are also an important factor affecting electrical losses in electric power systems and grids [4].

Defects in the metering system can lead to miscalculation of electricity consumption, which, in turn, can lead to increased electricity losses The results of the expert assessment are presented in Table 2.

Table 2. The results of the expert assessment.

Factors affecting losses in transmission lines	**The share of factors affecting losses in electric power systems and grids was verified by the expert evaluation method in the ratio of 100%.**									
	Ordinal numbers of the members of the expert group									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Service life	50	15	30	10	30	25	20	40	10	15
Emergency lines	10	10	25	25	10	15	10	35	40	15
Voltage in networks	10	15	20	30	40	20	30	10	30	20
Load loss	10	15	20	15	10	20	20	10	10	25
Imperfection of the accounting system	10	40	10	5	15	20	20	5	10	25

The analysis of the data obtained during the study allows us to conclude that the electrical losses associated with the voltage of power lines occupy one of the leading places. The average number of such losses is about 24%. These results indicate the need for active work towards increasing the voltage level in electric power systems and networks, which is a promising and relevant direction in the field of energy conservation [5].

Many studies conducted by domestic and foreign scientists confirm that an increase in voltage is the main factor influencing the reduction of electricity losses and improving the quality of its transmission to the consumer. This is confirmed by our expert assessment.

As a result of the analysis of the existing power grids of the Republic of Uzbekistan, the high durability of power transmission lines has been determined, in some cases they reach 40-60 years without carrying out the necessary measures to modernize them. This leads to an increase in electrical losses in the networks. The increase in losses is also associated with an increase in consumption due to the appearance of many industrial facilities [6].

Research shows that the service life of power transmission lines depends on many factors, such as the material they are made of, working conditions, climatic conditions, etc. However, although some networks may have high reliability, this does not mean that they do not need to be upgraded. The old lines do not meet modern requirements for the efficiency and safety of electricity transmission, which increases the likelihood of accidents.

An increase in electricity consumption is also a factor influencing an increase in network losses. However, there are methods to reduce electrical losses, for example, increasing the voltage in the networks. Research shows that increasing voltage is an effective way to reduce electrical losses in networks. Therefore, upgrading power transmission lines and increasing voltage are important measures to improve the efficiency of electric networks and reduce electricity losses [7].

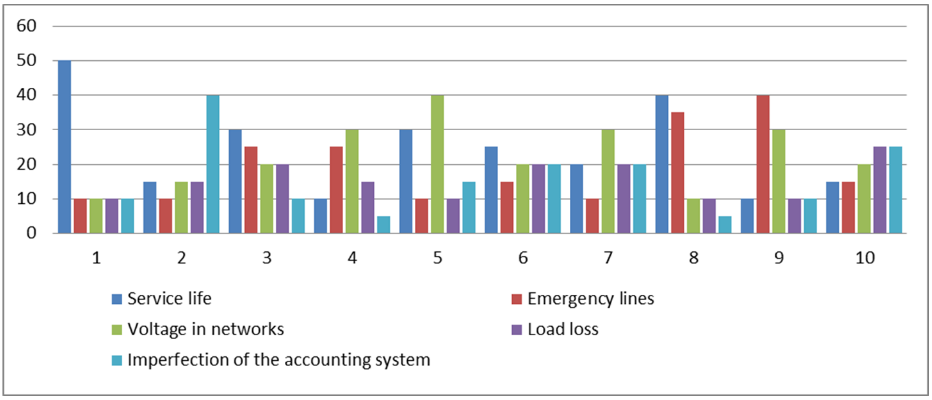

Fig.1. Factors influencing electricity losses.

One of the effective ways to reduce electrical losses in electrical networks is to increase the voltage in distribution networks. Switching to a voltage of 20 kV is one such method and can lead to a significant reduction in power and electrical losses. Today, the construction of cities in every city center of our country causes a sharp increase in electrical loads. Increasing the voltage to 20 kV is especially important for networks with a high density of electrical loads. This is due to the fact that with an increase in voltage, the current flowing through the transmission lines decreases, which, in turn, reduces power losses in the lines. In addition, increasing the voltage allows you to increase the capacity of the lines and the service range.

It is essential to acknowledge that the efficacy of employing a 20 kV voltage is intricately intertwined with a multitude of scientific parameters, encompassing the geometrical characteristics of power lines, the material composition and impedance properties of the conductive wires and transformers, as well as the operational capacity and utilization dynamics of the electrical network [8].

3 Results and discussion

In Uzbekistan, the construction of 10 kV voltage class networks continues in the development of electricity distribution, the main technological and circuit solutions for which were formulated in the middle of the last century. Taking into account the experience of developed European countries, we propose to switch distribution networks with a rated voltage of 6-10 kV to a voltage of 20 kV and further switch from a three-stage (110-35-(6)10 kV) power transmission and distribution system to a two-stage (110-20 kV) [9].

A comparative analysis of electricity losses in distribution zones at different voltages (6, 10, 20 kV) was carried out. The calculation of the electrical losses of the network section in which it is performed is shown in Table 3. The transformer substation receives power from the 110/6(10, 20) kV head step-down substation. The distance from the main step-down substation to checkpoint 1 is 4 km. The energy consumption of electricity in the network is determined by the equation (1):

$$\Delta W = 3 \cdot I_{max}^{2} \tag{1}$$

here: $I_{\max}$ is the maximum load current; τ – The time interval during which the load of the network element with resistance R is assumed unchanged; R - equivalent network resistance.

The results of the calculation are summarized in Table 3.

Table 3. Annual energy losses in the medium voltage network of 4 km.

Rated voltage	**Cross-sectional surface of AC overhead power lines, square millimeters**								
	25	**35**	**50**	**70**	**95**	**120**	**150**	**185**	**240**
	Loss of energy in the network, kWh/year								
6 kV	1912.9	1297.6	993.3	704.1	501.9	407.2	341.5	257.4	197.3
10 kV	689.1	467.4	357.8	253.6	180.8	146.7	123.2	92.6	71
20 kV	172.2	116.8	89.4	63.4	45.1	36.6	30.7	23.1	17.7

A graph of energy loss reduction based on the results from Table 3 is shown in Figure 2.

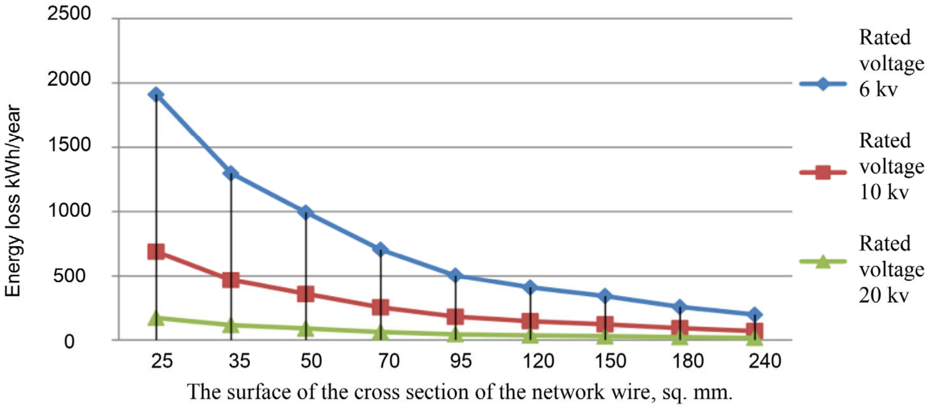

Fig. 2. Graphs of reduction of annual energy losses in a medium voltage network with a length of 4 km.

Figure 1 shows that reducing electrical energy losses without changing the material of the network cable is carried out mainly by increasing the cross-sectional area of the conductor and the voltage due to two factors. According to formula (1), an increase in cross-sectional area leads to a decrease in resistance, and an increase in voltage leads to a doubling of the maximum load current, that is, energy losses are significantly reduced [10].

Based on the above data, let us consider the advantages of 20 kV class over other voltage classes.

Compared to 6, 10 kV classes:

- high transmission capacity, which is important given the current growth in electricity consumption;
- this voltage class doubles the service radius of substations;
- Construction of 6-10 kV lines is inefficient due to high technological losses;
- considering the loss of 5 to 7% of converted power in each conversion, we can say that this means huge money and millions of tons of fuel savings;
- reduces power losses by 1.5 times.

Compared to the 35 kV class:

- that the cost reduction of laying comparable lines is almost identical to the cost of laying 6(10) kV lines;
- smaller area of the protected zone, which reduces the cost of cutting down trees, and also reduces the negative impact on the environment;
- construction of 35 kV lines for small capacity consumers is very expensive;
- the average cost of 20 kV structures built to replace the planned 35 kV networks was 45-50% [11].

The logic here is as follows: in the range of 10-20 kV, the consumption characteristics of transmission lines are practically the same. The existing difference in the cost of transformer substations 10/0.4 and 20/0.4 kV is compensated by reducing power losses in the lines even at relatively low loads. The cost characteristics of 20/0.4 and 35/0.4 kV transformer substations for the 20-35 kV range are the same as before, only slightly different. However, the cost characteristics of overhead lines are significantly different and reduce the efficiency of the 35 kV network due to the increased cost of the construction part [12].

Indeed, the usual comprehensive reconstruction of existing 6-10 kV distribution networks when replacing equipment with high-capacity equipment does not increase their capacity and does not give an objective economic effect, except for the restoration of operability, so as an optimal option we propose to replace obsolete 6 kV distribution networks with new 20 kV networks, and the next stage will be a step-by-step replacement of 10 kV networks. When installing 20 kV networks instead of 6 (10) kV networks, the dimensions of transformers are practically unchanged, the invariability of supports and wires of the network sharply reduce the cost of construction and reconstruction [13].

For the transition to the construction of 20 kV networks it is necessary to fulfill a number of mandatory conditions:

1) updating the regulatory framework with the development of new national standards and technical regulations;
2) availability of capacity reserves at the 110 kV voltage level in 20 kV power centers;
3) elaboration of a concept for the development of 20 kV networks in a certain territory;
4) creation of the 20 kV equipment market.

The task of converting electrical networks to nominal voltage of 20 kV can be divided into two parts, each of which has independent approaches to the solution: conversion of existing 6(10) kV networks into networks with nominal voltage of 20 kV and construction of new 20 kV networks [14].

The use of steel aluminum wires on overhead power lines during the transition from 10 kV to 20 kV led to a slight increase in the distance between phases (0.2-0.45 m), but when using cable lines on overhead power lines, this distance does not change. From this it can be seen that for the use of steel aluminum wires it is necessary to make changes in the design of the transmission line. In practice, in conventional structures of reinforced concrete supports, the distance between phases is about 2.5 times greater. The cost of insulators and their modifications is a small amount of the total cost of the overhead line. Therefore, the difference in capital costs between 10 kV overhead lines and 20 kV overhead lines practically does not exceed 1%.

It should be noted that in medium voltage 110/6-10-20-35 networks the feasibility of transition from the extended system of nominal voltage kV to the maximum reduced 110/20 kV has been proposed in a number of other articles. The 110/20 kV system with direct 20/0.4 kV conversion in overhead networks requires much less money, non-ferrous metals and especially transformer power in a wide range of load densities [15].

4 Conclusion

It can be said that the use of 20 kV voltage in the existing 6-10 kV distribution networks will allow to move to a higher level of power supply to consumers in Uzbekistan, will allow to increase the capacity compared to the existing networks, reduce technological losses, improve the quality of electricity, energy safety and reliability of power supply systems.

Thus, construction of 20 kV overhead lines is a priority for the energy system of the country, as it allows doubling the capacity consumed by them compared to 10 kV lines at practically the same price. The price characteristics of 10 and 20 kV overhead wires in the

10-20 kV range are almost identical. Reduced power losses on the lines even at relatively low loads compensate for the difference in costs between 10/0.4 and 20/0.4 kV substations. A 20 kV network can transmit twice as much power for a given wire cross-section as a 10 kV network and can reduce power and energy losses by a factor of almost four for the same transmitted power. The cost characteristics of 20/0.4 and 35/0.4 kV substations, as mentioned above, are slightly different in the range of 20-35 kV. However, due to the high cost of network construction, the cost characteristics of overhead lines are very different. In particular, for 10-20 kV overhead lines 11-meter reinforced concrete vibration supports are most often used, and for 35 kV overhead lines much larger 22.6-meter reinforced concrete supports are used. The reduction of power losses in the grid during the transition from 10 to 35 kV does not compensate for the increase in the cost of conductors and electrical equipment.

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