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DEVELOPMENT AND IMPLEMENTATION OF 20 KV INTELLIGENT POWER DISTRIBUTION NETWORKS

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Abstract- The issues of employment of 20 kV voltages for power distribution networks (PDN) have been considered in this paper. The main advantages of 20 kV PDNs, compared to 6-10 kV PDNs are: reduction of electrical power loss, increasing transmission capacity of lines, increase power transmission range, reducing the short-circuit currents, etc. The results of the comparative calculation of load loss of electrical energy for 6, 10 and 20 kV PDNs are also shown.

Keywords: Overhead and Cable Power Line, Loss of Electrical Energy, Power Distribution Network, Electrical Supply Network.

I. INTRODUCTION

Upgrading power distribution networks is one of the major areas. Currently, the grave state of power distribution networks is due to:
- High degree of physical deprecation and obsolescence of electrical equipment;
- Significant loss of electrical energy (up to 15% of power loss);
- Low level of automation.

Growth of electric load often leads to the technical limit of the use of existing networks. Alternatively laid lines, new generating supplies are introduced in order to provide new consumers with electric supply. However, the mentioned approaches do not solve the problem of provision industrial enterprises and cities with electric power of required quantity and quality.

One of the ways to reduce electric power loss in a power network is to employ 20 kV voltages instead of 6-10 kV. A number of regulations establishes the priority of transition to a 20 kV voltage from 6 (10) kV, as a promising and necessary line of development of the PDN complex [1-6].

Majority of the average voltage urban PDNs are currently functioning as passive means of electric power transmission and distribution. These networks are characterized by high wear on equipment, large electric power loss. In addition, the existing networks sometimes do not meet the requirements of power supply reliability and prevent more widespread use of renewable sources of electrical energy.

Smart Grid Intelligent Networks technology is implemented in a number of energy systems in North America, Europe and Asia. Intelligent network combines complex tools to control and monitor the state of its elements, information technology and means of communication, provides automatic efficient management of power production, distribution and consumption. Such a network can automatically adapt, restore itself by changing its configuration, depending on modes of and disturbances in the network.

Russia's energy strategy for the period of up to 2030 [1] states the target of transfer of the power industry to an innovative path of development which is based on building of a smart energy system (SES) based on active-adaptive grid (smart grid) (AAG).

Most of works are devoted to the basics of building a smart grid (AAG) energy systems and smart substations. Problems of intelligent urban power networks in Russia have not been properly worked out yet. There are no scientifically based technical solutions on topology of intelligent urban PDNs, their modes of operation, control and protection, restraining their widespread use.

II. WORLD EXPERIENCE IN OPERATION OF URBAN 6-20 KV PDNs

Power supply system means an array of electrical networks of all voltages, located in the city and intended for power supply of its consumers. There are power supply networks of 35-110 kV voltage and PDNs of 0.38 kV and 6-20 kV. [3] Special attention should be given to the structure and topology of 6-20 kV average voltage networks, as they are located as close to the consumer as possible and have a greater extent in comparison with the baseline networks.

The results of foreign studies have shown that taking into account all factors and related power industry development risks requires, in the future, a review of conventional approach, principles, and its functioning mechanisms, development of new ones, capable to ensure sustainable development, a breakthrough increase in consumer properties and energy efficiency [6].

This solution required the development of a new concept of innovative development of the power industry, which, on the one hand, would correspond to modern ideas, goals and values of social and community development, to emerging and anticipated needs of people and society in general, and, on the other hand, would as much as possible take into account the main trends and directions of scientific-technical progress in all sectors and areas of life and activity of the society. Smart Grid Technology (SMART - Self Monitoring Analysis and Reporting Technology - self-diagnostic, analysis and reporting technology, GRID (Eng.) - Grid, grid, grid), has become this type of concept, which is the subject of many publications [1-2].

The network functioning has to be optimized, acquired data analyzed, it is also necessary to reduce electric power loss, increase its safety and efficiency. There are software that meet these requirements. They are developed by such large companies as Schneider Electric, Siemens, ABB, of Alstom, etc.

The problem of a structure selection is important for urban networks, since it predetermines the condition of uninterruptibility of power supply to consumers. In accordance with applicable rules and regulations, inhabited localities are subdivided into groups depending on population (Table 1) [3].

Table 1. Subdivision of cities and villages into groups

City, Village	Population (thousands)	
	City	Village
Largest	> 1000	-
Large	500-1000	> 10
Big	100-250	5-10
Middle	50-100	3-5
Small	< 50	< 3

Urban power supply systems currently used, depending on their size and historical development**.** In 6-20 kV networks with cable lines double-beam and loop circuits [2, 3], open in normal mode, are most often used.

A. Technical and Operational Problems of Existing Distribution Networks

Radial, main and loop circuits have been used since times of GOELRO **(**State Electrification of Russia**)**plan for electrification up to the present day up to the present day and have proven themselves in practical use. However, according to a large number of experts, the electric grid complex has reached the peak of its life cycle and requires modernization.

The emergence of new and renewable energy sources (RES) has opened up new opportunities for "clean" energy and the development of small and distributed energy [2].

Modern technologies of information and communication systems, digital signal processing techniques and computing power of modern processors enable new control systems, capable of operating in real time, and intelligent digital devices of adaptive relay protection, quickly analyzing the current situation in the network and proactively receive control solution.

Thus, the trends in the development of the electric power industry indicate that the movement of power in electrical distribution networks will be "bi-directional", which introduces technical difficulties in management of urban network modes.

Existing urban PDNs are characterized by a number of significant problems. The physical deprecation and obsolescence of basic assets. Electrical power loss in PDNs is large and accounts for about 10-15% of the production of EE [5, 6]. Network infrastructure, loads and needs to increase and RES leads to complication of operation.

The 6-10 kV electrical networks in operation are barely controlled. In urban areas there is yearly increase in requirements for power supply reliability. Power outage, even for the consumers of 3rd category of power supply, often leads to loss of valuable data, economic loss in business. Therefore, responsible consumers often install additional stand-alone diesel generators or uninterruptible power supplies.

Analysis of the experience of 20 kV voltage application for power supply of large settlements. 20 voltages widely used in countries of the European Union and the United States

1900–a power system was created in Baku, linking the two stations: 36.5 MW and 11 MW with power transmission line cable 20 kV. The EPS of Azerbaijan (Baku) linking the two stations: 36.5 and 11 MW electricity transmission line cable 20.

The 20 kV was introduced as a standard in the early 60s in Russia, but has not historically had wide application. Currently, dozens of countries and regions in the world use 20 kV as average voltage of PDNs. In 1948, parts of networks of this voltage were used in the United States, France and Germany for the first time.

Many European countries - Italy, Austria, Bulgaria, Poland, Hungary, etc. (80% of the area of Europe) began transition to 20 kV voltages since the 60s of the 20th century. Currently, the networks of this voltage are widely used in Asian countries, including China, Korea, Taiwan, Singapore, etc. 20 kV voltage is used throughout Finland and Estonia.

Deep input substations with secondary 20 kV voltage are used in many major cities with a high building density, for example, in central areas of Paris. The 20 kV secures foothold in major metropolitan areas of Russia these days. According to most expert power men, employment of 20 kV voltage is the main direction of development of the average voltage networks in the capital.

Estimation of optimal urban PDN voltage. Advantages of higher category voltage for large urban networks are apparent. Various technical and economic estimations of the optimal voltage selection for distribution networks are shown in [3].

If the cross section of the line is changed from 50 to 150 mm^2 reduction in the unit cost of 6 kV cables is 1.63; for 10 kV cables - 1.55; for 20 kV cables - 2.06 and for 35 kV cables - 2.35 times. Thus, the efficiency of application of large cross section cables increases with increasing voltage of the transmission line.

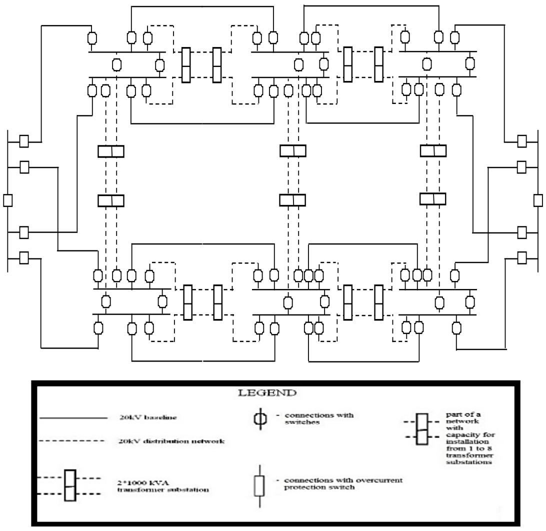

Figure 1. Plotting principle for drawing a 20 kV power supply network

The 35 kV voltages have unquestionable advantages in power transmission efficiency. However, there are a number of shortcomings hindering its development in cities with high building density: 35 kV switchgears are, most often, carried out open, but power lines - overhead.

This requires a large territory for the right of way, making it impossible to use this voltage in urban environment with the high building density and high cost of land for substations, distribution substations and transformer substations;

• execution of the complete gas-insulated switchgear (GIS) and 35 kV cable lines leads to large capital expenditure and unjustified increase in the cost of load nodes (Table 1.11.);

• dimensions till live parts are 2.46 times greater than for 10 kV, and 1.6 times greater than for 20 kV, which increases proportions of equipment 2-2.5 times. The effect: difficulties in use in intra shop networks and high-rise buildings;

• increased demands on service personnel and operation difficulty in comparison with 10-20 kV.

The 20 kV equipment, in fact, is not very different from 10 kV networks. They are the same category networks in terms of switchgear circuits and layout.

The 20 kV equipment (transformers, switches, switchgear cabinets) is a complete, compact size and is comparable with the 10 kV equipment. The difference is only in the level of isolation.

III. ANALYSIS OF ELECTRICAL POWER LOSS IN 6, 10 AND 20 KV NETWORKS

Electrical power loss is one of the most important economic indicators of an electrical network enterprise. Its value reflects the technical condition and level of operation of all transmission units, the state of registration systems and metrological provision for instrumentation stock, the effectiveness of electrical power sales activity.

Load power loss in the line is determined by one of two formulas, depending on available information about the load of the head part - transmitted active W_P and reactive energy W_Q during T period, or the maximum current carrying capacity $I_{\max}$:

$$\Delta W_H = 3I_{\max}^2 T R_{eq} \tag{1}$$

where, R_{eq} is equivalent resistance of the line; T is the time period; and $I_{\max}$ is maximum current load.

Analysis of the specific and electrical power loss in 6-10 kV and 20 kV cables is carried out. Figure 2 shows dependence of specific and electrical power loss on transmission capacity for a 120 mm^2 cross-section cable (0.258 Ohm/km). The analysis results show 2.7 times less power loss in 20 kV equipment than in 10 kV equipment and 7.5 times less than in 6 kV equipment as shown in Figure 3.

Maximum transmission length of a unit of power provided 10% power loss for 6, 10 and 20 kV networks was determined using analytical method. The study showed that 1 MW power can be transmitted to a maximum 4.3 km with less than 10% power loss through a 120 mm^2 cross-section cable in a 6 kV network, in a 10 kV network – 12.1 km and in a 20 kV network – 48.5 km. Thus, 20 kV networks allow increase the customer service area by 4-10 times and reduce the number of cells in the feeding centers. Transmission capacity for 120 mm^2 cross section cable has been determined as shown in Figure 4.

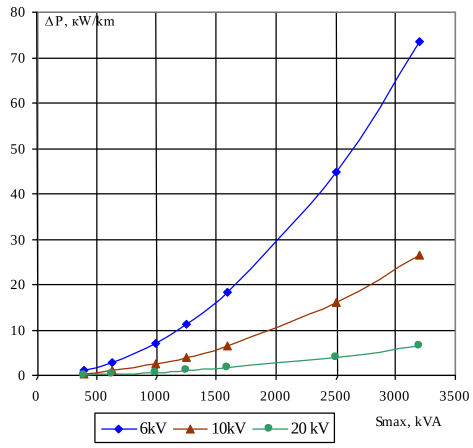

Figure 2. Dependence of specific power loss on transmission power

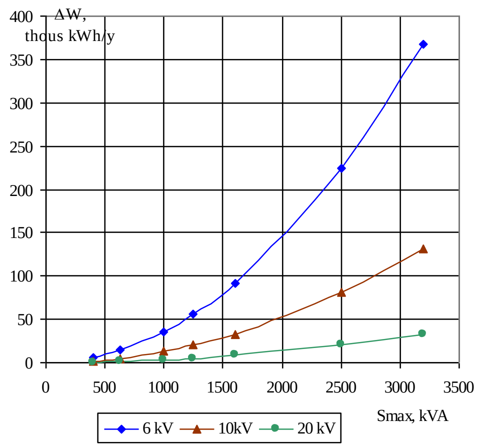

Figure 3. Dependence of specific loss of electrical energy on transmission power

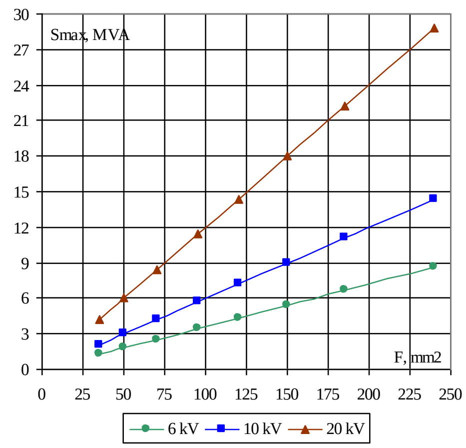

Figure 4. Dependence of cable line transmission capacity on voltage

Comparative analysis revealed that the 20 kV line transmission capacity is three times the 6 kV line transmission capacity and 1.9 times that of the 10 kV.

IV. DEVELOPMENT OF FORMATION PRINCIPLES OF THE INTELLECTUAL URBAN 20 KV PDN

In its current state majority of baseline PDNs are not capable of ensuring effective connection of a large number of small power stations (distributed generation), running on renewable energy sources (RES) [5]. Distribution systems were not historically designed for integration of a large number of power generating units, namely decentralized and distributed energy sources [6].

To date, as a rule, energy generated by these power stations is not properly covered by supervisory control, and the power of electrical energy transmitted to the network is dependent either on natural conditions or the power plant owner's wish. For a variety of political and economic reasons in Europe significant increase in capacity due to distributed generation is expected. Introducing new capacity with distributed power generation will demand growth of both baseline and power distribution networks (PDNs) [9].

There is a need to replace and build PDN and organize a new intelligent control system and control the power flow. Therefore, establishing an intelligent, "flexible", self-regulating average voltage distributed network ensuring automatic, efficient production management, distribution and consumption of electric power capable of automatic adaption, regeneration and changing its configuration depending on the network mode and disturbances is a pressing task.

V. CONCLUSIONS

1. Construction expediency of 20 kV distribution networks for new urban development areas and reconstruction of old ones is grounded.
2. Numeric technological and operational advantages in terms of 2-3-fold transmission capacity increase while maintaining the transformer capacity, customer service range increase by 3-8 times, reducing electrical power loss and loss in equipment power by 3-7 times are determined.
3. According to results during transition from 6 kV to 20 kV voltage power saving is up to 15-20%.
4. It has been established that there should be a systematic approach to elimination of the abovementioned drawbacks of urban PDNs and to implementation of new, efficient, automated, self-restoring 20 kV distribution networks.

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