ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 8, Issue 10 , October 2021

Increasing the Capacity of Cable Lines with Dynamically Changing Load

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ABSTRACT: The article discusses the development of cable lines with a dynamically changing load and the choice of cable cross-sections for different laws of load growth on the basis of an optimization model.

KEY WORDS: unification, billing period, initial load, load growth factor, dynamic programming.

I.INTRODUCTION

At present, electrical distribution networks are characterized by a constant increase in loads. In these conditions, the correct choice of the parameters of power transmission lines and, first of all, the cross-sections of wires of overhead lines and cables of cable lines (CL) is of great importance, taking into account the increase in the capacity of the lines [1].

II. PRACTICAL

Increasing the transmission capacity of cable lines is impossible due to their design features [2]. In connection with the difficulties of increasing the transmission capacity of cable lines and dynamically developing networks, the problem of choosing the optimal cross-section of cable cores for lines with a constantly growing load is becoming more acute. Based on the foregoing, two options for the development of the cable network are theoretically possible. The first option is to select the cross-section of cables based on the load at the end of the design period, equal to the service life of the cable line, in order to provide the required line throughput without reconstruction during the entire service life of the cable. The second option is that the cable cross-section is selected based on the load at the end of the design period, which is less than the service life of the cables, and then the throughput is increased by laying a parallel cable.

At the same time, based on the conditions of comparability of comparison of possible development options, taking into account the specifics of cable lines, the full settlement period should be taken equal to the service life of the cable line. However, in real conditions, there is no necessary reliable information about the change in load for such a long period. Therefore, it is necessary to initially determine the optimal trend in the development of cable lines with a dynamically changing load, which would allow making the right decisions in terms of cable networks based on information for a shorter period than the service life of cable lines.

III. ANALYSIS LOAD GROWTH LAWS

When researching, it is advisable to investigate the development of CL with a sawtooth pattern of load growth. Such an increase in the load also makes it possible to conduct research in conditions similar to those in reality, when the load is broken down. In this case, the load grows according to one of the considered laws until the moment of time when its downsizing occurs (let's call it the network reconstruction time t_{pi}). In this case, the load decreases abruptly to a certain value, and then again its further increase in the next reconstruction. Graphically, such a change in load is shown in Fig.1. For the service life of the cable line, equal to 30 years, it is advisable to consider no more than two load breakdowns, and therefore two load surges on the power transmission line under consideration.

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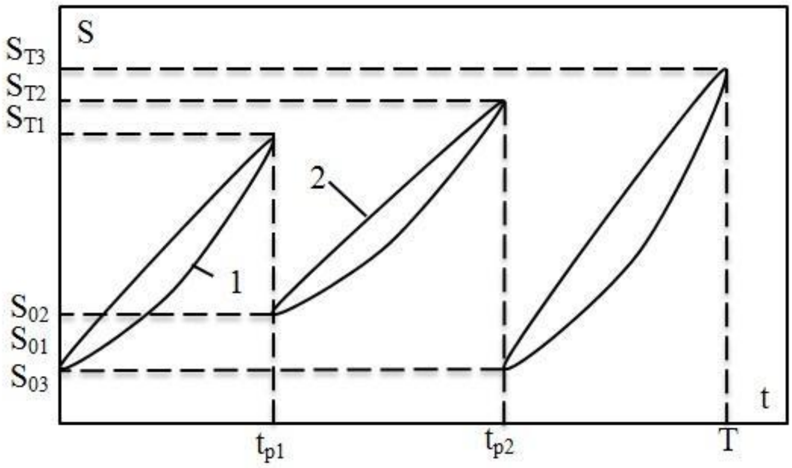

Fig. 1. Load growth laws.
1 - exponential with sawtooth load growth; 2 - linear with sawtooth load growth.

Mathematically, such a change in loads can be expressed as follows. With an exponential law of load growth and two downsizing in accordance with Fig.1 can be written:

$$\text{if} \quad \begin{cases} 0 \le t \le t_{\text{p1}} \\ t_{\text{p1}} < t \le t_{\text{p2}} \\ t_{\text{p2}} < t \le T \end{cases} \quad \text{then} \quad \begin{cases} S_t = S_{T1}\left(1 + k_{\text{пр1}}\right)^{t - t_{\text{p1}}} \\ S_t = S_{T2}\left(1 + k_{\text{пр2}}\right)^{t - t_{\text{p2}}} \\ S_t = S_{T3}\left(1 + k_{\text{пр3}}\right)^{t - T} \end{cases} \tag{1}$$

However, in what form it is not very convenient to carry out the analysis. Let us express$S_{\text{т}2}$ and $S_{\text{т}3}$in terms of the coefficients $S_{T1} = S_T$, which we will call the load downscaling coefficients k_{pi}. Moreover, they can be either more than 1 or less than 1. Then you can write

$$S_{T1} = S_T;\ S_{T2} = k_{p1} S_T;\ S_{T3} = k_{p2} S_T.$$

Thus, finally, we get

$$\text{if} \quad \begin{cases} 0 \le t \le t_{\text{p1}} \\ t_{\text{p1}} < t \le t_{\text{p2}} \\ t_{\text{p2}} < t \le T \end{cases} \quad \text{then} \quad \begin{cases} S_t = S_T\left(1 + k_{\text{пр1}}\right)^{t - t_{\text{p1}}} \\ S_t = k_{p1} S_T\left(1 + k_{\text{пр2}}\right)^{t - t_{\text{p2}}} \\ S_t = k_{p2} S_T\left(1 + k_{\text{пр3}}\right)^{t - T} \end{cases} \tag{2}$$

By analogy for the linear law of load growth, we can write

$$\text{if} \quad \begin{cases} 0 \le t \le t_{\text{p1}} \\ t_{\text{p1}} < t \le t_{\text{p2}} \\ t_{\text{p2}} < t \le T \end{cases} \quad \text{then} \quad \begin{cases} S_t = S_T\left(1 + k_{\text{пр1}} t_{\text{p1}}\right)^{-1}\left(1 + k_{\text{пр1}} t\right) \\ S_t = k_{p1} S_T\left(1 + k_{\text{пр2}} t_{\text{p2}}\right)^{-1}\left(1 + k_{\text{пр2}} t\right) \\ S_t = k_{p2} S_T\left(1 + k_{\text{пр3}} T\right)^{-1}\left(1 + k_{\text{пр2}} t\right) \end{cases} \tag{3}$$

With the sawtooth nature of the load change between reconstructions, it is inappropriate to consider the load growth according to the law of a simple modified exponent. In this case, the load grows up to a certain limit, and then its growth stops. Consequently, in this case, there is no need to reconstruct the network in order to increase its throughput, since the power line can be immediately designed for this final load.
To select the cable section of the cable line and increase its throughput with a further increase in the load, an optimization model has been developed [3], which corresponds to the following situation possible in real conditions. The algorithm, which is as follows:

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1. There is a consumer, for whose power supply it is necessary to build a cable line with a certain cable cross-section and in the future, due to an increase in the load, to increase its throughput. For a given consumer, the dynamics of load growth during the study period is known. Cables with nominal cross-sections are available.
2. Initially, the laying of one cable of each of the cross-sections or two parallel cables of any of the cross-sections, including equal ones, is considered. In the course of operation, with an increase in the consumer's load, the following options are considered for each year: the originally accepted cable (or parallel cables) remains or an additional second cable is laid in parallel with the existing cable. In this case, options are considered with all nominal cable cross-sections.
3. In the first case, the choice of the cable cross-section is made according to the nearest load, and then when the load reaches the maximum permissible value, the line capacity is increased by laying a parallel cable. With this approach, the initial capital investment is small, but the cost of covering electricity losses in the line is higher and there are additional capital investments for reconstruction.
4. In the second case, the cable cross-section of the cable line is chosen immediately of such a size (or it is immediately planned to lay two parallel cables with the corresponding cross-sections of the conductors) so that in the future, within the accepted period, it is not necessary to increase the throughput of the power transmission line in question. At the same time, there will be large initial capital investments, but relatively lower costs for reimbursing electricity losses.
5. At each step, the accepted cable cross-sections are checked for throughput. Continuous permissible load current and permissible voltage loss are taken as limitations. If the considered cable core sections do not correspond to the conditions of long-term permissible load currents or permissible voltage losses, a penalty function is introduced (i.e., a value is added in terms of costs, several orders of magnitude higher).

IV. ANALYSIS THE CHOICE OF CABLE CROSS-SECTIONS WITH A SAWTOOTH NATURE OF THE LOAD GROWTH

The results of the study based on the optimization model with the sawtooth nature of the load growth are shown in Fig.2. In this case, the change in the initial load was set in the range from 20 to 1000 kW. The boundaries of the loads for the sawtooth nature of its growth are constructed with the following initial data: the calculated period of years$T = 30$; time of the first reconstruction years $t_{p1} = 10$; time of the second reconstruction years $t_{p2} = 10$. The value of the coefficients $k_{p1}$and k_{p1} was taken equal to 1. The value of the load growth coefficient was taken to be the same for the entire calculation period and equal to 0.075. To study the influence of the law of load growth (exponential or linear) with the sawtooth nature of its change, the conditions of comparability were met, i.e. the same multiplicity of growth of the load with exponential and linear laws of its growth.
With the sawtooth nature of the increase in the load for the entire calculation period, cables with the required cross-section of conductors are immediately selected and an increase in the throughput of the cable line during operation is not required. Fig.2, it can be seen that with the sawtooth nature of the change in the load for the linear and exponential laws of growth, not only the trends in the choice of the section coincide, but also the boundary loads.

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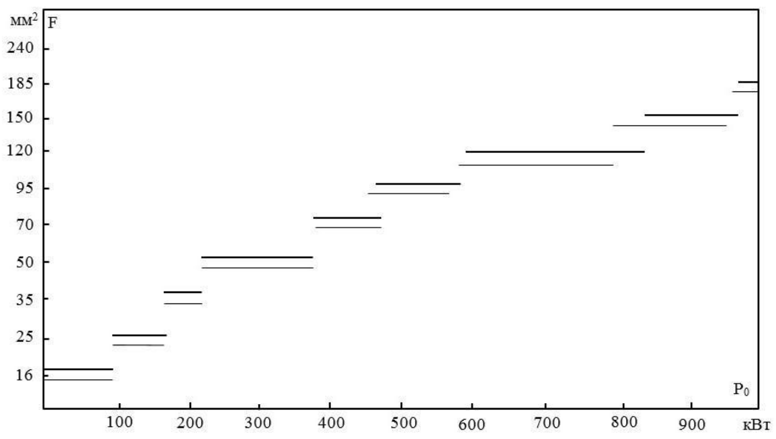

Fig. 2.The choice of cable cross-sections with a sawtooth nature of the load growth.
Load growth law: ——— linear; ———exponential

The only exceptions are the boundary loads for cables with cross-sections of 95, 120 and 150 mm^2. With an exponential law of growth of the load, the boundaries for these sections are slightly higher. Thus, with the sawtooth nature of the change in the load, the law of its growth also does not affect the established optimal tendency for the selection of the cable cross-section.

V. CONCLUSIONS

Thus, a comparison of the tendency in the selection of the cable cross-section with a sawtooth nature of the load change and with the corresponding law of load growth for a calculated period equal to the time period before the first reconstruction with a sawtooth nature of the load change showed that the tendencies in both cases are the same. However, in the first case, the choice of the same section occurs at lower initial loads than in the second. That is, taking into account the increase in load outside the design (10 years) period affects the choice of the size of the cable cross-section, which can be seen from Fig.2 (thick lines show the boundary loads for the sawtooth nature of the load change with an exponential law of its growth and thin lines - with an exponential law of load growth and a calculated period of years$T = t_{\text{p}1} = 10$.

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