SELECTION OF 6-500 kV CABLE LINES TAKING INTO ACCOUNT OVERLOADS

Mikhail Dmitriev, PhD
info@voltplace.com

In the previous article [1], the question was raised about the need to systematize the approach to choosing the power load of 6-500 kV cable lines with cross-linked polyethylene (XLPE) insulation. In particular, when choosing a sufficient cross-section of the core, it is proposed to take into account the ability of the cable to overload.

An analysis of a number of projects in the field of electric power industry shows that the permissibility of overloads is often not taken into account not only for new types of equipment, but even for well-known and long-used in networks. Let's talk about the overload capabilities of transformers and cables, which designers should take into account.

Keywords: cable line, cross-linked polyethylene (XLPE), operation mode, cable overload, permissible temperature, current-carrying capacity.

1. INTRODUCTION

One of the important points in the development of any high-voltage project is the selection of equipment and its nominal parameters for current, power, etc. Realizing the importance of the decisions taken, but at the same time not having sufficient knowledge and experience, young designers, who are now in the majority of design institutes, just in case overestimate the requirements for equipment, preferring a more powerful one that will work with a reserve.

There are also cases when the reserve is provided not by overstating the requirements for parameters, but by the appearance of additional pieces of equipment in the project: the number of metal-oxide surge arresters (MOA) increases, a decision is made to install shunt reactors on the overhead transmission lines, although this is often not necessary [2].

The ideology of reserves as a whole is justified because there is not always reliable information about the network development scheme, its operating modes, and electric loads. But do not forget that the equipment of the electrical network allows overloading. If this is not taken into account, then the released design solutions, in fact, will have a double reserve:

– a reserve "just in case" when formulating equipment requirements (for example, it may be associated with taking into account the prospective growth of network loads under an excessively active scenario);
– reserve directly when choosing the equipment itself, associated with the failure to take into account permissible overloads for equipment, permitted by a number of regulatory documents and manufacturers.

The double reserve that arises for these reasons can hardly be considered justified, because it leads to a significant increase in the cost of energy facilities, and sometimes it cannot increase, but even reduce the network reliability. In particular, unloaded transformers enter into ferroresonance, reactors on the lines cause problems with aperiodic currents and resonant overvoltages [2], MOA due to an incorrect choice cause short-circuits to ground.

The purpose of the article is to put the attention of specialists to the fact that overloads, sometimes very significant, are permissible for network equipment. Let's explain this by the example of power transformers and cable lines (Fig.1).

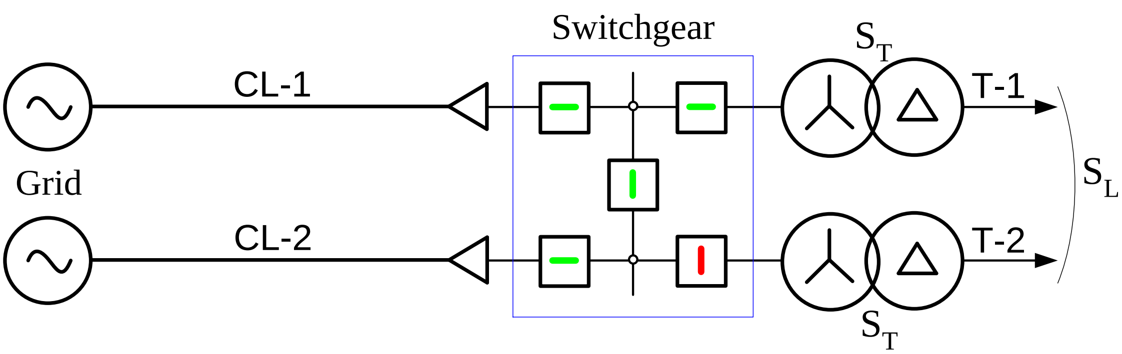

Fig.1. Power supply scheme of a switchgear with two installed transformers.

2. POWER TRANSFORMERS

Consider the diagram in Fig.1, where a switchgear with two power transformers (T) receives power via a two-circuit cable line (CL).

In the scheme, when choosing the transformer power S_T, the calculated situation is assumed when one transformer (T2) is put into long-term repair, and another is in operation. The power S_T of each of two transformers can be found from the expression:

$$K_{OV} \cdot S_T = S_L \tag{1}$$

where S_L is the total load power for entire substation, K_{OV} is the transformer overload factor.

In general, the value of the K_{OV} depends on many circumstances, including the design of the transformer itself (oil-type or dry), and the number of parallel transformers operating, and the variability of the load during the day. All these factors ultimately make it possible to understand whether the operation of a power transformer with a load in excess of its rated power (overload operation) is permissible, what is the magnitude of such an overload, with what frequency it can occur and how long it lasts.

As a rule, overload is permissible if the mode in which it occurs is time-limited. As an example, Fig.2 shows a daily load schedule with hours of increased power consumption. The ability of the transformer to work with some overload allows you to choose its rated power S_T not for the maximum load S_L, but for a smaller amount S_L/K_{OV} according to (1).

Permissible overloads of equipment, taking into account their duration, are the most important information necessary when designing electrical networks. The load graph is also important. For example, in Fig.2a it can be seen that the load remains at a minimum level for most of the day, that is the temperature of the transformer windings is low. Hence, here for the transformer, increased K_{OV} is permissible and the rated power S_T will be noticeably less than the maximum load value S_L.

In Fig.2b, the load graph, in contrast to Fig.2a, is more uniform, and the rated power S_T is not so much different from the maximum load S_L.

It is obvious that the joint competent accounting of the overload capacity (factor K_{OV}) and the daily load graph gives grounds to use transformers selected not for the maximum of the electric load, but for a smaller amount. Such transformers will be cheaper.

We will further give estimates of the coefficient K_{OV} for various transformers. For dry-type transformers, the overload capacity depends on the manufacturing technology [3]:
– for transformers with cast insulation, overload is not allowed, $K_{OV} = 1$;
– for transformers with "open" windings, an overload of 20% is permissible, $K_{OV} = 1.2$.

For oil transformers, unlike dry ones, overload resistance has been studied in more detail, and the corresponding standard GOST [4] is valid in USSR. It establishes a method for calculating permissible systematic loads and emergency overloads according to the specified initial data, as well as the norms of such loads and overloads for the daily load graphs of transformers, taking into account the temperature of the ambient cooling medium. Important provisions [4] are:

1. Permissible systematic loads do not cause a reduction in the normalized service life of the transformer, since during the duration of the load graph, normal or reduced calculated insulation degradation is provided compared to normal.
2. Permissible emergency overloads cause increased calculated insulation degradation compared to normal, which can lead to a reduction in the normalized service life of the transformer, if the increased degradation is not subsequently compensated by loads with degradation of the coil insulation below the nominal.

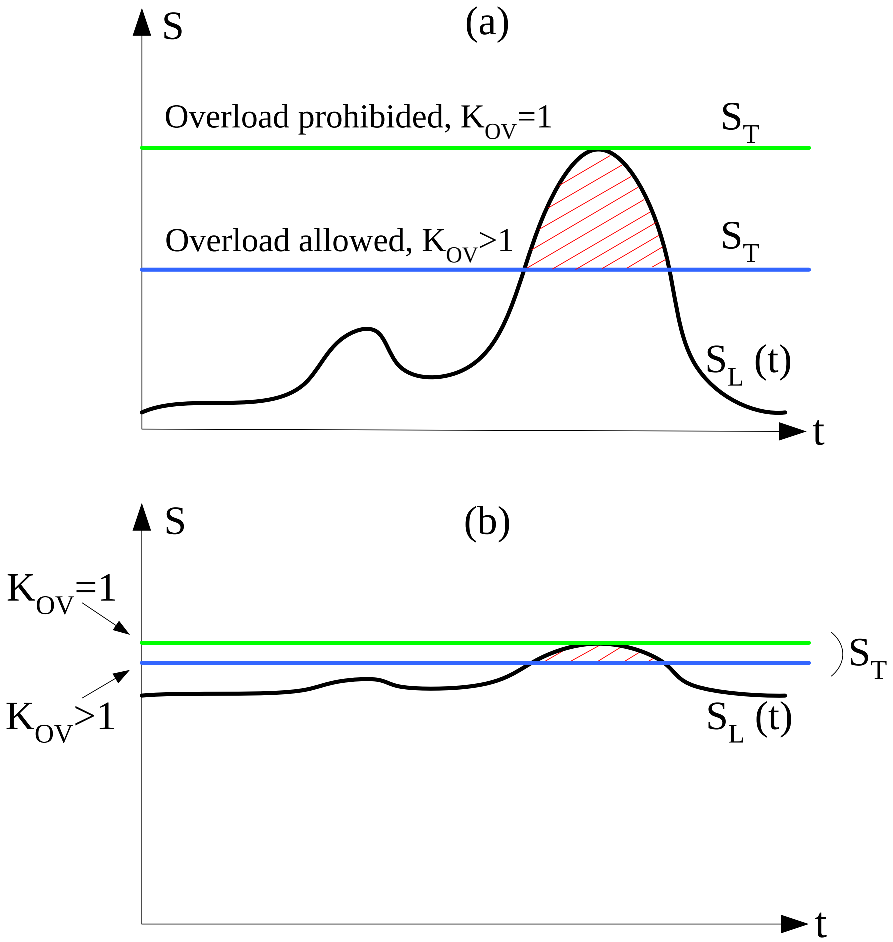

Fig.2. Selection of the rated power S_T of the transformer according to the load type $S_L(t)$:
(a) – sharply variable load $S_L(t)$;
(b) – almost uniform load $S_L(t)$.

For example, according to the standard [4], under certain conditions, systematic (daily) is permissible for oil transformers load increase by 40% ($K_{OV} = 1.4$), and emergency overloads can reach 60-80% with no dangerous coils' insulation degradation.

In addition to the overload coefficient K_{OV}, such a concept as load coefficients K_L could be used for transformers. In normal operation mode, when both transformers are at work (Fig.1), each of them carries half of the substation load S_L and then the load factor:

$$K_L = \frac{S_L/2}{S_T} = \frac{K_{OV}}{2} \quad (2)$$

where K_L is the transformer normal mode load factor, K_{OV} is the transformer overload factor.

If overloads are not allowed for the transformer or they are possible, but are not taken into account, then when choosing a transformer according to (1), $K_{OV} = 1$ is assumed, and then in normal mode according to (2), the load is only $K_L = 0.5$. This means the following:

– almost the entire service life of the transformer it operates with a load of less than 50%;
– only at certain hours of the daily graph does the transformer work with a load of 50%;
– only a few times during the service life there is a situation when, due to the disconnection of a neighboring transformer, work takes place at full load up to 100%.

In the considered case excluding overloads ($K_{OV} = 1$, $K_L = 0.5$), it is necessary, when purchasing a transformer, to use at best half of its rated power. Unfortunately, in recent years such projects are not uncommon, even when it comes to oil transformers, which according to [4] have a good overload capacity.

If we take into account, as it should be, the overload capacity of the transformer, for example, $K_{OV} = 1.4$, then in normal mode $K_L = 0.7$, which is more like the efficient use of funds invested in equipment:

– almost the entire service life of the transformer works with a load of less than 70%;
– only at certain hours of the daily graph does the transformer work with a load of 70%;
– only a few times during the service life there is a situation when, due to the disconnection of a neighboring transformer, work takes place at full load up to 140%.

3. CABLE LINES

Unfortunately, not every type of high-voltage electrical equipment has a methodology for calculating permissible systematic loads and emergency overloads, as it is done earlier for power oil-type transformers [4]. The reasons may be as follows:

– no need for such a technique (for example, if the equipment does not allow overloading);
– insufficient operational experience to produce a method that would take into account the issues of resource consumption during overloads and its savings during underloads.

Currently, cable lines (CL) with XLPE insulation are increasingly used in 6-500 kV networks. As a rule, CL have two parallel circuits at once, and when choosing the core cross-section (or rated power), exactly the same questions appear that had to be dealt with in the diagram Fig.1 for two parallel transformers.

Sorrowfully, the established practice is such that when designing cables, their ability to overload is ignored and $K_{OV} = 1$ is accepted. Therefore, the load factor in normal mode is only $K_L = 0.5$. In other words:

– almost the entire service life of the cable works with a load of less than 50%;
– only at certain hours of the daily load graph the cable works with a load of 50%;
– only a few times during the service life there is a situation when, due to disconnection of the adjacent cable, work takes place at full load up to 100%.

In fact, even during the maximum hours of the daily load graph, the real (actual) cable load factor is often not 0.5, but less (for example, 0.3-0.4). The fact is that when designing networks, not the real load is considered, but the prospective one, determined taking into account the plans for the development of the energy system and the growth of consumption, which often remains "on paper".

Given the high cost of 6-500 kV cable lines, reaching million euro for each kilometer of the route, their small load (in fact, no more than $K_L = 0.3 \div 0.4$) seems wasteful. A way out of the situation can be found if, by analogy with the transformer standard [4], the issue of permissible systematic loads and emergency overloads for cables is worked out.

For example, it was noted in [5] that cables with XLPE insulation can be overloaded. For a certain number of hours a year, we assume that they are heated not to 90°C, but to 105°C. In [1], an expert assessment is given that such an increase in temperature will correspond to an increase in the power transmitted over the cable by about 10%, i.e., it will amount to $K_{OV} = 1.1$. Such a coefficient is noticeably less than for transformers according to [4] ($K_{OV} = 1.4$), but it would also allow in some cases to save on the cost of the cable by reducing the cross-section of the core.

Taking into account the ability of the cable to overload allows you to justify the possibility of using a smaller core cross-section, which means saving on the cost of the cable, but the cost of power losses in the core also requires comments, because it will increase.

The cost of power losses in the core is determined mainly by the mode in which the cable operates most of the time, and as has been shown, this is the mode of about $K_L \approx 0.5$. In this mode, the power loss proportional to the square of the current will be 0.25 p.u., i.e., 4 times less than if the cable was operating at a nominal load of $K_L \approx 1$. It is not difficult to show that the cost of losses of the 0.25 p.u. level, that cable line has during its lifetime, is too small in comparison with the cost of the cable itself, and therefore, when choosing the optimal core cross-section, it is necessary to be guided by the possibility of reducing the cost of the cable, without paying attention to some increase in the cost of active power losses.

A graphical interpretation of these considerations is presented in Fig.3, which shows the cost of the cable and the cost of power losses depending on the core cross-section F_C. It is advantageous to take such a core cross-section F_C, at which there will be a minimum cost of ownership of the cable, equal to the sum of the cost of the cable itself and power losses in it. It is achieved when the cross-section of the core corresponds to the point of intersection of green and blue curves. The selected cross-section should then be checked for the ability to pass load currents in repair operation modes when one of the two circuits is disconnected.

As follows from Fig.3, with a load factor of $K_L \approx 0.5$, the curves of the cost of the cable and the cost of losses will intersect with such a small core cross-section F_C that it will clearly be insufficient to provide the necessary current-carrying capacity in repair modes. Therefore, the choice of the cable core is made for reasons of ensuring its sufficient capacity, taking into account the resistance of the cable to overload, but not according to the criterion of minimum active power losses.

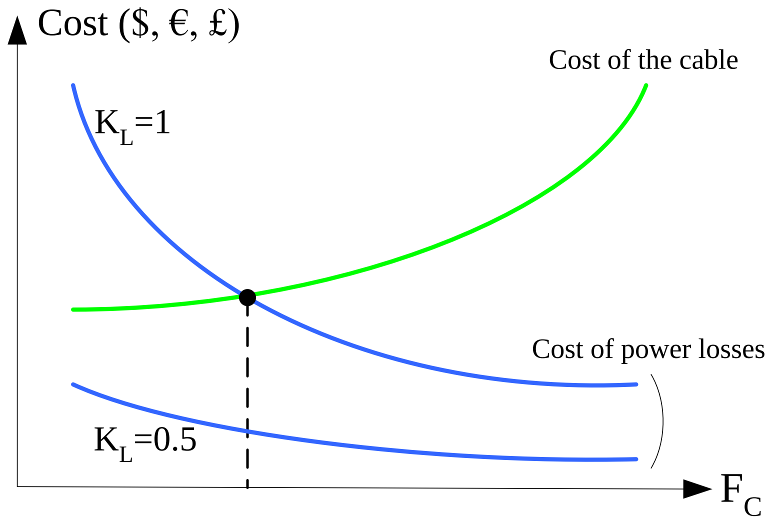

Fig.3. Choosing the optimal core cross-section, taking into account the cost of the cable and cable active power losses.

4. CONCLUSIONS

Projects in the field of electric power industry implemented in recent years are such that the equipment of the networks is operated at loads significantly lower than those long-term permissible values specified in the documentation.

The reason for this is a kind of double reserve in the design. Firstly, focusing on the planned (expected) active development of electric networks, excessive requirements for the characteristics of equipment electric power load are formed. Secondly, even when choosing equipment, the unevenness of the power load and the ability of the equipment to perform its functions in conditions of systematic and emergency overloads are mistakenly ignored.

In order to increase the efficiency of electrical networks, it is recommended to study more closely the admissibility of overloads for various types of equipment by analogy with how it is done in standard [4] for power transformers of paper-oil insulation type.

First of all, it is advisable to focus on 6-500 kV cables with cross-linked polyethylene (XLPE) insulation due to their high cost, and therefore a significant economic effect from taking into account the ability to overload. There is reason to believe that the power (current) overloads of at least 10% are permissible for such cables.

REFERENCES

1. Dmitriev M. "Selection of load parameters of 110-500 kV cable lines" // "The Electrical Engineering News" magazine, No1(91), 2015
2. Dmitriev M. "Requirements for compensation of 500-750 kV overhead line charging power" // "The Electrical Engineering News" magazine, No5(83), 2013.
3. Ivanov S.N. "Dry power transformers. Variety of types and parameters" // "The Electrical Engineering News" magazine, No2(68), 2011.
4. GOST 14209-85 "General purpose oil power transformers. Permissible loads".
5. STO 56947007-29.060.20.072-2011 "Power cable lines with a voltage of 110-500 kV. Organization of operation and maintenance. Norms and requirements" //JSC "FSK EES", 2011.