International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 4, Issue 4, April – 2020, Pages: 29-32

Types of Power Losses in Electric Networks

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Abstract — *In recent years, the demand for electricity has increased sharply due to the superiority of electricity over all other types of energy, and the expansion of electricity production and transmission has been severely limited due to limited resources, environmental constraints, and lack of privatization, as can be found in developing countries such as Uzbekistan, etc. Regardless of how the power system is designed, losses are inevitable and must be modeled to an accurate calculation the view can be calculated. This work is devoted to the mathematical analysis of losses occurring in electrical networks power system.*

Keywords — electric energy; consumer; losses of electricity ; technological losses ; Load losses;

INTRODUCTION

When electric energy is transferred, losses occur in each element of the electric network. In order to study the components of losses in various network elements and assess the need for an activity aimed at reducing losses, an analysis of the structure of electricity losses is performed.

Actual (reported) losses of electricity ΔW_{act} are defined as the difference between the electricity received into the network and the electricity supplied from the network to consumers. These losses include components of a different nature: losses in the network elements that are purely physical in nature, energy consumption for the operation of equipment installed in substations and providing power transmission, errors in the fixation of electricity by metering devices and, finally, theft of electricity, non-payment or incomplete payment meter readings, etc.

Separation of losses into components can be carried out according to various criteria: the nature of losses (constant, variable), voltage classes, groups of elements, production units, etc. Given the physical nature and specificity of methods for determining the quantitative values of actual losses, they can be divided into four components:

1) Technical power loss ΔW_T, due to physical processes in wires and electrical occurring in the transmission of electricity for the electricity grid.

2) the energy consumption for the auxiliary needs of substations ΔW_{AN}, necessary to ensure the operation of the technological equipment of the substations and the life of the maintenance personnel, determined by the readings of meters installed on the transformers of the auxiliary needs of the substations;

3) energy losses due to instrumental errors in their measurement (instrumental losses) ΔW_{ins};

4) commercial losses ΔW_{com} due to theft of electricity, inconsistency of meter readings with payment for electricity by household consumers and other reasons in the field of organization of control over energy consumption. Their value is defined as the difference between the actual (reporting) losses and the sum of the first three components:

$$\Delta W_{com} = \Delta W_{act} - (\Delta W_T + \Delta W_{AN} + \Delta W_{ins.}) \qquad (1)$$

The first three components of the loss structure are determined by the technological needs of the process of electric power transmission through networks and instrumental accounting of its receipt and supply. The sum of these components is well described by the term *technological losses* . The fourth component - commercial losses - is the impact of the " human factor " and includes all its manifestations: conscious theft of electricity by some subscribers by changing meter readings, non-payment or incomplete payment of meter readings, etc.

The criteria for attributing part of the electricity to losses can be physical or economic. [1].

The sum of technical losses, energy consumption for own needs of substations and commercial losses can be called *physical* losses of electricity. These components are really related to the physics of energy distribution over the network. In this case, the first two components of physical losses relate to the technology of electric power transmission through networks, and the third - to the technology of controlling the amount of electric power transferred.

The economy defines *losses* as part of the electricity for which its registered productive supply to consumers turned out to be less than the electricity produced at its power plants and purchased from its other producers. At the same time, the registered useful supply of electricity here is not only that part of it, the money for which really came to the settlement account of the energy supplying organization, but also the one that was billed, i.e. energy consumption is fixed. In contrast, the actual readings of meters that record energy consumption by household customers are unknown. The useful supply of electricity to household subscribers is determined directly by the payment received per month, therefore, all unpaid energy is attributed to losses.

From the point of view of the economy, the energy consumption for the auxiliary needs of substations is no different from the consumption in network elements for transferring the rest of the electricity to consumers.

The underestimation of the volumes of useful electricity supplied is the same economic loss as the two components described above. The same can be said about the theft of electricity. Thus, all four of the loss components described above are the same from the economic point of view.

Technical energy losses can be represented by the following structural components:

load losses in substation equipment. These include losses in lines and power transformers, as well as losses in measuring current transformers, high-frequency traps (HT) HF - communications and current-limiting reactors. All these elements are included in the " dissection " of the line, i.e. sequentially, therefore the losses in them depend on the power flowing through them.

open circuit losses, including losses in electricity in power transformers, compensating devices (CD), voltage transformers, meters and devices for connecting HF communications, as well as losses in the insulation of cable lines.

climatic losses, which include two types of losses: losses on the crown and losses due to leakage currents through the insulators of overhead lines and substations. Both species are weather dependent.

Technical losses in the electrical networks of energy supplying organizations (power systems) should be calculated over three voltage ranges [4]:

in high voltage power supply networks of 35 kV and higher;

in distribution networks of medium voltage 6 - 10 kV ;

in distribution networks of low voltage 0.38 kV.

Distribution networks of 0.38 - 6 - 10 kV , operated by RES and PES, are characterized by a significant share of electricity losses in total losses along the entire chain of electricity transmission from sources to power consumers . This is due to the peculiarities of the construction, operation, organization of operation of this type of network: a large number of elements, branched circuits, insufficient supply of metering devices, relatively low load of elements, etc. [3]

Currently, for each DES and TES of power systems, technical losses in the networks of 0.38 - 6 - 10 kV are calculated monthly and summed over the year. The resulting loss values are used to calculate the planned standard for electricity losses for the next year.

Next, we consider in more detail the structural components of technical losses of electricity.

LOAD LOSSES OF ELECTRICITY

Energy losses in wires, cables and transformer windings are proportional to the square of the flow thereon the load current and therefore of the call load losses. The load current, as a rule, varies over time, and load losses are often called variables [1].

Load losses of electricity include:

Losses in lines and power transformers, which in general terms can be determined by the formula, thousand kWh :

$$\Delta W_{Transmission} = 3\cdot R\cdot\int_0^T I^2(t)dt = 3\cdot\Delta t\cdot\sum_{i=1}^{T/\Delta t} I_i^2, \quad (2)$$

where *I (t)* is the current of the element at time *t* ;

Δt is the time interval between successive measurements, if the latter were carried out at equal sufficiently small time intervals. Losses in current transformers. Losses of active power in a CT and its secondary circuit are determined by the sum of three components: losses in the primary ΔP_1 and secondary ΔP_2 windings and losses in the load of the secondary circuit ΔP_{n2}. The normalized value of the load of the secondary circuit majority TT voltage of 10 kV and a rated current of less than 2000 A, the main constituent of all BTs operating in networks is 10VA with accuracy class CT K_{CT} = 0,5 and 1 VA at K_{CT} = 1,0. For CTs with a voltage of 10 kV and a rated current of 2000 A or more, and for CTs with a voltage of 35 kV, these values are two times higher, and for CTs with a voltage of 110 kV and higher - three times more. For losses of electricity in the CT of one connection, thousand kW-h for the settlement period of duration T , days:

$$\Delta W_{CT} = (a + b\cdot\sqrt{K_{CT}})\cdot\beta_{CTequ}{}^2\cdot T\cdot 10^{-6}, \quad (3)$$

where β_{CTeq} - coefficient of equivalent current load CT ;

a and *b are the* coefficients of the dependence of the specific power losses in the CT and in its secondary circuit Δp_{CT}, having the form:

$$\Delta p_{CT} = 2\cdot[40 + 2\cdot(6 + 0.5\cdot 15\sqrt{K_{CT}})] = 104 + 30\sqrt{K_{CT}}\ . \quad (4)$$

Losses in high-frequency communication choke. The total losses in the airspace and the connection device on one phase of the overhead line can be determined by the formula, thousand kWh:

$$\Delta W_{HF} = (\Delta P_{nom}\cdot\beta_{HT}{}^2 + \Delta P_{cd})\cdot T\cdot 10^{-3}, \quad (5)$$

where β_{HT} is the ratio of the rms operating current HT for the calculated period to its rated current;

ΔP_{CR} - losses in the connection devices.

LOSS OF IDLE

For electric networks 0.38 - 6 - 10 kV, the components of idling losses (conditionally constant losses) include:

-Losses of idle electricity in a power transformer, which are determined for time T by the formula, thousand kWh:

$$\Delta W_I = \frac{\Delta P_I}{U_N} \cdot \int_0^T U^2(t)dt \text{ , (6)}$$

where ΔP_I - transformer idle power loss at rated voltage U_N; U (t) is the voltage at the connection point (at the HV input) of the transformer at time t.

-Losses in compensating devices (CD), depending on the type of device. In distribution networks of 0.38-6-10 kV, mainly static capacitor banks (BSC) are used. The losses in them are determined on the basis of the known specific power losses ΔP_{BSC}, kW / kvar:

$$\Delta W_{BSC} = \Delta P_{BSC} \cdot \Delta W_{QBSC} \text{ , (7)}$$

where $W_{Q\,BSC}$ is the reactive energy generated by the capacitor bank during the billing period. Typically, ΔP_{BSC} = 0.003 kW / kvar.

-Losses in voltage transformers. Active power losses in VTs consist of losses in the VT itself and in the secondary load:

$$\Delta P_{VT} = \Delta P_{1VT} + \Delta P_{2VT}. \text{ (8)}$$

-Losses in the VT itself ΔP_{1VT} consist mainly of losses in the steel core of the transformer. They grow with the growth of the rated voltage and for one phase at the rated voltage are numerically approximately equal to the rated voltage of the network. In distribution networks with a voltage of 0.38-6-10 kV, they are about 6-10 watts.

-Losses in the secondary load ΔP_{2VT} depend on the accuracy class of K_{VT} of VT. Moreover, for transformers with a voltage of 6-10 kV, this dependence is linear. At rated load for VTs of this voltage class $\Delta P_{2VT} \approx 40$ W. However, in practice, the secondary circuits of VTs are often overloaded, therefore, the indicated values must be multiplied by the load factor of the secondary VT circuit β_{2VT}. Given the foregoing, the total loss of electricity in the VT and the load of its secondary circuit is determined by the formulas, thousand kWh:

$$\Delta W_{VT} = (\mathrm{U} + \beta_{2VT} \cdot \Delta P_{2VT} \cdot K_{VT}) \cdot T \cdot 10^{-6} \text{ , (9)}$$

-Losses in the insulation of cable lines, which are determined by the formula, kWh:

$$\Delta W_{cab} = T \cdot b_c \cdot U^2 \cdot tg\phi \cdot L_{cab} \text{ , (10)}$$

where b_c is the capacitive conductivity of the cable, Siemens / km;
U is the voltage, kV;
L_{cab} - cable length, km;
tgφ is the dielectric loss tangent determined by the formula:

$$tg\phi = (0.003 + 0.0002 \cdot T_{oy}) \cdot (1 + a_\tau \cdot T_{oy}) \text{ , (11)}$$

where T_{oy} is the number of years of cable operation;
a_τ - aging coefficient taking into account aging of insulation during operation. The increase in the tangent of the angle dielectric loss is reflected by the second bracket of the formula.

CONCLUSION

In conclusion, we can say that since the power consumption in electrical networks depends on various factors. Including, which are external environmental impact, feature of cable lines, voltage value, processing time, reactive power compensation equipment.

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