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Electrical energy losses in the time zones

Streszczenie. *W artykule pokazano zasady podziału strat napięciowych, obciążeniowych i handlowych na strefy czasowe z uwzględnieniem przepływów energii w sieciach. Straty energii w strefach czasowych są obliczane według czasów odpowiednich dla danego rodzaju strat, przy znanych stratach bilansowych. Podano podział strat energii dla stref czasowych w sieci dystrybucyjnej jednej ze SD. (**Straty energii elektrycznej w strefach czasowych**)*

Abstract. *The paper presents the rules, making possible - with regard of the energy flows in the network - dividing of the voltage, load, and commercial energy losses into the assigned–to-the-particular-time-zones parts. The energy losses in the time zones are being calculated – under the known balance losses – according to the times corresponding with the particular categories of the losses. The division of the energy losses into the time zones has been demonstrated for an exemplary Distribution Company network.*

Słowa kluczowe: sieć dystrybucyjna, straty energii elektrycznej, taryfy
Keywords: distribution network, electrical energy losses, tariffs

Introduction

The problem of calculating the duration of peak loads and of maximal losses in the time zones is relatively new. Meters measuring electrical energy and power consumption in the time zones are not installed with every consumer. The computer programme used by a number of distribution companies for calculating losses in distribution networks computes the total loss in 24-hour periods. It is sufficient for loss analysis, however, for the sake of developing energy tariffs the detailed knowledge of loss distribution among the time zones is necessary. Obviously, the division of loss into time zones cannot be proportional to the zone duration, losses are not distributed equally. A method of dividing losses among the time zones with the consideration of the flow structure in the low-voltage, medium-voltage and 110 kV networks will be discussed in this paper. It is assumed that the total loss is known.

Principles of Dividing Losses Among the Network Types

The energy flowing through the 110 kV network can be sold to consumers fed at 110 kV as well as to consumers fed at medium and low voltages. The Energy Act prohibits cross-subsidy (section 2 clause 17) thus, the loss occurring in the 110 kV network has to be divided among consumers fed from all the networks. Voltage losses and current losses will be divided in different ways.

Load loss division

The load loss depends on the square of energy flowing through the network. If the energy flowing in the 110 kV network and sold to consumers fed from 110 kV is E_{110}, from the medium-voltage network is E_{SN} and from the low-voltage network is E_{nN}, then losses in the 110 kV network are

(1) $$\Delta E_{110} = k(E_{110} + E_{SN} + E_{nN})^2 = \\ = k\left[E_{110}^2 + E_{SN}^2 + E_{nN}^2 + E_{110}(E_{SN} + E_{nN}) + E_{SN}(E_{110} + E_{nN}) + E_{nN}(E_{SN} + E_{110})\right]$$

where: k- is the proportion factor, ΔE_{110}- losses energy in the 110 kV network, E_{110} – energy sold to consumers fed from 110 kV, E_{SN} - energy sold to consumers fed from medium voltage networks, E_{nN} - energy sold to consumers fed from low-voltage network.

As can be seen in Eq. (1) it is impossible to uniquely determine the loss occurring in a given network. It can be done by means of numerical methods or by establishing mean losses per 1 MWh of energy sold, since there is no way of differentiating energy sold to medium-voltage consumers from that sold to low-voltage consumers. Then, losses corresponding to the medium- and low-voltage consumption can be obtained.

Loss Division

Three categories of time values must be distinguished for the adequate account of loss division:

- The yearly duration T_r, jointly 8760 h, divided into time zones depending on the prescribed zones within 24 hours, treating Saturdays, Sundays, and holidays as off-peak zones. Voltage losses are divided according to this pattern.
- The duration of the maximal load T_s. The duration is calculated depending on the energy flow structure in a particular set of network components and duration times T_r for the particular zones. The sum of maximal load durations T_s is obtained from the programme STRATY'96. Accounting losses are divided accordingly.
- The duration of the maximal loss τ, calculated on the basis of the duration times T_s. Load losses are divided accordingly.

The simplest case is the division of voltage losses, which are independent of load and can therefore be divided proportionally to the duration times T_r.

The departure point for analyzing losses in time zones is the yearly duration time T_r. It is used not only as the basis for computing voltage loss, but also as the basis for computing the other times. The yearly duration time is the sum of the time zones, specified within the 24 hours period, with the consideration of 1- season of the year differences, 2-separate treatment of holidays, included in the off-peak zone.

Loss Proportions

The load loss is proportional to the duration time τ, as follows from

(2) $$\Delta E_{obc} = k \cdot P_s^2 \cdot \tau$$

where: k – proportion coefficient, ΔE_{obc}-the load loss of energy, P_S - the peak load, τ - duration of the maximal loss.

Expressing differently P_s (2), one obtains the formula

(3) $$\Delta E_{obc} = k \frac{E^2}{T_s^2} \tau$$

where *E* - the energy sold to consumers.

Since the peak power is the most reliable, its value is taken into account in formulas for the duration of the peak load and of the maximal loss in the zones. Thus, the energy sold to consumers in a network can be represented as

$$E = \sum_i E_i = P_s \sum_i T_{si}$$

where: i-index of time zone.

The load loss is

$$\Delta E_{obc} = \sum_i \Delta E_{obci} \tag{4}$$

Inserting into (4) the dependences for the time zones resulting from (2) and (3), one obtains the formula

$$\Delta E_{obc} = k \sum_i \frac{E_i^2}{T_{si}^2} \tau_i = k P_s^2 \sum_i \tau_i \tag{5}$$

The comparison of (4) to (5) leads to the formula

$$k P_s^2 \tau = k P_s^2 \sum_i \tau_i \tag{6}$$

For three time zones the (6) can be represented as

$$k P_s^2 \tau = k P_s^2 \left(\tau_{s1} + \tau_{s2} + \tau_{s3} \right) \tag{7}$$

Multiplying both sides of (7) by $\Delta E_{obc} / \left(k P_s^2 \right)$, one obtains the formulae

$$\Delta E_{obc} \tau = \Delta E_{obc} \left(\tau_{s1} + \tau_{s3} + \tau_{s3} \right) \tag{8}$$

$$\Delta E_{obc} = \Delta E_{obc} \frac{\tau_{s1}}{\tau} + \Delta E_{obc} \frac{\tau_{s2}}{\tau} + \Delta E_{obc} \frac{\tau_{s3}}{\tau} \tag{9}$$

Comparing (9) with (5) and generalizing, one obtains the final result

$$\Delta E_{obci} = \Delta E_{obc} \frac{\tau_{si}}{\tau} \tag{10}$$

It follows that when dividing the load loss into the time zones it is enough to know the loss for the whole network and the ratio of the maximal loss duration in the i-th time zone to the maximal loss duration in the whole network.

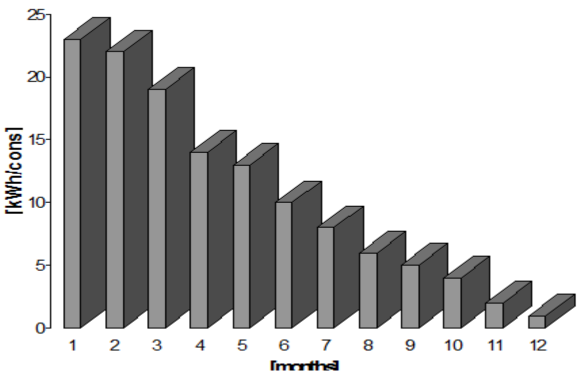

Fig. 1 Ordered load curve for the accounting loss

The third kind of loss is the accounting loss, typical of low voltage consumption and occurring with the consumers, and not in the network. The analysis of the accounting loss, mainly associated with illegal electricity consumption, in a few tens of distribution network areas was performed and indicated that the loss runs parallel to the basic load. Accounting losses [2,5] occur mainly in autumn and winter and it can be assumed that their division into time zones is similar to the load, i.e. proportional to the duration times T_s

Fig.1 shows the ordered load curve for the illegal electricity consumption (accounting loss) in 37 distribution areas. The graph is not identical to those load graphs commonly used for calculating the duration T_s. Such graphs represent 15-minute powers, and the one for the accounting loss represents the monthly energy loss. What matters most however, is to compare the values of T_s with the values of T_{sh} (comercial loss duration) for a given low-voltage network. The value of T_s is typically known from the programme STRATY96, whereas the value of T_{sh} may not be known.

At the beginning of the analysis it has to be noted that the accounting loss ΔE_h is the loss of energy flowing through the network. Thus, talking about the accounting loss, one must remember that this a linear relationship, and not a square value in the function of power [3], as in the case of the load loss.

The ordered graph shown in Fig.2 can be replaced by two straight lines [1,4], whose construction is based on finding the coordinates of point $A\left(P_o, t_{sh}\right)$. For the sake of convenience, relative units will be used: T_r=1and P_s=1.

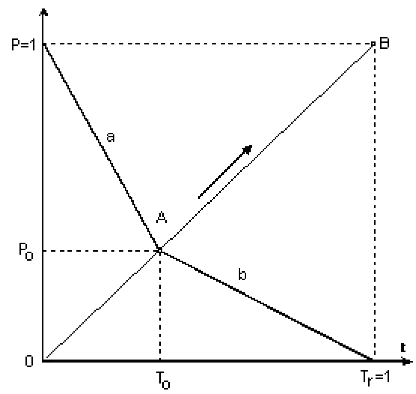

Fig. 2 Ordered load curve replaced by two straight line sections [1]

The equations of the lines for the low-voltage network are

$$P_{ta} = 1 + \left(1 - \frac{1}{P_o} \right) t \tag{11.a}$$

$$P_{tb} = \frac{P_o}{P_o - 1} \left(t - 1 \right) \tag{11.b}$$

The accounting loss is

$$\Delta E_h = \int_0^{t_{sh}} \left[1 + \left(1 - \frac{1}{P_o} \right) t \right] dt + \int_{t_{sh}}^{1} \left[\frac{P_o}{P_o - 1} \left(t - 1 \right) \right] dt \tag{12}$$

where t_{sh}- relative duration of the peak load with the accounting loss.

Since $P_o = t_{sh}$ [4], the following is true

(13)

$$\Delta E_h = \left[t + \frac{1}{2} \left(1 - \frac{1}{t_{sh}} \right) t^2 \right]_0^{t_{sh}} + \left[\frac{1}{2} \frac{t_{sh}}{t_{sh} - 1} t^2 - \frac{t_{sh}}{t_{sh} - 1} t \right]_{t_{sh}}^{1}$$

Having solved (13), one obtains the result

$$t_{sh} = \Delta E_h \tag{14}$$

In order to obtain the accounting loss in relative units it is necessary to calculate the area under the ordered load graph. For the situation examined the accounting loss is 0,43, i.e. t_{sh}=0,43. The result obtained from the programme STRATY96 for the load in the same network t_s=0,3. On the basis of these data it is possible to represent the load as two lines for the energy sold and for the accounting loss, as shown in Fig. 3.

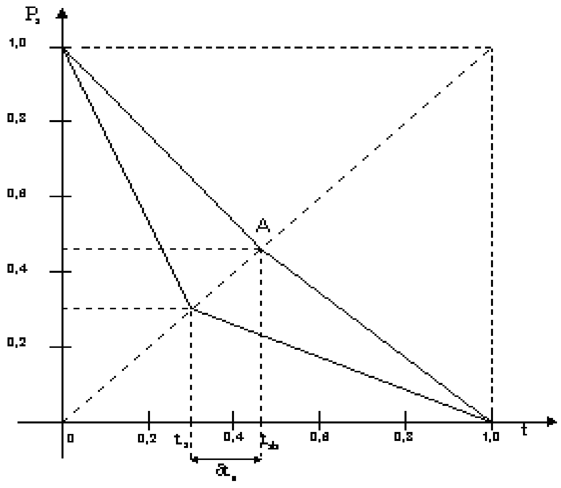

Fig. 3 Load represented as two lines for energy sold and for the accounting loss

As evident in Fig. 3, the time t_{sh} diverges from t_s. Since only the time t_s is known in the network, it is necessary to use the proportion coefficient α to bring t_{sh} to t_s. Thus

(15) $$t_{sh} = \alpha \cdot t_s$$

The accounting loss in the time zones is

(16) $$\Delta E_h = \sum_i \Delta E_{hi} = P_{sh} \sum_i T_{shi}$$

For the three time zones Eq. (16) can be represented as

(17) $$P_{sh} T_{sh} = P_{sh} \left(T_{sh1} + T_{sh2} + T_{sh3} \right)$$

Multiplying both sides of Eq. (17) by $\Delta E_h / P_{sh} T_{sh}$, one obtains the formula

(18) $$\Delta E_h = \Delta E_h \frac{T_{sh1}}{T_{sh}} + \Delta E_h \frac{T_{sh2}}{T_{sh}} + \Delta E_h \frac{T_{sh3}}{T_{sh}}$$

Inserting (15) into (18) and solving, one obtains the formula

(19) $$\Delta E_h = \Delta E_h \frac{T_{s1}}{T_s} + \Delta E_h \frac{T_{s2}}{T_s} + \Delta E_h \frac{T_{s3}}{T_s}$$

Generalising formula (19), one obtains finally

(20) $$\Delta E_{hi} = \Delta E_h \frac{T_{si}}{T_s}$$

It follows that to divide the accounting loss into the time zones it is enough to know the loss in the whole network and the ratio of the peak load duration in the i-th zone to the peak load duration in the whole network for the energy flowing in it.

Computation example

The energy losses, divided into the load, voltage, and commercial ones, have been demonstrated in figure 4; they concern an exemplary Distribution Company power network.

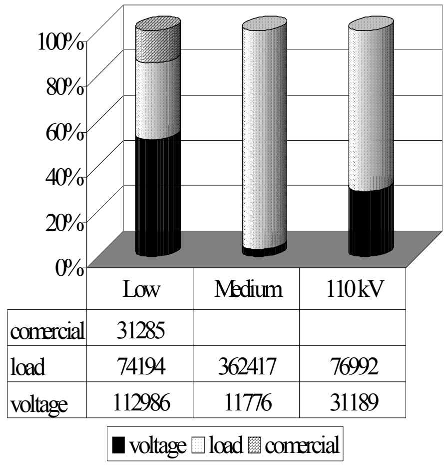

Fig.4. Electrical energy losses for a Distribution Company

It has been assumed that the low-voltage network supplies with the electrical energy in two time zones 20% of consumers, while 80% of consumers are being supplied in one time zone. The figures 5-7 show the energy losses divided into the particular time zones.

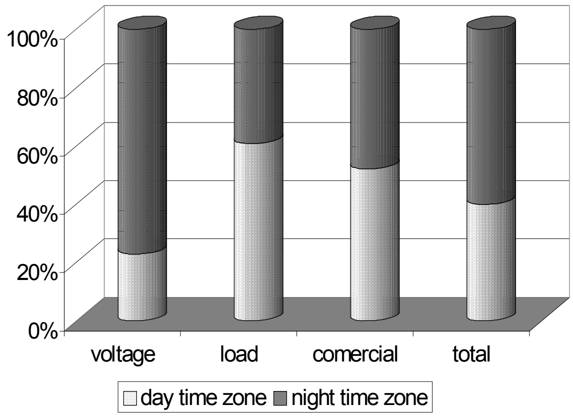

Fig.5. Energy losses, divided into two time zones, in the low-voltage network

The greatest voltage losses in the low-voltage network occur during the night time zone, while the greatest load and commercial ones – during the day time zone. The voltage losses constitute 52% of the balance losses, so majority (60%) of the low-voltage balance losses arises during the night time zone.

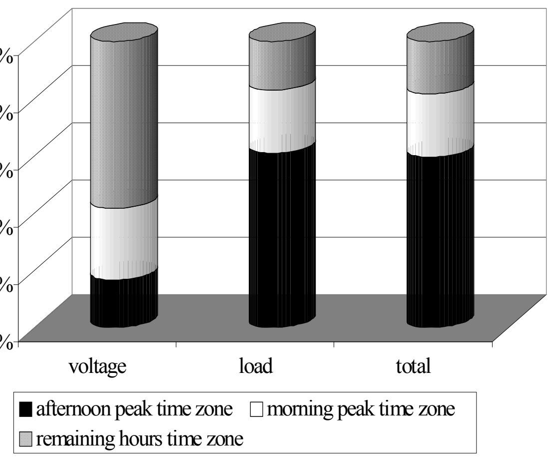

Fig.6. Energy losses, divided into three time zones, in the medium-voltage network

The greatest voltage losses in the medium-voltage network arise during the peak time zone. The voltage losses constitute 3,1% of the balance losses, so they slightly influence the division of losses into the time zones.

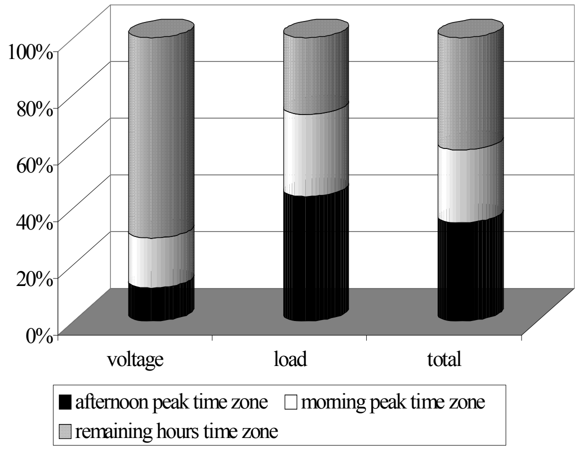

Fig.7. Energy losses, divided into three time zones, in the 110 kV network

The greatest voltage losses (80%) occur in the remaining hours time zones. The load losses divide themselves into the particular time zones as follows: 44% - afernoon peak time zone, and 27% - morning peak time zone, and 29% - remaining hours time zone. The majority of the total losses (39,6%) arises during the remaining hours time zonem but the time duration of this zone constitutes 70,7% of the annual time.

Conclusion

The peak load duration time and the maximum loss duration one – in the particular time zones – are necessary in order to divide the total energy losses into parts corresponding to the time zones. A connexion between the maximum loss duration time and the peak load duration time can be determined [1, 4] by substituting of the orderly load curve with two segments of straight line. If these times, and the yearly energy losses: load, voltage, commercial are known, then the balance losses in the distribution network can be calculated for the particular time zones.

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