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DETERMINATION OF POWER LOSSES FROM TRANSIT FLOW IN ELECTRIC NETWORKS

The paper proposes a procedure for determination of power losses from transit flows in the electric system .networks. The procedure is based on the superposition method. Calculations are performed on the basis of current distribution for the linear model of the normal mode of the electric system operation, which is fully equivalent to the initial non-linear model for a given moment of time.

Key words: *electric power system, power transit, power losses distribution.*

Introduction

In the conditions of parallel operation of electric systems (ES) as the components of the integrated power systems (IPS) of Ukraine, for the intersystem effect realization, rational use of power resources as well as for compensating the shortage of power and electric energy in some regions there exists a necessity for considerable transit electric energy flows via the networks of power systems. This causes additional (as compared with the operation mode without electric energy transit) technological electric energy consumption in the transit networks – electric energy losses from transit flows [1].

The latter are not taken into account as a separate characteristic of the efficiency of the Ukrainian IPS operation because optimal modes are developed by the electric modes optimization service of “Ukrenergo” national company according to the criterion of minimal total fuel consumption with the losses in the main (system-making) electric networks being taken into account.

Therefore, growth (or reduction) of the electric energy losses from transit flows in the transit networks as compared to the initial value could be caused by the changes in the amount of electric energy transit due to economy considerations as well as with emergency situations in the adjacent power systems.

Another case connected with the influence of transit flows on the amount of electric energy losses concerns voltage variations in the control points of the transit power system due to its operation modes optimization as to the reactive power and transformation ratio. Such optimization within one power system may contradict the operative instructions of “Ukrenergo” optimization service concerning the operation modes because the reduction of energy losses in the transit power system can lead to the growth of total losses in the system and, consequently, to the increased total fuel consumption.

Thus, the amount of transit flows and corresponding electric energy losses are not influenced by the control service of the power systems they are going through. [2].

At the same time, technological electric power consumption in the networks of electric power systems is one of the planned indices. On the results of its fulfillment and according to the agreement between the administration and the working personnel, the effectiveness of the personnel work is evaluated and bonuses are given.

Therefore, for objective evaluation of the power system personnel activities as to the reduction of the technological consumption of electric energy in the networks, among the balance losses it is necessary to distinguish electric energy losses caused by transit flows as those which cannot be objectively reduced using the available means.

Electric energy losses from transit flows cannot be measured with counters or determined from the electric energy balance. Their amount can be found using calculations based on the volume and the character of transit as well as on the operation modes in the electric networks of the power system.

Relationship between permissible and transit electric energy losses in the networks of power systems

Calculation of the permissible electric energy losses in the networks of power systems is performed in order to find the substantiated level of the electric energy losses using the balance-sheet information as well as information about design and modes of the lines operation within the reporting period. To find the final amount of losses it is necessary to summarize the losses caused by the consumer’s load, corona losses and losses in the instrument transformers [3]. For the corona losses calculation the data of hydrometeorologic center are used as well as typical specific corona losses from voltage and environmental influence. Electric energy losses in the instrument transformers are calculated proceeding from their number and normative value of the average losses. In order to find the load component of electric energy losses using the reporting data and the method of element-by-element calculations or its modifications are used. The losses caused by electric energy transit are included into the load losses, but they are not represented as a separate component.

In accordance with the above-mentioned components of the permissible losses the following organizational and technical measures are planned to be conducted: the electric network circuit optimization, application of the devices for voltage regulation and the reactive power compensation, replacement of the instrument transformers that do not correspond to the accuracy class as a result of the missing design load etc.

Calculations [4] show that variations of the electric energy losses from transit flows are, in many cases, proportional to the effect obtained from the organizational and technical measures conducted by the power system personnel. Increase of the power transit flow in accordance with the operative instructions on the optimal operation modes can minimize the effect from the mentioned measures and reduce the effectiveness of the power system personnel work.

Therefore, consideration of the electric energy losses as a separate component while using the existing calculation method is the problem of current importance. Its solution will make it possible to develop a more efficient system of material stimulation for the power system personnel.

Determination of power losses from transit flows in PS

The problem of finding electric energy losses from transit flows can be represented as the problem of finding the corresponding components of losses in the branches of the equivalent circuit of PS via which transit electric energy is transferred. In [4] the method of distinguishing power losses from mutual flows is elaborated on the basis of coefficients of power losses distribution. The method is implemented using the expression:

$$\Delta \dot{S}_i = 3 \cdot \left(\sum_{j=1}^{m} I_{ij}^{\prime 2} \mu_j^{\prime} + \sum_{j=1}^{m} I_{ij}^{\prime\prime 2} \mu_j^{\prime\prime} \right) \cdot \dot{Z}_i \ , \qquad (1)$$

where $\mu_j^{\prime} = 1 + \frac{\sum_{\eta=1\ \eta \neq j}^{m} I_{i\eta}^{\prime}}{I_{ij}^{\prime}}$ $\mu_j^{\prime\prime} = 1 + \frac{\sum_{\eta=1\ \eta \neq j}^{m} I_{i\eta}^{\prime\prime}}{I_{ij}^{\prime\prime}}$ – influence coefficients; $\dot{Z}_i$ – resistance of the i-branch; $I_{ij}^{\prime}$, $I_{ij}^{\prime\prime}$ – active and reactive current components in the i- branch from the load current of the j-junction

From (1) it is clear that power losses in the branches of the equivalent circuit of PS, caused by the j-junction current, depend not only on the current load of this junction flowing through them but also on the values of other partial currents that are flowing through this branch, i.e. mutual influence of the partial currents is observed. The measure of this influence is characterized by the coefficients $\mu_j^{\prime}$ and $\mu_j^{\prime\prime}$.

While applying this method for finding power losses from a separate transit flow, it should be taken into account that before the transit appeared, power losses caused by the mutual influence of the currents had been equal to zero. It means that power transit is determined both by the additional losses from the transit current flow and losses caused by the mutual influence. Therefore, power losses from transit must include losses from the current load of the transit as well as those caused by the mutual influence of the main and transit current distribution.

Let's consider the example of the electrical networks circuit with power transit from junction 1 to junction 4 (fig. 1). Current loads of the electric network are determined due to the application of the $\dot{U}$ voltage, known from the mode calculation, and the power of the circuit junction load. The transverse component of the equivalent circuit equivalences in the design loads of the junctions.

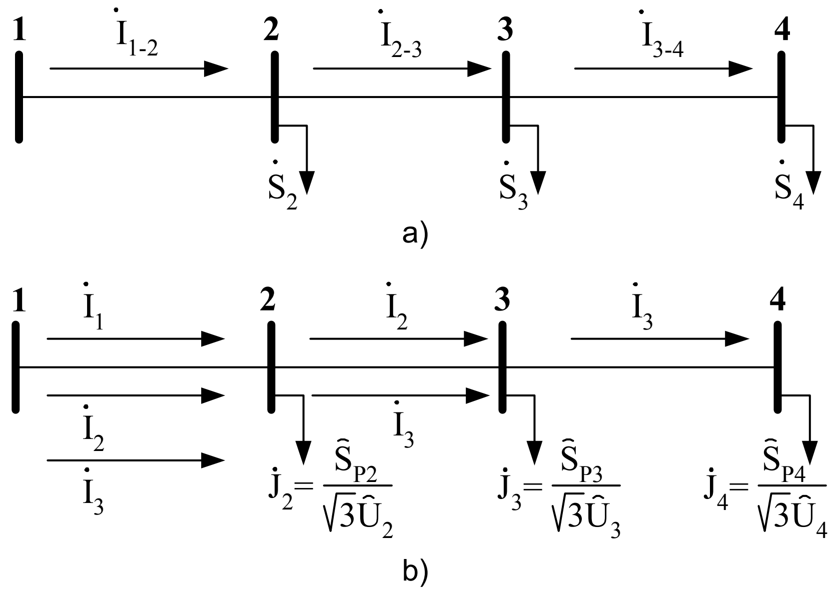

Fig.1 Flowchart of the simplest case of power transit

In accordance with the superposition method, in the line 1 – 2 concordantly directed partial currents $\dot{I}_1,\ \dot{I}_2$, determined by the load of separate consumers, will be flowing as well as current $\dot{I}_3$, caused by the transit power flow. In this case partial flows (see fig. 1b) are equal to the corresponding setting currents $\dot{I}_1 = \dot{J}_2,\ \dot{I}_2 = \dot{J}_3,\ \dot{I}_3 = \dot{J}_4$. Hence, power losses in the line 1 – 2 are determined as:

$$\Delta\dot{S} = 3\cdot\left|\dot{I}_{1-2}\right|^2\cdot\dot{Z}_{1-2} = 3\cdot\left|\dot{I}_1+\dot{I}_2+\dot{I}_3\right|^2\cdot\dot{Z}_{1-2}.$$

In the real plane the equation will have the form of:

$$\Delta\dot{S} = 3\cdot\left[\left(I_1'+I_2'+I_3'\right)^2+\left(I_1''+I_2''+I_3''\right)^2\right]\cdot\dot{Z}_{1-2}, \tag{2}$$

where $I',\ \ I''$ – real and imaginary current components.

After a number of algebraic transformations this expression can be reduced to the form (3):

$$\begin{aligned}\Delta\dot{S} = 3\cdot\Big[&I_1'^2+2I_1'I_2'+I_2'^2+I_1''^2+2I_1''I_2''+I_2''^2+\\&+I_3'^2+2I_1'I_3'+2I_2'I_3'+I_3''^2+2I_1''I_3''+2I_2''I_3''\Big]\cdot\dot{Z}_{1-2},\end{aligned} \tag{3}$$

where transit flow (with mutual influence being taken into account) and load currents are considered as separate components:

$$\begin{aligned}\Delta\dot{S}' &= 3\cdot\left[\left(I_1'+I_2'\right)^2+\left(I_1''+I_2''\right)^2\right]\cdot\dot{Z}_{1-2};\\ \Delta\dot{S}_{tr} &= 3\cdot\left[I_3'^2+2I_1'I_3'+2I_2'I_3'+I_3''^2+2I_1''I_3''+2I_2''I_3''\right]\cdot\dot{Z}_{1-2},\end{aligned} \tag{4}$$

or

$$\begin{gathered}\Delta\dot{S}' = 3 \cdot \left|\dot{I}_{1-2} - \dot{I}_3\right|^2 \cdot \dot{Z}_{1-2}; \\ \Delta\dot{S}_{tr} = 3 \cdot \left[I_3'^2 + 2I_3'(I_1' + I_2') + I_3''^2 + 2I_3''(I_1'' + I_2'')\right] \cdot \dot{Z}_{1-2},\end{gathered} \tag{5}$$

where $\Delta\dot{S}'$ – power losses from current loads of the junctions of the transit electric network without transit; $\Delta\dot{S}_{tr}$ – power losses from transit.

After simplifications, having performed the substitution $\left(I_1' + I_2'\right) = \left(I_{1\text{-}2}' - I_3'\right)$, $\left(I_1'' + I_2''\right) = \left(I_{1\text{-}2}'' - I_3''\right)$ and $I_3' = J_4'$, $I_3'' = J_4''$ we receive:

$$\Delta\dot{S}_{tr} = 3 \cdot \left[J_4'^2\left(2\frac{I_{1\text{-}2}'}{J_4'} - 1\right) + J_4''^2\left(2\frac{I_{1\text{-}2}''}{J_4''} - 1\right)\right] \cdot \dot{Z}_{1-2}. \tag{6}$$

The expression of the form (6) is generalized analogous to (1) for random quantity of partial currents, flowing via the electric circuit element:

$$\Delta\dot{S}_{tri} = 3 \cdot (J_{tr}'^2 \mu_{tri}' + J_{tr}''^2 \mu_{tri}'') \cdot \dot{Z}_i, \tag{7}$$

where $\mu_{tri}' = \left(2\frac{I_i'}{J_{tr}'} - 1\right)$, $\mu_{tri}'' = \left(2\frac{I_i''}{J_{tr}''} - 1\right)$ – coefficients of the power losses from transit flow; I_i', I_i'' – active and reactive components of the total current in the i-branch; n – the number of branches where transit power is flowing.

Expression (7) is valid for the case of finding power losses from one separate transit flow, because the result also includes power losses from the mutual influence caused by this transit.

As a transit flow, that is used for finding $\dot{J}_{tr}$, we take the least value of the total power which the power system receives or gives to the adjacent power systems, or the value that is agreed upon between the parties of the power exchange.

In the case of several transits flowing via the transit networks mutual influence is observed both between transit flows themselves and between load currents of the transitory network, which requires the usage of procedure (4) and expression (1).

For finding the electric energy losses there are two variants to perform calculations: a continuous monitoring of the losses using the telemetric data and application of the load graphs characteristics [5]. In the latter variant power losses calculation is performed for the operation mode of maximal loads ΔP_{max} or for average loads ΔP_{av}. Using said power losses, the electric energy losses ΔW are calculated for T period by the following formulas:

$$\Delta W = \Delta P_{max} \tau, \tag{8}$$

$$\Delta W = \Delta P_{av} T\, k_f^2, \tag{9}$$

where τ – the number of hours with maximal losses; k_f^2 – coefficient of the load graph form.

Conclusions

1. Parameters of the transit flows and corresponding electric energy losses from them, practically, cannot be adjusted by regulating means of the power system, the networks of which they are flowing through. They cannot be also measured by counters or determined from the electric energy balance. Said component of the losses can be found using calculations based on the volume and character of the transit flow as well as on the operation modes of the power system main network.
2. Increase of the power transit flow according to the operative instructions on the power system modes may reduce the effect from the implementation of organizational and technical measures. Therefore, considering electric energy losses from transit flows as a separate component, using the

calculation procedures, will enable adequate evaluation of the work on the reduction of the technological consumption of electric energy in the power system networks.

3. The method for finding power losses from a separate transit flow is based on the physically substantiated scheme of the losses calculation, main notions of the electric engineering and generally accepted procedures for steady-state mode calculation. Unlike many other methods, it enables determination of power losses from transit flow for a definite moment of time proceeding from the results of the electric network current mode calculation and measured (specified) transit power.

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