N. V. Semeniuk

STRUCTURING OF POWER LOSSES IN ELECTRIC ENERGY GRID, TAKING INTO ACCOUNT THE INTERACTION OF DIFFFERENT FACTORS

The paper considers the existing approaches to calculation of losses emerging while power transmission, the pros and cons of their practical application. The possibilities of application of the method of transit losses calculation, using the matrices of node resistances of electric grid and nodes power for various approaches to determination of transit losses are shown.

Key words: *power transit, transit power load losses, matrices of node resistances, network inhomogeneity, losses components.*

Introduction. The existing problem of rather low profitability of some energy-supplying companies (ESC) urges to look for the new approaches of power loss calculation in electric energy grids . This primary index of their economical functioning indicates both the efficiency of ESC energy distribution, and reveals the problems appealing to up-to-date solutions of development, reconstruction and technical re-equipment of electricity grids; improvement of methods and means of their operation and control; enhancement of energy metering accuracy, effectiveness of collection policy for already consumed electricity etc.

On the whole, the increase of power losses in electric energy grids is specified by a number of rather objective laws of energy sector development. Transition to the market relations stipulates for tough policy of the wholesale market of electric energy (WME) concerning the load mode of generating assets which nowadays is more dependent on electric energy cost price criteria. This also results in more irregular load of the backbone network, sometimes causing overlap of transit power fluxes even in distribution networks of ESC. At present, power load losses in the networks of some Ukrainian ESC exceed the similar indexes of other European countries.

Problem statement. Official laws in Russia [1], Australia [2] indicate the necessity of methodically reasonable sharing of grid losses among all the market players, as a factor of competitiveness of energy-supplying companies and energy market liberalization. It is planned to change over the energy market model to the system of bilateral contracts and balancing market in Ukrainian electric power industry. That will really give much more possibilities to suppliers, consumers, and producers of electric energy. According to the law passed in October, 2013 by Supreme Rada of Ukraine, "About the fundamentals of electric energy market operation in Ukraine", as from the year 2017 it will be possible to choose independently the electric energy supplier by contracting the bilateral agreements, and also by purchasing the electric energy at spot energy market.

Obviously it is required to take into account the component of transit load losses in order to provide the real liberalization of WME and equal conditions for each market player. And the problem solution is to be based both on the theory of electric technology and economic factors.

The aim of the article is to consider the possibilities of structuring the network power losses caused by transit fluxes using the method of losses calculation, applying the matrix of node resistances of electric grid and node loads, taking into account the interaction of different factors .

Analysis of the published articles. The problem of research and definition of transit loss phenomenon has been considered as far back as in the 1970s and '80s. However when the single energy system belonged to government property, the transit loss problem had a purely theoretical or electrotechnical character and its solution was just an additional way to analyze the electric network operation. As for the example, the "Instructions…"[3] were developed according to the «Coordination plan of continuation, further development, and application of the works for the decrease of electric energy losses in the electric energy networks during 1976 – 1978 years» approved by the Ministry of Electric Energy of the USSR. In [4, 5] this problem was also considered as a mean for specification and clarification of mutual accounts of the energy companies. Proceeding from the concepts, specified in [6, 7], it became possible to determine the factual power losses (or electric energy losses as an integral value) caused while transmission to every consumer on the basis of laws of electric engineering and representing the actual degree of electric network usage. Further we consider the different possibilities of the method of losses calculation application, based on the matrix of node resistances of electric grid and node loads.

Basic statements. Let us list main practically applied methods of calculation the power and energy losses in the network caused by transit power fluxes (transit losses):

– of direct computations of energy operation modes of transit ESC network at each time slice on the basis of equivalent network model and the data of operation node parameters, obtained through the telemetry system; determination of average power and electric energy losses for the estimated period;

– on the basis of characteristic of rate power (energy) loss in transit network. The characteristic is a dependence of power (energy) losses on power fluxes obtained by means of approximation of the results of previously performed variation calculations of the transit ESC network operation modes;

– on the basis of rate quotas of power (energy) losses, representing as a percentage of corresponding values of transit power fluxes.

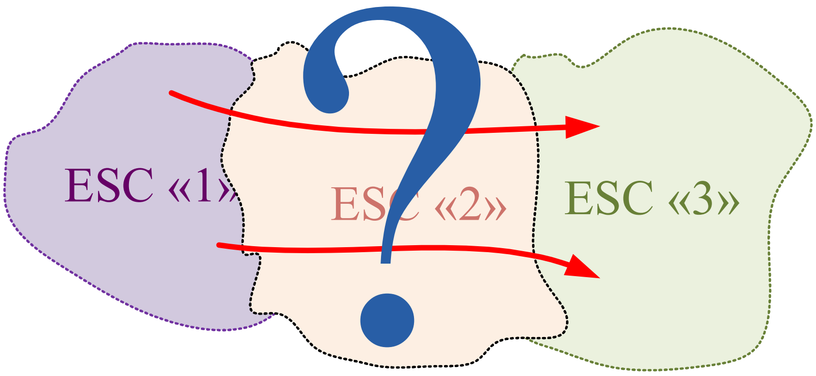

Fig. 1. Different approaches to transit losses determination

The first one of the mentioned above methods is considered to be the most grounded so let us scrutinize it more thoroughly. According to the direct computation method, power load losses in transit energy grids are calculated for each time slice in two operation modes:

• real operation mode when transit power equals $P_{tr.}$,

• calculated operation mode when transit power equals $P_{tr.} = 0$.

Power losses at a time moment caused by transit flux [1] are to be determined by the formula:

$$\Delta P_{tr.} = \Delta P_1 - \Delta P_2, \tag{1}$$

where ΔP_1 and ΔP_2 – total power load losses in the transit networks for corresponding operation modes. Besides ,while carrying out calculations in transit energy system in the second operation mode the following values must be kept:

– all the active powers of generators;

– voltages in all the nodes where it is regulated;

– all the active and reactive loads;

– if possible, transformation ratios (except for those, being changed according to the condition of voltage maintaining in control points).

One and the same balance node is to be chosen for both operation modes. Change of the loads in the receiving energy system is performed by decreasing of active and reactive powers in load nodes proportionally for each node. Variation of loads in generating nodes is to be carried out at all the power plants engaged in mode regulation.

We would like to draw your attention to the fact that the condition of node voltages maintaining in regulated nodes doesn't guarantee the identity of the node voltages in the rest of nodes of the network for the considered load modes. And what is more, additional voltage regulation results also in partial neglecting of the superposition principle thus lowering the reliability of obtained results. Zeroing of load nodes stipulates voltage rise, and as a result, decrease of calculated value of power losses as compared with factual one.

In [8] the approach to calculation of transit power losses is considered. They are supposed to be determined as the value of power losses in the investigated grid when *its own loads and generation are disconnected*. As the losses have a square law variation, it is obvious that in this case the value of transit losses will be considerably less .It should be noted that it can be performed without any computation difficulties for regional investigated energy system, constituting *smaller* part in common calculated circuit of electric grid. For better approximation of voltage values in electric grid to initial values it seems to be expedient to introduce in one of external (relatively investigated system) nodes the generator its power being equal to the power balance of the tested energy system.

We would like to draw your attention to the problem of node voltages fixation as a necessary condition of computation reliability.

Let us illustrate the above- mentioned approaches on the example of power losses determination in a certain electric energy system EES "2", proceeding from the assumption of generation excess in the EES "1" and power shortage in EES "3" (Fig. 1):

$$\Delta P_{tr.}^{ES2} = \Delta P_{\Sigma}^{ES2} - \Delta P_{S(ES3_{load})=0}^{ES2}, \qquad (2)$$

where $\Delta P_{tr.}^{ES2}$ – is transit losses in the EES "2" energy system, MW; $\Delta P_{\Sigma}^{ЭС2}$ are total power losses in the EES "2", caused by its own loads and transit of power into EES "3", MW.

or

$$\Delta P_{tr.}^{ES2} = \Delta P_{S(ES2)_{load}=0}^{ЭС2}, \qquad (3)$$

where $\Delta P_{tr.}^{ES2}$ – are transit losses in EES "2", MW, defined in case of zero loads and generation of EES "2" and transit power fluxes into contiguous EES "3", MW.

Existence of these two approaches arises doubts regarding the correct solution of the suggested problem in spite of the fact that direct computation method is believed to be the most substantiated. One of the requirements of the introduced legislation and one of the main factors of fair and transparent operation of WME according to the Article 14 "Charges for access to grids" stated in the Directive 2009/72/EU – is non-discriminatory grids access:

«*1. Charges applied by grids operators for access to grids shall be transparent, take into account the need for grid security and reflect actual costs incurred in … and must be applied in a non-discriminatory manner. Those charges shall not be distance-related.*

2. Where appropriate, the level of the tariffs applied to producers and/or consumers shall … take into account the amount of network losses and congestion caused, and investment costs for infrastructure».

To illustrate the revealed discrimination let us consider the conditions of electricity supply to "inner" consumers of separately taken utility. There should be no privileged consumers by the principle of losses calculation caused by power transfer (taking into account square law dependence of losses). For example, losses for certain consumer № 1 are defined if loads in the grid are missing (minimal losses), for consumer № 2 – with power transfer to consumer № 1 (depend on the value of this load), for consumer № 3 – if loads № 2 and № 3 etc. are available Obviously that such approach will not be fair, regarding payment for technical losses of electric power while its transfer. The same conclusions can be drawn while considering the approaches to transit losses determination, illustrated in Fig.1, by the expressions (2), (3). As a result ,we obtain either overstatement of transient losses value in favor of ESEC "2", or understatement in favor of EES "3". It is seems to be true that power transit, overlap on own transfers into neighboring EEC and additional losses must be compensated. Although by applying the above-mentioned approaches we violate the main principles of non-discriminatory access to grids.

It goes without saying that consumption growth in any part of the grid causes the corresponding increase of losses for power transfer to the rest of consumers. In is suggested to use such method of power loss calculation by means of which their fair and transparent distribution both for the consumers of separately taken EES and outside it could be provided.

Method of node resistances of grid matrix, besides the solution of the main problem solves the problem, provides additional opportunity to allocate from total losses of active power the component, caused by inhomogeneity of complex loop electric grid.

Active power losses caused by power transmission to certain consumer k of electric grid , consisting of $n+1$ nodes (consumers) are represented as a sum of two components [6, 7]:

$$\Delta P\langle k\rangle = \Delta P_{\min}\langle k\rangle + \delta P_{add.}\langle k\rangle, \tag{4}$$

where $\Delta P_{\min}$ – minimal value of active power losses; $\delta P_{add.}$ – additional active power losses in complex loop network which are computed by the expressions (5) through node currents:

$$\Delta P\langle k\rangle_{\min} = \boldsymbol{J}_{ak}\sum_{j=0}^{n}\boldsymbol{J}_{aj}\boldsymbol{\Re}_{k,j} + \boldsymbol{J}_{pk}\sum_{j=0}^{n}\boldsymbol{J}_{pj}\boldsymbol{\Re}_{k,j},$$
$$\delta P\langle k\rangle_{\partial on.} = \boldsymbol{J}_{ak}\sum_{j=0}^{n}\boldsymbol{J}_{aj}\boldsymbol{A}_{k,j} + \boldsymbol{J}_{pk}\sum_{j=0}^{n}\boldsymbol{J}_{pj}\boldsymbol{A}_{k,j}, \tag{5}$$

where $\boldsymbol{J}_a$, $\boldsymbol{J}_p$ – active and reactive components of node currents, $\boldsymbol{\Re}$ – matrix of economic node resistances of electric grid, $\boldsymbol{A}$ – matrix of node resistances that characterize additional active power losses.

That is, in case of sufficient reliability of initial data, regarding node consumption input data we can define network losses even without computation of steady state mode and line currents. Separation of components of minimal power losses $\Delta P_{\min}$ and additional inhomogeneity losses $\delta P_{add.}$ provides the possibility to optimize active power transit network losses just only by the component $\delta P_{add.}$.

Sample calculations.

This method is applied to compute power loss in the transit electricity circuit shown in Fig.2. Let the node №7 be contiguous with the grid, characterized by excessive generation, and the node №5 is adjacent to certain deficit grid.

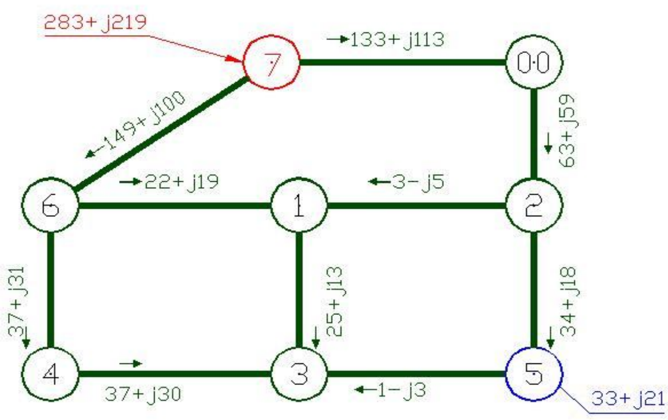

Fig. 2. Part of 220 kV electric grid

Loads of the investigated transit network do not change, and power cotake-off value of a deficit network is gradually increased. Results of the computations are shown in Table 1.

Total consumption of investigated grid load (except for load of the node №5) equals S=771+j408 MW. In the considered example losses , caused by own consumption are almost equal to losses caused by power transit in contiguous grid, when power transfer is $\dot{S}_5$=132+j84 MW, representing 18% of inner consumption. This aspect should be taken into account as an important factor while account reconciliation, technical and economic assessment of network development, and connection of new consumers or generation, especially renewable sources of energy. So transit network losses can be partially decreased.

Table 1

Results of power losses computation for the fragment of electric grid

Total power losses in the grid, MW		Losses caused by power transfer to the node № 5 , MW		Consumption in the node № 5, S, MWA	Grid losses caused by loads of "inside" consumers, MW	Grid losses caused by load of the node № 5, MW
ΔP_{min}	$\delta P_{add.}$	ΔP_{min}	$\delta P_{add.}$			
2,893	0,080	0,0	0,0	**0,0**	2,973	0,0
3,977	0,094	0,613	0,150	**33 + j 21**	3,307	0,763
5,347	0,140	1,514	0,609	**66 + j 42**	3,363	2,123
8,949	0,323	4,177	0,245	**132 + j 84**	4,850	4,422
11,181	0,461	5,939	0,384	**165 + j105**	5,319	6,323
26,648	1,616	19,057	1,541	**330 + j210**	7,666	20,598

In case we use the direct computation method, total power losses of transit electric grid remain at the level of 2.973 MW independently on the overlap transit power flux. In this way, consumers of a deficit network are discriminated in their right to network access. The method using the matrices of node resistances allows determination of active power losses caused by power transmission to every consumption node allowing for loads of all network nodes.

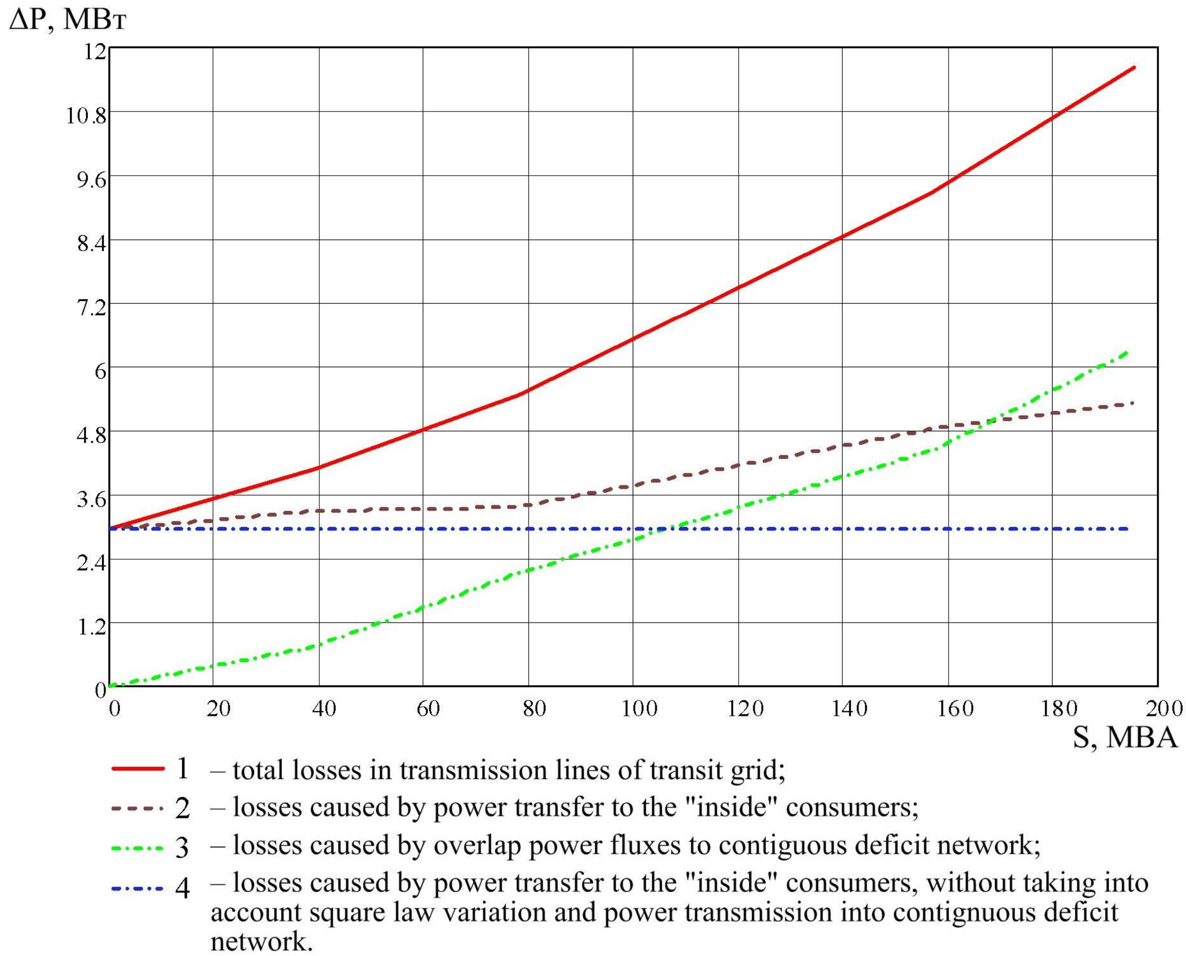

Fig. 3. Dependency of grid losses on the volume of transit power fluxes

Fig. 3 shows the dependencies of transit network losses on transit and overlap power fluxes. So we can see that network losses caused by power transmission to the "own" consumers (curve 2) are in nonlinear relationship with overlap transit power fluxes. Network losses caused by overlap power flux to neighboring deficit network are also increased according the nonlinear law (curve 3). These losses are separated out of total network losses as an exact value. Thus if there is corresponding legislation signed by ESC and electricity consumer, they have the possibility of grounded allocation of network losses costs to contiguous deficit ESC or the ESC with excessive generation, or allocate them due to the degree of mutual influence by the expressions (5).

Conclusions. Method of calculation of active power network losses caused by transit fluxes applying the matrices of node resistances of electric network and node loads allows determination of overlap transit flux losses by separating out of total network losses, and establish their dependency on loads (generation) in network nodes. Moreover, here is a way to address transit network losses to every electricity consumer; to determine how overlap transit fluxes influence network losses caused by power transmission to the "own" consumers; and conversely, to determine how overlap power fluxes to neighboring deficit network effect upon network losses caused by power transmission to the "inner" consumers of the network.

This method allows structuring of power losses in electric energy network into components subject to interaction of different factors. So there is a possibility to create automated system of power loss allocation at every time slice, which takes into account non-linear dependency of all active loss components on transit fluxes, with interaction of changing load patterns and transit power fluxes. Input data are network model parameters and mode parameters from operating information complex that provides loss allocation, and transit loss allocation in a real time mode.

Resulting values of components of network active power (energy) losses give market players the ability to exactly and objectively clarify the possible electricity supply opportunities and choose the optimal one. Information on network loss components and their dependency on interaction factors allows for objective problem solution of loss compensation by every system operator. It facilitates the realization of non-discriminatory access to networks.

We arrive at a conclusion that there are different ways to apply the suggested method, and transit power losses are to be balanced and mutually accounted depending on the bilateral agreements, and future legislation of electric power industry. Listed in the article possibilities of practical applying of the method are exceptionally engineering means of computation, although questions of financial compensation between transmission system operators are still undecided.

REFERENCES

1. Методика расчета транзитных потерь мощности и электроэнергии в электрических сетях субъектов оптового рынка электроэнергии: постановление ФЭК РФ от 14.12.01 [Електронний ресурс] : Офиц. изд. – М.: 2001. (Российское акционерное общество энергетики и электрификации РАО «ЕЭС России». Методика). Режим доступу: http://www.yug.so-ups.ru/Page.aspx?IdP=272.
2. Distribution Loss Factor Calculation Methodology/ Powercor Australia Ltd. [Електронний ресурс] : Расчет коэффициентов распределения потерь. Методика ООО «Powercor Australia», 2013. – Режим доступу: http://www.powercor.com.au/.
3. Указания о расчете расхода электроэнергии на транзитные межсистемные перетоки: РД 34.09.252:1976. – Офиц. изд. – М. : Союзтехэнерго, МЭЭ СССР, Главтехуправление ЦДУ ЕЭС СССР, 1976. – 8 с. – (Министерство Энергетики и Электрификации СССР. Инструкция).
4. Determination of power losses from transit flow in electric networks [Електронний ресурс] / A. B. Burykin, V. A. Vydmysh, P. P. Medianiy // Scientific works of Vinnytsia National Technical University. – 2010. – № 1. Режим доступу до журн.: http://praci.vntu.edu.ua/article/view/1024/42.
5. Клипков С. И. Особенности определения адресности передачи электроэнергии в электроэнергетических системах переменного тока / С. И. Клипков, А. И. Ришкевич, А. В. Семенюк // Новини енергетики. – 2008. – № 3. – С. 32 – 43.
6. Лежнюк П. Д. Інформаційне забезпечення розрахунків втрат потужності й електроенергії від транзитних перетоків / П. Д. Лежнюк, Н. В. Семенюк // Вісник Вінницького політехнічного інституту. – 2012. – № 1. – С. 66 – 69.
7. Лежнюк П. Д. Визначення втрат від адресних транзитних перетоків за даними ОІУК / П. Д. Лежнюк, Л. Р. Пауткіна, Н. В. Семенюк // Наукові праці Донецького національного технічного університету. – 2013. – № 1. – С. 163 – 167.
8. Ольшванг В. М. Собственные и транзитные потоки и потери региональных енергосистем: (доклад на семинаре энергетиков по потерям в сетях 22.02.01) [Електронний ресурс] : В.М. Ольшванг / Режим доступу: http://mvo.ipc.ru/sobstv23/sobstv23.htm.

Semeniuk Nadia – Applicant for a Cand. Sc.(Eng.) Degree with the Chair of Electric Stations and Systems, Engineer of the 1-st category at Central Dispatching Department of economically autonomous structural subdivision "Donbass Energy System" of National Energy Company "UkrEnergo".

"Donbass Energy System" of National Energy Company "UkrEnergo".