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Control of power flow and voltage in parallel working electrical GRIDS

Abstract. *A method for determining optimal locations joining cross-transformer in the electrical distribution network, which is based on compensation non-uniformity parallel working electrical networks and method for determining optimal values reactive component of the transformation coefficients transformer connections in electrical distribution networks by taking into account cross-corner shifting transformers allowing the use of these factors in the optimal management of power flows to reduce losses of power and electricity distribution network or, depending on the problem in the transmission and distribution electrical grids.*

Streszczenie*. W pracy przedstawiono metodę określania optymalnego miejsca łączenia krzyżowego transformatora sieci dystrybucji elektrycznej. Jest ona oparta na kompensacji niejednorodności równoległej pracy sieci elektrycznych i metodzie określania optymalnych wartości współczynników transformacji dla składowej biernej, przyłączy transformatorowych w sieciach dystrybucyjnych. Uwzględniono transformatory cross-corner shifting, pozwalające na korzystanie z tych czynników w optymalnym zarządzaniu przepływem energii, celem zmniejszenia strat w sieciach dystrybucji energii elektrycznej. (****Sterowanie przepływem mocy i napięcia w sieciach energetycznych pracujących równolegle****).*

Słowa kluczowe: transformator krzyżowy, nierównomierność dystrybucji energii w sieci energetycznej, kąt przesunięcia fazowego.
Keywords: Cross-transformer, electrical distribution non-uniformity network, phase shift angle, power loss.

Introduction

One of the main reasons not optimal modes (optimum power losses of electrical grids) is the non-uniform grids. This is especially true parallel operating transmission and distribution electrical grids. Between the power grids through mutual non-uniform arising overflows power that network load related supply companies. We also know that the network HV discharged in parallel working LV network (Fig. 1) [6, 9, 18, 19].

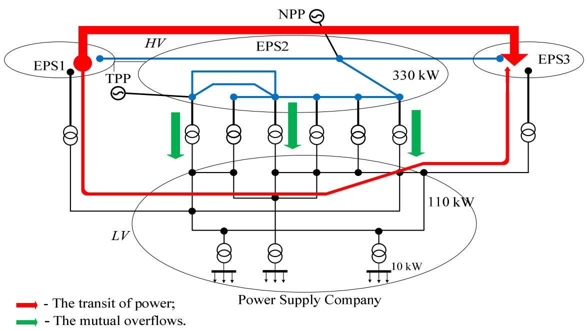

Fig.1. An example of the power grid in which the transit capacity

The result is more power losses and switching devices and overload power lines of LV [4].

Reducing this non-uniformity is done by the reconstruction of existing or introduction of new transmission lines, and so regulated reactors etc. However, the problem of realization of optimum mode in this way is the lack of funds to implement measures for reconstruction and commissioning of the transmission line.

Also, the problem of implementing the optimal mode is the low quality of operation or insufficient amount available for the implementation of optimal active power losses means of compensation for the negative impact of non-uniformity, such as transformers OLTC, adjustable reactive power compensation and so on. The problem of the realization of optimum mode is also insufficient automation of transformer substations, which manifests itself in the lack of them means automatically determine optimal settings (for active power losses) regime and the lack of means of determining the optimal vector of control impacts of OLTC transformer substations and t. p.

Through organizational separation of power system of Ukraine to the main network (MN) and network distribution companies (NDC) problem of implementing optimal modes worsening quality and informative exchange of information regime between companies and businesses that service these networks. Compounding the problem of optimal control of flow between NDC and MN also that adjusting devices are subordinate to the main networks. This situation leads to the transmission line load currents NDC and MN transit flows and, consequently, increases the power loss, especially in LV networks.

Depending on conditions and relations between enterprises NDC and MN two options reduce power losses. First, an agreement can be reached to minimize the total losses networks HV and LV and determine the optimal transformation coefficients transformers and autotransformers connection:

$$min\left\{\Delta P_{\Sigma} = \Delta P_{HV} + \Delta P_{LV}\right\}, \tag{1}$$

where: ΔP_{HV}, ΔP_{LV} – power loss accordingly in HV and LV networks.

In this case HV and LV networks are shared. In particular, LV network, if they have stock carrying capacity may be used provided the backbone network reimbursement LV network to transport electricity, including power losses. If such an agreement is not reached, the reduction of power losses in the LV network, which is the result of parallel networks of HV and LV and, consequently, increase the total losses in LV networks, is only a matter of NDC. The problem boils down to "crowding out" transit overflows of power from the LV grid in HV grid. That solved this problem:

$$min\left\{\Delta P_{HV} = \Delta P_{LV\,DM} + \Delta P_{HV\,DM}\right\}, \tag{2}$$

where: $\Delta P_{LV\,DM}$ – power losses in the networks of NDC caused his own load, $\Delta P_{HV\,DM}$ – power losses in the networks of NDC caused transit facilities MN.

The complexity of the implementation of the results of solving the problem (2) is that the means by which they can be practically achieved (transformers, auto-connection, linear regulators, etc.), usually located in MN and so operational staff NDC enterprises can manage mode using this equipment.

Thus, from the perspective NDC one of the solutions to the problem of optimizing regime is setting LR in their networks. This raises the problem: determining the optimal, the criterion of reducing power losses, the site of the HR in SEM, its design features (such as LR, which provides lateral adjustment or longitudinal-transverse regulation) and parameters (eg, voltage, phase angle LR and so on. p.); evaluation of the feasibility of using the proposed LR type (with regulated or unregulated, active, reactive or complex transformation coefficients) [5, 8, 12, 13].

In world practice, often use a type of linear regulator - shifting transformer (RST). PST primarily used in the United Kingdom, France, Belgium, Holland [2, 3, 7], which clearly demonstrates the efficiency PST energetic flows for optimal control in electric networks. This makes it possible to control the flow of power, thus enhancing the reliability of electric power supply at short circuits in the lines.

In electrical networks Maharashtra and Uttar Pradesh [17] (India) PST also used to improve the reliability of electricity transmission to consumers. It was decided to establish PST overloaded or underused parallel working lines. This allows you to extend the life of overloaded lines that dumped PST and improve modes of electrical networks states.

So PST installed in congested or underused lines for redistribution of electrical power. As a result - reduced additional power losses, increase network reliability and quality of power supply [1, 14]. But such measures are not always positive. Thus, when unloading or loading line power loss are reduced, and sometimes - increasing.

Based on the above considerations and economic situation of energy in Ukraine, it is advisable to explore the possibility of establishing national and effectiveness of HR-type cross-transformer (CT) [10, 15, 16] in the NDC.

Determination of seat installation and optimum angle in NDC CT

The method of determining the optimal site of the CT. What is the definition of a matrix system performance non-uniformity:

$$\boldsymbol{\gamma} = \mathbf{k}_{\mathrm{CT+OLTC}}\left(\mathbf{M}_{\mathrm{t}}^{-}\mathbf{x}\,\mathbf{r}^{-1} - \mathbf{x}_{\mathrm{B}}\mathbf{r}_{\mathrm{B}}^{-1}\mathbf{M}_{\mathrm{t}}^{-}\right) + \left(\mathbf{M}_{\mathrm{t}}^{+}\mathbf{x}\,\mathbf{r}^{-1} - \mathbf{x}_{\mathrm{B}}\mathbf{r}_{\mathrm{B}}^{-1}\mathbf{M}_{\mathrm{t}}^{+}\right) \quad (3)$$

where: $\mathbf{M}_{\mathrm{t}}^{+}$ – matrix containing a fragment of the matrix compounds whose elements are zeros and units with the sign "+", $\mathbf{M}_{\mathrm{t}}^{-}$ – the same array, but its elements are zeros and units with the sign "–", $\mathbf{k}_{\mathrm{CT+OLTC}}$ – diagonal matrix transformation coefficients CT $\mathbf{k}_{\mathrm{OLTC}}$ (if the i-th age CT is not, then, is the diagonal element $\dot{k}_{i,i} = 0 \cdot j$) and the transformation coefficients transformers OLTC ($\mathbf{k}_{\mathrm{OLTC}}$) (if the i-th age transformer OLTC missing, the i-th diagonal element $\dot{k}_{i,i} = 1$), r, **x** – active and reactive components of the matrix of nodal resistances.

And in determining the vector of generalized indicators non-uniformity of each element of which is the Euclidean norm respective branches gamma matrices

$$|\gamma|_{i=1,2,\ldots,m} = \left[\sqrt{\sum_{j=1}^{n}\gamma_{i,j}^{2}}\right]_{i=1,2,\ldots,m}, \quad (4)$$

where: where n - number of units of electricity network.

The optimal branch responsible for the establishment of CT branch with a maximum value element vector $|\gamma|$

$$max\left\{|\gamma|_1, |\gamma|_2, \ldots, |\gamma|_m\right\}. \quad (5)$$

The method of choosing the optimal tag for installation on CT was tested simple brute-force options and shows the match results.

To realize optimal current flow in NDC must enter the contours egalitarian emf. Their introduction by using transformers with OLTC and CT, which is set in a selected branch. Contoured egalitarian emf associated with the transformation ratio of the transformer OLTC and shifting angles CT ambiguous. To achieve uniqueness egalitarian communication emf coefficients of transformation, emf defined for a system of basic circuits. Moreover, the system of basic circuits formed so that the transformer CT were branches of its chords. Then, for the i-th circuit, which established a transformer with a longitudinal adjustment and transformation ratio CT transformation ratio of the transformer and CT scan angle will look like:

$$\mathrm{k_i} = 1 - \mathrm{E}_{*\mathrm{lev\,r\,i}}, \quad (6)$$

$$\delta_{\mathrm{i}} = \mathrm{arctg}\left(-\frac{\mathrm{E}_{*\mathrm{lev\,a\,i}}}{1 - \mathrm{E}_{*\mathrm{lev\,r\,i}}}\right), \quad (7)$$

where: $\mathrm{E}_{*\mathrm{lev\,a\,i}}, \mathrm{E}_{*\mathrm{lev\,r\,i}}$ – active and reactive components of the relative values of egalitarian emf and the second circuit, which is the ratio of voltage values to the base unit, $\dot{\mathrm{k}}_{\mathrm{i}}$ – ratio transformer, part of the i-th circuit; δ_{i} – CT shifting angle and the second circuit.

The method of determining the optimal angle CT depicted as a flowchart algorithm (Fig. 2). This method involves determining the optimal angle for the CT results comparing annual changes in losses of active electrical energy at different angles CT, CT provided the location of the previously defined optimum leg CT.

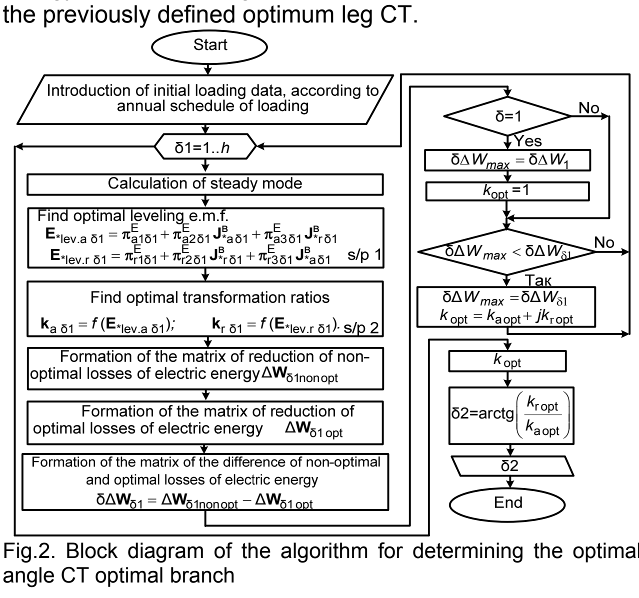

Fig.2. Block diagram of the algorithm for determining the optimal angle CT optimal branch

According to Fig. 2: δ1 – CT angle for optimal branch chosen for each stage of the annual load demand; $\mathbf{E}_{*eg.a\ \delta1}$, $\mathbf{E}_{*eg.r\ \delta1}$ – relative values of active and reactive components egalitarian emf taking into account the set of optimum transformer CT branch to be put into the contours of the power grid to offset the impact of varying parameters of transformers and circuit inhomogeneity; $\pi^{E}_{a1\delta1}$, $\pi^{E}_{a2\delta1}$, $\pi^{E}_{a3\delta1}$, $\pi^{E}_{r1\delta1}$, $\pi^{E}_{r2\delta1}$, $\pi^{E}_{r3\delta1}$ – similarity criteria parameters current mode parameters saving mode homogeneous network incl CT, $\mathbf{k}_{a\ \delta1}$, $\mathbf{k}_{p\ \delta1}$ – longitudinal and transverse components of transformation coefficients investigated optimal transformer branches, $\Delta\mathbf{W}_{\delta1\ non\ opt}$, $\Delta\mathbf{W}_{\delta1\ opt}$ – power losses in branches of the power grid caused by suboptimal and optimal (respectively) of transformer ratios and OLTC angle CT study branches during electrical network j1-th degree load demand, $\delta\Delta\mathbf{W}_{\delta1}$. – reduction of energy losses in branches of the power grid caused by the use of transformers and OLTC CT study optimal leg while working on the electrical grid j1 rate schedule load, k_{opt} – optimum value of the transverse component of CT, which will be introduced or discharged under different operating electric network, δ2 - optimal angle CT for the selected optimal branch.

With subprogram 1 (s / p 1 in Fig. 2) defined the elements of similarity matrices. In the first step the s / p 1 input parameters required for the calculation of normal power grid. After calculating mode arrays formed diagonal matrix voltages at the nodes, nodal load vector and vector determined current basic mode. Then, using the Count parameters and equivalent circuit of the electrical grid matrix formed by the first joints in view of the complex transformation factors regulating devices explicitly. Using this matrix, the matrix of nodal conductivities determined that meets Balancing nodes. Formed current flow coefficient matrix corresponding to the economic regime based on the equivalent r-design of the electrical network with complex coefficients balanced transformation. Then the second matrix compounds formed on the basis of comprehensive transformation factors. In the next step the s / p 1 is defined contour emf vector that is used to determine the egalitarian emf basic mode. At the final phase of s / p 1 is performed forming matrix of similarity, which is used to determine the results of previous calculations.

Egalitarian emf in the circuits and circuits containing CT, with optimal regimes are determined by constant coefficients (similarity criteria) $\boldsymbol{\pi}^{E}_{a}$ and $\boldsymbol{\pi}^{E}_{r}$ that do not depend on the parameters of the current mode

$$\begin{aligned}\boldsymbol{\pi}^{E}_{a} &= \left[\mathbf{E}^{(b)}_{a\,levCT}\right]^{-1}_{d} \mathbf{N}\,\mathbf{x}_{br}\mathbf{C}_{r}\left[\mathbf{J}^{(b)}_{r}\right]_{d} = \mathrm{idem} \\ \boldsymbol{\pi}^{E}_{r} &= \left[\mathbf{E}^{(b)}_{r\,levCT}\right]^{-1}_{d} \mathbf{N}\,\mathbf{x}_{br}\mathbf{C}_{r}\left[\mathbf{J}^{(b)}_{a}\right]_{d} = \mathrm{idem}\end{aligned}, \tag{8}$$

where: **N** - direct matrix connections of branches in the contours of the scheme,

$\mathbf{C}_{r} = \mathbf{r}_{b}^{-1}\mathbf{M}'_{t}\left(\mathbf{M}'\mathbf{r}_{b}^{-1}\mathbf{M}'_{t}\right)^{-1}$ – matrix coefficients calculated design of the electrical network in which the support legs submitted only their active components (r-Equivalent circuit of electric network),

$\mathbf{r}_{br}$ – diagonal matrix resistances branches,

$\mathbf{M}'$ – intsydentsiy first matrix network that has struck strings corresponding generating units (this is equivalent to combining all sources of supply in a calculated balancing node),

$\mathbf{M}'_{t}$ – first transposed matrix intsydentsiy network $\mathbf{M}'$;

$\mathbf{J}^{(b)}_{a}$ and $\mathbf{J}^{(b)}_{r}$ – vectors of active and reactive components of the current node in a mode with a minimum loss of interference.

They are similar to the corresponding emf regime adopted for the base. That is, the outlet egalitarian emf these different modes.

Components egalitarian emf Criteria defined in form:

$$\begin{aligned}\mathbf{E}_{*eg.aCT} &= \boldsymbol{\pi}^{E}_{a1} + \boldsymbol{\pi}^{E}_{a2}\cdot\mathbf{J}^{B}_{*a} + \boldsymbol{\pi}^{E}_{a3}\cdot\mathbf{J}^{B}_{*r}, \\ \mathbf{E}_{*eg.rCT} &= \boldsymbol{\pi}^{E}_{r1} + \boldsymbol{\pi}^{E}_{r2}\cdot\mathbf{J}^{B}_{*r} + \boldsymbol{\pi}^{E}_{r3}\cdot\mathbf{J}^{B}_{*a},\end{aligned}, \tag{9}$$

where: $\pi^{E} = \begin{bmatrix}\pi^{E}_{a1} & \pi^{E}_{a2} & \pi^{E}_{a3} \\ \pi^{E}_{r1} & \pi^{E}_{r2} & \pi^{E}_{r3}\end{bmatrix}$ - of similarity matrix of criteria for egalitarian model emf circuits in the power grid.

Emf egalitarian determined that these emf basic mode (for r-scheme), similar for different power grid. To realize optimum mode of the power grid must enter their outlines into independent circuit by adjusting the ratios of transformation of transformers and OLTC angle CT.

With subroutines s / p 2 (s / p 2 in Fig. 2) determined the optimal transformation coefficients and angles CT. Using the parameters of the current mode of the electrical grid vectors determined set current independent units. Then calculated the optimal egalitarian emf entered in independent circuits circuits using transformers transformation ratios.

In the s / p 2 (to determine the optimal transformation coefficients and angles CT) provides readers with a matrix of similarity S / S together with 1 set egalitarian currents and emf basic mode. Ends s / p 2 determine the optimal transformation coefficients and angles CT.

Formed column vector difference in energy losses, which selects the maximum value of reducing power losses and output CT optimum angle at which this reduction has been achieved. Then output an optimal angle δ2 CT.

Active and reactive component of the transformation coefficients of transformer and CT OLTC defined by the following expressions:

$$\begin{aligned}\mathbf{k}_{a} &= 1 - \left(\mathrm{Re}\left(-\mathbf{N}_{k\,levCT}\,\mathbf{Z}\mathbf{C}_{r}\,\mathbf{J}\right)\right)_{d}\mathbf{U}_{b}^{-1}\mathbf{E}_{*lev.aCT}, \\ \mathbf{k}_{r} &= -\left(\mathrm{Im}\left(-\mathbf{N}_{k\,levCT}\,\mathbf{Z}\mathbf{C}_{r}\,\mathbf{J}\right)\right)_{d}\mathbf{U}_{b}^{-1}\mathbf{E}_{*lev.rCT}.\end{aligned}, \tag{10}$$

Thus, comparing between the annual power losses in branches of electric networks for different angles CT selected for different levels of daily load schedule, should choose a CT optimum angle by which these losses will be minimal.

Practical implementation of the proposed method

To determine the optimal location of CT and CT angle studied their impact on loss [11].

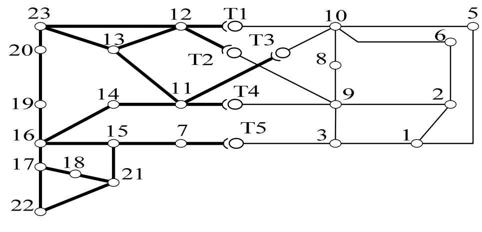

Fig.3. Test network 230/138 kV at 23 knots

Computing experiment conducted by the example of 230/138 kV test network comprising 23 units and 33 branches (Fig. 3) and its network parameters (Table. 1).

Table 1. Parameters 230/138 kV network test

Line No.	No. of lines begin ning	No. of end of the line	Active resistanc e of the line	Rective resistance of the line	The transformation ratio of transformers	
No	No. beggi ning	No. end	[R, Om]	[X, Om]	Kactive	Kreactive
1	11	10	0.6	27	0.6487	0
2	12	9	0.37	9.28	0.6498	0
3	11	9	0.3	13	0.6479	0
4	7	3	0.21	11.53	0.65	0
5	1	2	0.4951	2.6471	0	0
6	1	3	10.398	40.2209	0	0
7	1	5	4.1516	16.0922	0	0
8	2	4	6.2464	24.1287	0	0
9	2	6	9.4649	36.5645	0	0
10	3	9	9.882	20.962	0	0
11	4	9	5.1038	19.7486	0	0
12	5	10	4.342	16.8159	0	0
13	8	9	8.82	15.124	0	0
14	8	10	2.067	2.145	0	0
15	11	23	5.207	22.793	0	0
16	11	14	2.8566	22.1122	0	0
17	12	23	5.207	25.1804	0	0
18	12	13	6.5596	51.1014	0	0
19	23	13	5.8719	45.7585	0	0
20	14	16	2.645	20.5781	0	0
21	15	16	2.338	8.404	0	0
22	16	17	1.7457	13.7011	0	0
23	16	19	3.117	11.206	0	0
24	17	18	0.9522	7.6176	0	0
25	17	22	7.1415	55.7037	0	0
26	21	22	4.6023	35.8662	0	0
27	7	15	5.68	24.865	0	0
28	21	18	0.873	6.851	0	0
29	21	15	1.666	12.96	0	0
30	19	20	1.349	10.474	0	0
31	20	13	0.741	5.713	0	0
32	12	10	0.31	14	0.6524	0
33	10	6	2.6471	11.5216	0	0

Determination of the optimal branch to establish KT will hold for a generalized measure of non-uniformity (4) Fig. 4:

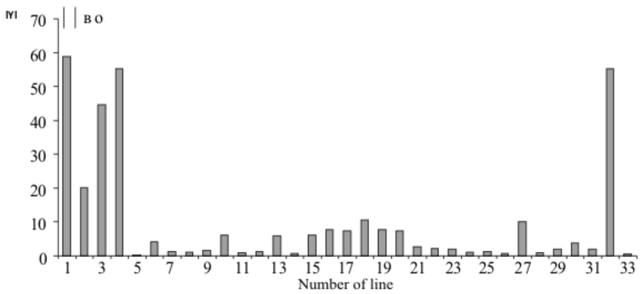

Fig.4. Measures of impact parameters of individual flowers on the definition of non-uniformity test network 230/138 kV

As shown in Fig. 4, CT, first of all, you need to install first branch, which is responsible transformer branch 11-10.

Selection of the optimal angle CT performed according to the daily schedule load (Fig. 5).

According flowchart algorithm Fig. 2 find the best angle CT. To find the egalitarian emf you must select the contours network diagram (see. Fig. 3) so that each path covered only two transformers. That circuit is a transformer branch in the tree scheme. This branch transformer T5. In order to simplify the calculations believe that the transformation ratio of the transformer OLTC will not change.

As a result, calculating the best mode for each segment of the schedule loads (Fig. 5) received optimal value ratios and angles transformation transformer CT provided alternately placing the latter in transformer branches, which are the chords in the system of basic circuits (branches 12-10, 11-9, 12-9, 11-10).

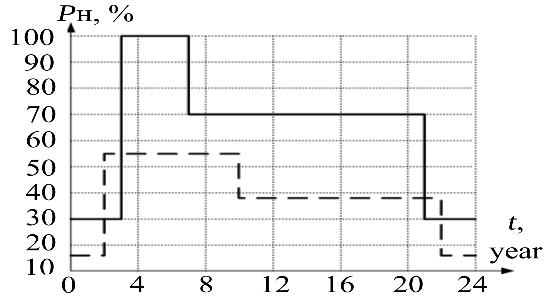

Fig.5. The daily schedule loads: — winter, - - - summer

In our example (Fig. 3 and 5) received six options for optimal δ branches of its location [12]. Of these, one must choose. Choosing δ is the criterion of minimum annual energy losses. If you hold the best choice for the minimum value δ power loss, it will lead to the choice δ, because at every change of load demand can vary optimal branch locations CT and the value of its angle. So choose the option of finding the optimal δ by the criterion of minimum annual energy losses. To do this, go to the considered loading schedules to review the annual schedule for the duration of the load. Calculation based regime conduct routine switching (input or output CT) during the year.

For the calculation modes built chart difference depending on power losses in the presence and absence of CT and its optimal control during the year (Fig. 6). f.

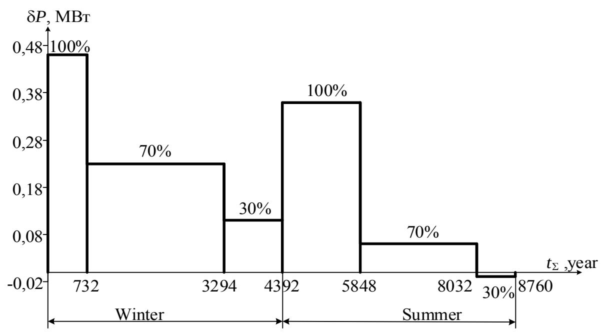

Fig.6. Dependencies difference in energy losses per year δ = 0,036 rad

The diagram in Fig. 6 column width corresponds to the length of annual reductions in energy losses (according to the daily schedule load) in the winter and summer modes of electric network. The height of the column of the chart corresponds to the active power saving when using CT. Negative values indicate losses of electricity off the need for CT. Otherwise, its use in the proposed branch and a specified δ instead of reducing power losses will lead to growth. To determine the optimal δ add all the difference in energy losses and get the following reduce energy loss for the year (ΣδW) (Table. 2).

Table 2. Values of reducing energy loss for the year

Optimal δ [rad]	Total difference of energy losses ΣδW [MW · h]
0.048	38368.8
0.036	**81643.2**
0.015	38719.2
0.03	28557.6
0.02	67101.6
0.01	29784.0

Therefore, CT is advisable to install from 11-10 of δ = 0,036 rad. As shown in the Table. 2, then most expected annual reduction of energy losses.

Conclusions

1. During parallel operation of transmission and distribution power networks because of their non-uniformity LV networks have additional power losses. To reduce these losses can be installed CT. It is possible and appropriate to establish on the part of network LV.

2. Installation of CT LV network must be determined by the results of optimal compensation of negative influence of non-uniformity of the electrical network. This can be used mathematical models and software for determining losses from transit overflows of power and determination of branches network, which most affect the non-uniformity of parallel working electrical networks.

3. The mathematical model of egalitarian emf in electrical networks, which, unlike the existing ones, contains transformation coefficients CT and transformers OLTC, which makes it possible to consider the impact of CT on egalitarian currents to reduce unbalanced transformation factors, non-uniformity of electrical networks and their interaction effects.

4. The criterion value that is associated vectors of optimal CT complex transformation coefficients and parameters of the current mode of the power grid through a matrix of constant coefficients (similarity criteria).

5. The use of CT branch in the optimum angle, determined by the proposed method of calculating the optimum location of CT can reduce the loss of power networks NN and total losses in the grid.

6. Using a cross-transformer technology reduces the additional power loss caused by unloading MN to NDC. The use of CT can expand opportunities for active power flow control in electric networks. This significantly improved conditions for OLTC transformers at substations of power supply companies.

7. The method of determining the optimum installation location of cross-distribution transformers in electric networks, taking into account the non-uniformity of parallel working electrical networks that can increase the effectiveness of the control flow capacity of the electricity grid in branches of electrical distribution networks.

8. It is shown that when the electrical distribution network established cross-transformer unregulated angle and place its location and the angle defined by the typical daily load schedules winter and summer, as the case may reduce power losses in the network and increase. To reduce achieved annual energy losses, the latter cross the transformer is switched off. For this scheme substation such a possibility should be provided.

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