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STUDY OF DSE IMPACT AND SECTIONALIZING ON OPERATION MODES OF LOCAL ELECTRIC SYSTEMS

The research studies the problem of decreasing active power losses in local electric systems, where distributed sources of energy of different types operate, solar power plants and hydroelectric stations being among these sources. The research contains computer model of local energy system operation mode, the model enables to determine the location of flow distribution points and calculate power losses in case of circuit disconnection in corresponding nodes. It is shown that if several distributed sources of energy are used in local electric system optimal by energy losses point of flow distribution (from several possible points of flow distribution) is selected according to the least nodal voltage. Power regulation by means of small hydroelectric station generation influences the change of flow distribution point in local electric system and, correspondingly, electric energy losses in it.

Key words: *distributed sources of energy, solar power plants, flow distribution point, local electric systems, hydroelectric power stations, active power losses.*

Introduction

Centrelized energy supply from large power plants is replaced by combined electric energy supply, when renewable sources of energy are directly constructed in distribution electric grids [1, 2]. These sources are windmills. solar plants and small hydroelectric power stations (WPS, SPP, small HPS). Distributed generation in electric network influences their modes, as a result, new possibilities and new problems emerge regarding optimal usage of distributed sources of energy (DSE).

DSE supply electric energy to the nearest consumers and in case of emerging the excess of energy it can be transmitted in the networks of centralized energy supply. Conventionally, DSE could be divided into controlled (diesel electric stations, cogeneration electric stations, etc.), conditionally controlled (small HPS in case of absence of sufficient amount of water for continuous operation) and uncontrolled, for instance, WPS, SPP [3]. Number of DES is growing every year, that leads to a situation when several different types of DES, both uncontrolled and conditionally controlled, may operate in electric grid [4,5]. By the set of problems, such electric grid has all the characteristics of local electric system (LES).

Distributed electric grids, to provide reliable energy supply are closed loop by their structure (it is provided that the consumers can obtain energy supply from several transmissions lines). However, in order to decrease short-circuit currents and reduce the number of emergency switchings of the consumers loop and ring feeders are disconnected [6]. The selection of disconnection location is complex, multicriterial optimization problem. Optimality criteria is a set amount of emergency switchings of radial parts of distribution grid , standart voltage deviations, overloads of transmission lines, losses of active and reactive power, etc. [7,8].

Growing number of DES complicates the selection of the location of loop circuits and circuits with bidirectional supply division in distribution electric networks. Installation of DES in local electric system (LES) leads to emerging of several points of flow distribution and division of the grid in the points of flow distribution by the above-mentioned optimality criteria is not always justifiable. At the same time large-scale introduction of modern high voltage and microprocessor equipment, introduction in the grids basic fundamentals of Smart Grid concept enables to automate the process of distribution electric networks modes control and shift of flow distribution point, caused by the load change in nodes, from nonoptimal node of the grid into others [9]. To achieve this aim it is possible and expedient to use controlled and conditionally controlled DES, in particular, small HPS [10]. The latter are used to maintain in the network, interrupted by the reliability criterion, such optimal power flows, that provide minimum active power and electric energy losses.

Aim of the research

The aim of the given research is development of the method of determination the optimal point of flow distribution and optimal location of the grid interruption in local electric system with the sources of distributed generation and maintaining of optimal flows in it by the criteria of reliability and minimum losses of active power.

Sectionalizing of 10 kV electric distribution grid

We will consider the fragment of electric circuit of Yampil district electric grid of 10 kV, shown in Fig. 1.

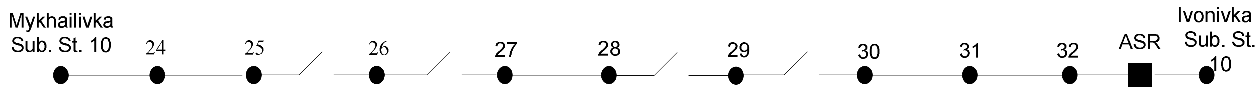

Fig. 1. Fragment of Yampil 10 kV district electric grid

As it is seen from the Figure, disconnectors are installed in 4 lines, namely: 25-26, 26-27, 28-29, 29-30. Using the recommendations on construction of sectionalizing circuits of 10 kV distribution electric networks (СОУ-Н ЕЕ 40.1-00100227-99: 2014), we will determine where it is better to disconnect electric grid, proceeding from the requirements of energy supply reliability.

In according with the technique, we will consider the choice of rational locations for switching devices (SD) installation for grids sectionalizing (SDGS). We determine relative powers of the first zone (zone from disconnect switch to the location of switching device installation) $P_{1\Sigma}^*$ by the expression (1).

$$P_{1\Sigma}^* = \frac{\sum_{i=1}^{m} P_i}{\sum_{i=1}^{n} P_i}, \qquad (1)$$

where P_i – average power of i^{th} transformer substations (TS) consumers during the year, кVA; m – number of TS (consumers) between disconnect switch and location of switching device installation; n – total number of TS in electric grid.

Let us determine the relative lengths of $L_{1\Sigma}^*$ by the expression (2).

$$L_{1\Sigma}^* = \frac{\sum_{i=1}^{l} L_j}{\sum_{i=1}^{k} L_j}, \qquad (2)$$

where L_j – length of j^{th} section of electric grid, km; l – number of transmission line sections between disconnect switch and location of switching device installation; k – total number of transmission line sections in electric grid.

Lengths of lines and nodes loading are given in Table 1 – 2

Table 1

Electric grid parameters

Transmission line		Type of the wire	Transmission line length, км	Z, Ohm/км	Availability of feeder disconnector
Start	End				
16	24	AC-50	1	0.63+0.418i	
24	25	AC-50	1.12	0.706+0.468i	
25	26	AC-50	1.12	0.706+0.468i	+
26	27	AC-50	1.5	0.945+0.627i	+
27	28	AC-35	0.7	0.637+0.3i	
28	29	AC-50	0.7	0.441+0.293i	+
29	30	AC-50	0.5	0.315+0.209i	+
30	31	AC-50	1.13	0.712+0.472i	
31	32	AC-50	1.23	0.775+0.514i	
32	23	AC-50	1.21	0.762+0.506i	

Table 2

Circuits nodes loading

Node	Corresponding node	Voltage	Load	Generation
Sub. St. 10 Mykhailivka	61, 63	10	0.2+0.11i	-
24	70, 71, 87	10	0.9+0.51i	-
25	72	10	0.6+0.34i	-
26	88	10	0.4+0.23i	-
27	68, Gal. SPP , Gal. HPS	10	0.3+0.17i	0.95
28	115	10	0.4+0.23i	-
29	90, 91, 95	10	0.9+0.51	-
30	173, 100	10	0.5+0.28i	-
31	160	10	0.09+0.05i	-
32	150	10	0.09+0.05i	-

Relative powers and relative lengths of lines are calculated for each of 4 zones, determined as locations for disconnect switches installation. Total power of consumers--- 3230 kW, total length of the line --- 9 км. The results of the calculation are shown in Table 3.

Table 3

Calculation parameters of distribution electric grid

Location of SD (end of section) installation	Power of the first zone $P_{1\Sigma}$, kW	Relative power of the first zone $P_{1\Sigma}^*$, r. u.	Length of the first zone $L_{1\Sigma}$, km	Relative length of *the* zone $L_{1\Sigma}^*$, r. u.
25	1500	0.464	2.12	0.236
26	1900	0.588	3.24	0.36
28	1650	0.511	5.44	0.604
29	2550	0.789	6.14	0.682

At the next step it is necessary to determine the type of power distribution in transmission line. Transmission line can be referred to certain type by power distribution according to λ criterion, determined by the expression (3).

$$\lambda = \frac{1}{\beta} \cdot \sum_{\alpha=1}^{\beta} \left[P_{1\Sigma}^{*}(\alpha) - L_{1\Sigma}^{*}(\alpha) \right], \qquad (3)$$

where $P_{1\Sigma}^*(\alpha)$, $L_{1\Sigma}^*(\alpha)$ – relative total power and relative total length of electric grid section between disconnect switch and location of SDGS installation in the α point on electric grid line; β – total number of locations of SDGS installation on electric grid line.

In our case λ criterion equals 0.121. Hence, it can be assumed that the power of consumers is equally distributed along the length of transmission line ($-0,2 \le \lambda \le 0,2$ – condition of uniform TS power distribution).

If one SDGS is installed, rational location of its installation must correspond to such point of electric grid where the total length of the first zone $L_{1\Sigma}$, limited by disconnect switch and SDGS, will be determined by the expression (4).

$$L_{1\Sigma} = x1 \cdot L_{\Sigma}, \qquad (4)$$

where $x1 = 0,5$ – is determined from the Tables [11], L_{Σ} – total length of transmission line.

It is expedient to install SDGS at the beginning of the line, so that the length of the line to the point of SDGS installation in real circuit would be less than the calculated length of the first zone $L_{1\Sigma}$. Calculated value is $L_{1\Sigma} = 4.5$ km, hence SDGS, installed in the lines 25-26, 26-27, meet the requirements of energy supply reliability.

The next step of the technique is determination of the calculated value of the expected relative gap of electric energy ΔW^* for the grid, where SPGS is installed in rational location, determined from technique Tables. [11]. In our case ΔW_{Σ}^* equals 0.5 r. u.

Calculated value of the expected gap of electric energy ΔW_{Σ} for the grid without SPGS is determined by the expression (5).

$$\Delta W_{\Sigma} = 0,93 \cdot P_{\Sigma} \cdot L_{\Sigma} \qquad (5)$$

where P – total average load of electric grid (without DSE) kW; L – total length of transmission lines in the grid, km.

Total average load of electric grid in kW is calculated by the formula (6):

$$P_{\Sigma} = \frac{W}{8760}, \quad (6)$$

where, W – annual consumption of electric energy in the grid, kW\h.

Without DSE total average load of the grid is 4180. Calculated value of the expected relative reduction of electric energy gap is determined by the formula (7):

$$\partial w_{\Sigma}^{*} = 1 - \Delta W_{\Sigma}^{*}, \quad (7)$$

where ΔW_{Σ}^{*} – calculated value of the expected relative underdelivery of electric energy. Expected value of electric energy gap reduction in kW\h\yr for calculation of the integral effect of SPGS installation is determined by the formula (8).

$$\partial w_{\Sigma} = \partial w_{\Sigma}^{*} \cdot \Delta W_{\Sigma}, \quad (8)$$

where δw_{Σ}^{*} – calculated value of the expected relative electric energy gap reduction; ΔW_{Σ}^{*} – calculated value of the expected relative gap of electric energy.

Calculated value of the expected electric energy gap ΔW_{Σ} for the grid , shown in Fig. 1, without SPGS is 34999 kW\ h\ yr and expected value of the reduction of electric energy gap after installation of SPGS is 17490 kW\ h\yr.

By the results of energy supply reliability calculations the conclusion could be drawn that the interruption of the circuit in Fig.1 is expedient to perform by SD, installed in lines 25-26, 26-27.

Thus, at the next step we determine by which of the SD it is better to interrupt the circuit on condition of active power losses decrease in the grid.

Determination of the flow distribution point

We will consider the method of flow distribution points determination on the simplified scheme of 110/ 10 kV electric grid. The model of electric grid with DSE is constructed in software environment Graph Scanner, shown in Fig. 2. Parameters of the circuit are given in the Table 4 and Table 5.

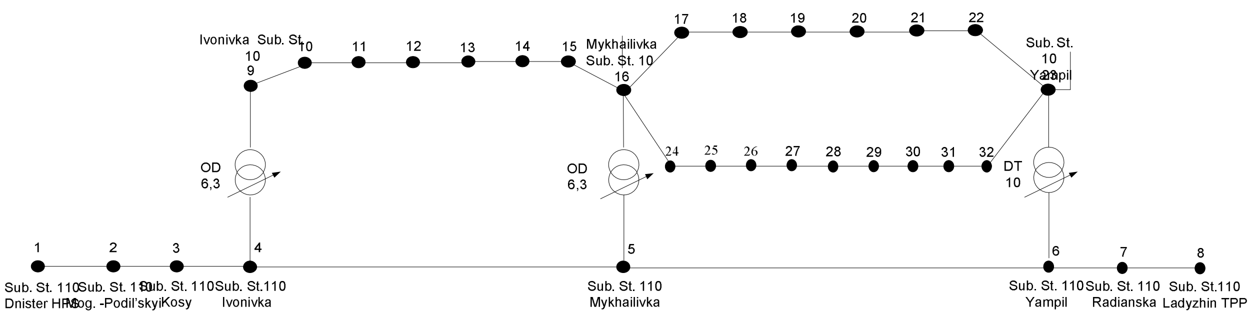

Fig. 2. Diagram of 110/ 10 kV electric grid

Dnistrovska HPS and Ladyzhin TPP serve as the centres of supply. Proceeding from the conditions of reliable electric energy supply in the grids of 110 kV lines with bidirectional supply must be disconnected .

Table 4

Parameters of circuit branches

Transmission line		Type of wire	Length of transmission line, km	Z, Ohm/km	Availability of feeder disconnector
Start	End				
1	2	AC-185	39.06	10.458+6.939 i	
2	3	AC-120	22.6	6.102+8.837i	
3	4	AC-120	22.4	6.048+8.758i	
4	5	AC-120	12.0	7.56+5.016i	
5	6	AC-120	18.37	4.96+7.18i	
6	7	AC-120	10.4	2.808+4.066i	
7	8	AC-120	2.8	0.756+1.095i	
9	10	AC-50	1.5	0.945+0.627i	
10	11	AC-35	1	0.91+0.429i	
11	12	AC-35	1.5	1.365+0.643i	+
12	13	AC-35	1.33	1.21+0.571i	
13	14	AC-35	3.22	2.935+1.384i	
14	15	AC-50	5.94	3.742+2.483i	
15	16	AC-50	5	3.15+2.09i	
16	17	AC-50	1.73	1.09+0.723i	
17	18	AC-35	1.78	1.62+0.764i	+
18	19	AC-35	2.86	2.603+1.227i	
19	20	AC-35	2.18	1.984+0.935i	
20	21	AC-35	1.91	1.738+0.819i	
21	22	AC-50	5.255	3.311+2.197i	
22	23	AC-35	1.6	1.456+0.686i	
16	24	AC-50	1	0.63+0.418i	
24	25	AC-50	1.12	0.706+0.468i	
25	26	AC-50	1.12	0.706+0.468i	+
26	27	AC-50	1.5	0.945+0.627i	+
27	28	AC-35	0.7	0.637+0.3i	
28	29	AC-50	0.7	0.441+0.293i	
29	30	AC-50	0.5	0.315+0.209i	
30	31	AC-50	1.13	0.712+0.472i	
31	32	AC-50	1.23	0.775+0.514i	
32	23	AC-50	1.21	0.762+0.506i	

Table 5

Load of LES nodes

Node	Corresponding node	Voltage	Load	Generation
1	Sub. St. 110 Dnister HPS	110		
2	Sub. St. 110 Mog.Podil'skyi	110	6+3.40i	-
3	Sub. St. 110 Kosy	110	0.37+0.21i	-
4	Sub. St. 110 Ivanivka	110	-	-
5	Sub. St. 110 Mykhailivka	110	-	-
6	Sub. St. 110 Yampil	110	-	-
7	Sub. St. 110 Radianska	110	0.44+0.25i	-
8	Sub. St. 110 Ladyzhin	110	-	4+3.48i
9	63	10	0.09+0.05i	-
10	641	10	0.4+0.23i	-
11	642	10	0.4+0.23i	-
12	Slob.Bush. SPP, HPS	10	0	1
13	1, 4, 8	10	1.2+0.68i	-
14	5, 6, 7, 9, 10, 11, 14, 16	10	0.35+0.2i	-
15	2, 3, 13	10	0.14+0.08i	-
16	61, 63	10	0.2+0.11i	-
17	64, 65, 82	10	0.76+0.43i	-
18	80, 81, 83, 89	10	0.41+0.23i	-
19	75, 77, 78	10	0.3+0.17i	-
20	93	10	0.53+0.3i	-
21	96, 97, Gal. SPP I-II, Gal. HPS	10	0.54+0.31i	1.5
22	99	10	0.26+0.15	-
23	62	10	0.3+0.17	-
24	70, 71, 87	10	0.9+0.51i	-
25	72	10	0.6+0.34i	-
26	88	10	0.4+0.23i	-
27	68, Gal. SPP, Gal. HPS	10	0.3+0.17i	0.6
28	115	10	0.4+0.23i	-
29	90, 91, 95	10	0.9+0.51	-
30	173, 100	10	0.5+0.28i	-
31	160	10	0.09+0.05i	-
32	150	10	0.09+0.05i	-

Installed generation power of Sloboda-Bushanska SPP is 1MW, Galzhbiivska SPP1 and SPP II-1.5 MW, Galzhibiivska SPP III-0.6 MW and did not change in the process of the study . First we will consider operation mode of LES , when HPS is disconnected and Dnistrovska HPS and Ladyzhin TPP and available SPP serve as supply sources.

In order to determine flow distribution points , we assume that all the circuits of the scheme are closed. As a result of the first experiment we obtained that calculated points of flow distribution will be in 13.18 and 28 lines, total losses of active power in the circuit are 0.5406 MW, power losses in 10 kV lines---0.3627MW, losses of active power in 110 kV lines are 0.1799 MW. Voltages in circuit nodes are given in Table 6 . In the second experiment , according to the flow distribution point 18 we interrupt line 17-18 , as a result total losses are 0.5541 MW, losses in 10 kV line -0.3746MW, losses in 110 kV line -0.1801 MW.

In order to shift the calculated point of flow distribution to the node of the circuit where the disconnector is installed, we connect Sloboda- Bushanska HPS. If generation power is 0.2 MW, flow distribution point shifted from the 13 node to 11 node. In line 11-12 there is feeder disconnector , thus, in the third experiment we interrupt the given line. After interruption of the lines total losses of active power are 0.5125 MW, losses in 10 kV grid-0.344 MW, in 110 kV grid-0.1685 MW. As a result of the second interruption total losses in the grid decreased.

At the next step , it is necessary to disconnect line with bidirectional supply 16-23. Calculated point of flow distribution is in 28 node and feeder disconnector- in the line 26-27. Hence, we connect Galzhbiievska HPS on the power 0.35 MW, flow distribution point shifted in 26 node. In the fourth experiment we interrupt line 26-27 . Total losses after interruption are 0.4671 MW, in 10 kV grid- 0.3160MW, in 110 kV grid---0.1511 MW. As KA are installed in the lines 26-27, 25-26 meet the requirements of energy supply reliability, we interrupt line 25-26, where as line 26-27 is connected.

As a results of such interruption, total losses of active power increased to 0.4939 kW. From the results obtained the conclusion can be made that it is expedient to disconnect line 26-27.

As it is seen from the results, after interruption in 10 kV grid , active power losses decreased as compared with the obtained results prior to interruption. The necessity of interruption is connected with the requirements of energy supply reliability. If for the given mode of grid operation the circuit is interrupted not in the points of flow distribution but in locations where disconnectors are installed, then the losses will increase. That is why, in the fifth experiment HPS is interrupted and we disconnect the lines where disconnectors are installed , i.e., lines 11-12, 17-18, 26-27. As a result of the experiment , total losses are 0.550 MW, losses in 10 kV grid – 0.3763 MW, losses in 110kV grid- 0.1827 MW. Thus, regulation by power generated by HPS enables to shift calculated point of flow distribution in the location, where disconnector is installed, as a result total losses in the grid decreased to 91 kW.

Table 6

Voltages in circuit nodes

№ of the node	Number of the experiment				
	1	2	3	4	5
1	115	115	115	115	115
2	113.77	113.77	113.81	113.86	113.77
3	113.42	113.42	113.49	113.59	113.41
4	113.08	113.07	113.17	113.31	113.07
5	112.82	112.81	112.92	113.1	112.79
6	112.93	112.91	113.03	133.22	112.83
7	113.14	113.12	113.23	113.43	113.07
8	113.2	113.18	113.3	113.49	113.13
9	10.84	10.85	10.64	10.65	10.63
10	10.51	10.52	10.37	10.39	10.36
11	10.32	10.33	10.24	10.25	10.22
12	10.25	10.26	10.38	10.43	10.2
13	**10.18**	**10.2**	10.31	10.37	10.15
14	10.24	10.27	10.36	1.41	10.24
15	10.32	10.35	10.43	10.48	10.35
16	10.66	10.7	10.74	10.79	10.76
17	10.03	10.17	10.21	10.26	10.23
18	**10**	9.77	10.79	9.84	9.67
19	10.11	9.91	9.93	9.98	10.82
20	10.36	10.23	10.25	10.29	10.14
21	10.67	10.58	10.6	10.64	10.49
22	10.82	10.76	10.78	10.82	10.68
23	10.91	10.86	10.88	10.93	10.78
24	10.5	10.53	10.56	10.63	10.61
25	10.4	10.42	10.46	10.54	10.51
26	10.36	10.37	10.4	10.51	10.47
27	10.35	10.53	10.38	10.5	10.2
28	**10.34**	**10.33**	**10.35**	10.47	10.18
29	10.35	10.35	10.37	10.46	10.19
30	10.42	10.38	10.41	10.5	10.15
31	10.55	10.53	10.55	10.63	10.48
32	10.72	10.59	10.71	10.77	10.59

Let us consider the fragment of circuit from node 23 to node 27, after interruption of the line 26-27. In the given fragment of the circuit , changing the power of HPS generation , we influence the losses in the circuit. In order to calculate active power losses, the method of nodal voltages was chosen [12].

Calculations were carried out in software environment Mathcad. As the input parameters we set the matrix of branches connection in nodes, matrix of branches resistances and matrix of nodal currents as it is shown in the following expressions. The circuit consists of 6 branches and 7 nodes . Node 23 is taken as a basic node, that corresponds to substation Yampil 10kV. DSE, namely Galzhbiivska SPP and Galzhbiivska HPS are located in the 27th node, correspondingly. Generation power of SPP is 0.6.MW, generation power of HPS in the process of the experiment changed from 1.5 MW to 3.5 MW.

Thus, the first matrix of incidences (M) has dimensionality 6x6 (without basic node)

$$\boldsymbol{M} = \begin{pmatrix} -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 0 & 0 & -1 \end{pmatrix} \qquad (9)$$

Having the parameters of transmission line and nodes loading we write down the matrix of branches resistances (z) and matrix of controlling currents in the nodes (J), expressions (10-11). Controlling current in the node from HPS is written, taken into account that HPS at the given moment generates 0.2 MW.

$$z = \begin{pmatrix} 0{,}762 + j\cdot 0{,}506 \\ 0{,}775 + j\cdot 0{,}514 \\ 0{,}712 + j\cdot 0{,}472 \\ 0{,}441 + j\cdot 0{,}293 \\ 0{,}441 + j\cdot 0{,}293 \\ 0{,}637 + j\cdot 0{,}3 \end{pmatrix}, \qquad (10)$$

$$\boldsymbol{J} = \begin{pmatrix} -5{,}196 - j\cdot 2{,}944 \\ -5{,}196 - j\cdot 2{,}944 \\ -28{,}868 - j\cdot 16{,}166 \\ -51{,}962 - j\cdot 29{,}445 \\ -23{,}094 - j\cdot 13{,}279 \\ 28{,}868 - j\cdot 3{,}291 \end{pmatrix}, \qquad (11)$$

where z – is matrix of circuit branches resistances, J-is matrix of controlling currents in the branches.

By the expression (12) we determine matrix of nodal conductances

$$\boldsymbol{Y} = \boldsymbol{M}\cdot z^{-1}\cdot \boldsymbol{M}^T , \qquad (12)$$

where z-is matrix of circuit branches resistances, M-is the first matrix of incidences, M^T-is the transposed first matrix of incidences.

We calculate matrix-column of nodal voltages, relatively balancing node, by the formula (13):

$$\boldsymbol{U_n} = \boldsymbol{Y}^{-1}\cdot \boldsymbol{J}, \qquad (13)$$

where $-Y$ –is the matrix of nodal conductances, J-is matrix of controlling currents in branches.

At the next step we calculate absolute voltages in the nodes by the expression

$$\boldsymbol{U} = \boldsymbol{U_n} + \boldsymbol{U_0}, \tag{14}$$

where U_n-is column of voltages relatively basic node, U_0-is voltage of basic node.

Voltage of basic node is assumed to be equal 10.74 kV (with Graph Scanner).

As a result of calculation , we obtained matrix of voltages in the nodes of the following form:

$$\boldsymbol{U} = \begin{pmatrix} 1{,}071 \cdot 10^4 \text{ - j} \cdot 95{,}105 \\ 1{,}068 \cdot 10^4 \text{ - j} \cdot 186{,}827 \\ 1{,}066 \cdot 10^4 \text{ - j} \cdot 266{,}526 \\ 1{,}065 \cdot 10^4 \text{ - j} \cdot 300{,}352 \\ 1{,}066 \cdot 10^4 \text{ - j} \cdot 305{,}967 \\ 1{,}068 \cdot 10^4 \text{ - j} \cdot 299{,}403 \end{pmatrix} \tag{15}$$

As it is seen from the results obtained, the smallest voltage will be in the 4$^{\text{th}}$ node, that is why the point of flow distribution will be the 4th node.

At the next step we will determine power losses prior to grid interruption . For power losses calculation we set the input parameters: matrix of nodal loads and matrix I –matrix of interconnection of nodal powers and power transfers in the system. Thus, matrix of nodal loads has the following form:

$$\boldsymbol{S} = \begin{pmatrix} -90 - j \cdot 50 \\ -90 - j \cdot 50 \\ -500 - j \cdot 280 \\ -900 - j \cdot 510 \\ -400 - j \cdot 230 \\ 500 - j \cdot 57 \end{pmatrix} \tag{16}$$

If the power is consumed, then, in the corresponding node we write down the value of the consumed power with the sign “-“, if the node contains the source of generation, this value is written with the sign “+“. Rows of matrix T correspond to the branches and columns- to the nodes of the circuit. Matrix T will be written in the following form:

$$\boldsymbol{T} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \tag{17}$$

Power transfers in the branches of the circuit will be defined by the expression (18)

$$\boldsymbol{S_b} = \boldsymbol{T} \cdot \boldsymbol{S}, \tag{18}$$

where T- is matrix of interconnection of nodal powers and power transfers in the system, S- is matrix of nodal loads.

Power losses are defined by the formula

$$\Delta S = \sum_{i,j=1}^{n} \frac{S_{\textit{в}i,j}^{2}}{U_i^2} \cdot z_{i,j} , \tag{19}$$

where $S_{в i,j}$ – is power transfer in the ij^{th} branch, U_i – is voltage in the i^{th} node , z_{ij} – is resistance of the ij^{th} branch, i=1..n-1, j=i+1..n.

Active losses are found by the expression (20)

$$\Delta P = Re(\,\Delta S\,)\,, \tag{20}$$

where S – are power losses in LES, kW.

Changing generation power of HPS, we also changed the point of flow distribution and active power losses, correspondingly.

The results of the calculations are given in Table 7.

Table 7

Dependence of active power losses on the generation power of HPS

№ experiment	$P_{GEN,}$ MW	$Q_{GEN \cdot HPS}$ MVar	Point of flow distribution, kW	ΔP, kW
1	0.15	0.085	5	34.1
2	0.2	0.113	4	32.39
3	0.25	0.142	4	30.47
4	0.3	0.17	3	28.67
5	0.35	0.198	3	26.89

As it seen from Table 7, the growth of power generation leads to the shift of flow distribution point closer to the centre of supply and decrease of active power losses.

Conclusions

Disconnection point of ring section of distribution electric grids from the point of view of circuit supply provision may not coincide with the point of optimal flow distribution by the criterion of minimal power losses, that may also change depending on the loading in the nodes. It is possible to support power flows in the LES that correspond to optimal flow distribution point by the criterion of minimal power losses by small HPS. Power regulation of small HPS is performed on condition of unchanged scheme of LES. Values of HPS power are determined and set , so that they must provide power flows, corresponding to optimal flow distribution point, calculated by the criterion of minimal power losses.

That is, real point of electric grid interruption does not change and power flows, on such conditions correspond to calculated optimal point of flow distribution. In such a way we provide the reliability of energy supply at minimal losses of electric energy in the process of its transmission.

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