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Satbayev University

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ИЗВЕСТИЯ

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REDUCING POWER AND VOLTAGE LOSSES IN ELECTRIC NETWORKS OF OIL FIELDS USING THE MOTH FLAME OPTIMIZATION ALGORITHM

Abstract. Modern methods of optimizing power flow distribution modes to reduce the technological consumption of electricity for its transmission are widely used for central and remote areas of electrical networks. One of the most effective ways is the integration of distributed generation. Several measures have been taken in Kazakhstan to stimulate the introduction of renewable energy, one of which is solar energy. The use of photovoltaic (PV) panels in the oil field as a distributed generation will allow regulating the voltage, which will reduce power and voltage losses in distribution networks of10/0.4 kV. At the same time, low-power capacitor banks can be used as an additional means for optimizing the modes. However, one of the most difficult tasks in electrical distribution networks is the selection of connection points for PV panels and capacitors (Cap) to effectively reduce power and voltage losses, based on the limitations of the number and volume of power of distributed generation sources (PV panels and capacitors). To solve this problem, the most effective method is based on the Moth-flame optimization algorithm. This article discusses the results of modeling the optimization of the flow distribution in the IEEE 69 test circuit using the heuristic Moth-Flame Optimization algorithm to find the optimal power ratio of distributed generation sources (PV panels and capacitors)in electric networks of oil fields. The application of the new heuristic optimization algorithm MFO allows, in conditions of constraints, to find the optimal connection points for sources of active and reactive power to minimize power losses and voltage deviations in load nodes, which increases the efficiency of operation of distribution electrical networks.
Key words: power losses, distribution electric networks in oil field, power supply of oil fields, heuristic optimization algorithms, MFO algorithm.

Introduction. Reducing the technological consumption of electricity transmission is always a priority for distribution power grids. Under the conditions of increasing consumption of electric power, it is obvious that variable losses of electric power in electric networks of 10 / 0.4 kV will increase [1]. In this regard, it is necessary to optimize the flow distribution to minimize voltage and power losses using distributed generation. This is especially true in connection with the widespread use of renewable energy sources in Kazakhstan [2], in particular, the adopted regulatory documents [3-4] promote the use of solar installations (solar panels, inverters, storage devices) by residents of cities, suburbs and industry to cover their energy consumption. The problems of using distributed generation in the oil sector have been previously studied [15-16]. But along with this issue, the problem of the distribution of distributed generation sources remains topical [17]. However, it is relevant to a search for the optimal connection points for PV panels and capacitors in the distribution electrical network in conditions of limited unit power to minimize power and voltage losses [5]. A review of recent literature shows that algorithms such as Particle swarm optimization (PSO), Ant Lion Optimization (ALO), Symbiotic Organisms Search (SOS), Gray Wolf Optimization (GWO), Optimal Power Flow (OPF) [5-10] and Dragonfly Algorithm [11] are used in different branches of science, including in the distribution of the optimal location of objects to minimize electricity losses. However, despite the advantages of these methods, the considered heuristic ones are limited by the peculiarities of the search behavior of natural subjects. Therefore, the most effective method is Moth-flame optimization (MFO) [12], which has a spatial orientation in 3-dimensional space.

MFO Algorithm. The functional basis of the MFO algorithm is based on the lateral orientation of the moths. The phenomenon of moths is their navigation at night using moonlight, a navigation mechanism called lateral orientation. Following this navigation mechanism, the moth flies, maintaining a fixed angle relative to the moon, which is very effective when traveling long distances along a straight path. Since the moon is far from the moth, this mechanism ensures flight in a straight line [13]. However, when a closer artificial light source appears, the moths spiral around the lights. This is due to the inefficiency of lateral orientation, which is useful for traveling long distances in a straight line when the light source is very far away. When moths see artificial light, they try to maintain a similar angle with the light to fly in a straight line to reach their target. This behavior is embedded in the Moth-Flame Optimization (MFO) mathematical algorithm. In the MFO algorithm, the solution object is the moths, and the problem variables are the position of the moths in space. Therefore, moths can fly in 1-D, 2-D, 3-D, or in hyperdimensional space with a change in their position vectors, which is a significant advantage over other algorithms [5-11]. Since the MFO algorithm is a population-based algorithm, the set of moths is represented as a matrix as follows:

$$M = \begin{bmatrix} m_{1.1} & m_{1.2} & \cdots & \cdots & m_{1,d} \\ m_{2.1} & m_{2.2} & \cdots & \cdots & m_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{n,1} & m_{n.2} & \cdots & \cdots & m_{n,d} \end{bmatrix} \quad (1)$$

where n is the number of moths and d is the number of variables (measurement). For all moths, we assume that an array exists to store the corresponding best suitability values as follows:

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ \vdots \\ OM_n \end{bmatrix} \quad (2)$$

where n is the number of moths. That being said, the best value is the return value of the fitness function (target) for each month. The position vector (for example, the first row in the M matrix) of each moth is passed to the best values function, and the fitness function output is assigned to the corresponding moth as its fitness value (for example, OM1 in the OM matrix). Flame is another key component of the proposed algorithm. A matrix similar to that of moths is calculated as follows:

$$F = \begin{bmatrix} F_{1.1} & F_{1.2} & \cdots & \cdots & F_{1,d} \\ F_{2.1} & F_{2.2} & \cdots & \cdots & F_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ F_{n,1} & F_{n,2} & \cdots & \cdots & F_{n,d} \end{bmatrix} \quad (3)$$

where n is the number of moths and d is the number of variables (measurement). It can be seen in matrix (5) that the sizes of the arrays M and F are equal. For flame, it is also assumed that an array exists to store the corresponding suitability values as follows:

$$OF = \begin{bmatrix} OF_1 \\ OF_2 \\ \vdots \\ OF_n \end{bmatrix} \quad (4)$$

where n is the number of moths. Moths are search agents that navigate the space of options, while flame sources are the best position for agents, that is, the most optimal solution to the problem. In our case, the space of variants is an electrical network consisting of an n-th number of nodes. Flame sources can be considered as the most optimal nodes for placing sources of distributed generation. The number of flame sources depends on our limiting conditions. In this work, the limiting conditions are the number of distributed generation sources and the range of their capacities. The objective or object function is to reduce voltage losses and active power. With a set of these limiting conditions, search agents - moths - can search for the most optimal sites for installation - sources of flame. After finding nodes for installing distributed generation sources, the MFO algorithm selects their powers. As a result, the MFO algorithm provides a solution in the form of nodes for connecting distributed generation sources and the amount of power.

Simulation conditions. In this paper, the results of a study on the optimal choice of places for connecting PV-panels and capacitors, based on the range of output power to maximize power and voltage losses, using the MFO optimization algorithm based on the IEEE 69-node test circuit, are presented. We can assume that IEEE 69-node test circuit can be shift camp of workers. Modeling of the MFO algorithm was performed in the Matlab software package using the OpenDSS package for the following options shown in Table 1:

Table 1 – Conditions limiting P_j and Q_j of distributed generation

Case 1		Case 2		Case 3		Case 4	
P	150 ÷ 200 kW	P	100 ÷ 200 kW	P	75 ÷ 200 kW	P	25 ÷ 200 kW
Q	75 ÷ 100 kVAr	Q	50 ÷100 kVAr	Q	25 ÷100 kVAr	Q	5 ÷ 100 kVAr

In Table 1 where P is the range of variation of the unit power PV - panels with a quantity of 8 pieces; Q range of variation of the unit power of 8 capacitors;

Optimization criteria are two parameters for reducing active power losses:

$$\Delta P = \sum_{i=1}^{n\Sigma} \Delta P_i \rightarrow \min \tag{5}$$

And minimizing the voltage deviation in the supply centers of the loads:

$$\Delta V = \sum_{i=1}^{n\Sigma} \Delta V_i \rightarrow \min \tag{6}$$

Based on the optimization criteria, the mathematical model (7) is presented as follows:

$$\min \sum_{t=1}^{N_{\text{итераций}}} \sum_{i=1}^{N_{\text{узел}}} [(V_i - 1)^2] + \sum_{t=1}^{N_{\text{итераций}}} \Delta P \tag{7}$$

$$\text{conditions} \begin{cases} Xi\ (i\ =\ 1, 2, \ldots n) \\ N_{\text{iterations}}\ (t =\ 1, 2, \ldots n) \\ \min \le P_j \le \max, \quad (j = 1, 2, \ldots n) \\ \min \le Q_j \le \max, \quad (j = 1, 2, \ldots n) \\ У_m\ \ (m =\ 2, 3, \ldots m) \end{cases}$$

Sequence optimization is achieved by adjusting the input data of the MFO algorithm, under the following conditions:

- set the population of moths M_i equal to 16 units;
- set the number of flame sources F_i equal to 16 units;
- the number of iterations $N_{iterations}$ - 1000 times;
- limited the number of installed generation sources to 16 units;
- 8 sources of active P_j and 8 sources of reactive power Q_j;
- limited their rated power within the specified cases 1,2,3,4;
- excluded the first node from the considered candidates Y_m to accommodate the generation.

Results and discussion.

The simulation results for finding the optimal connection points for distributed generation sources using the MFO algorithm are shown in Figures 1-4.

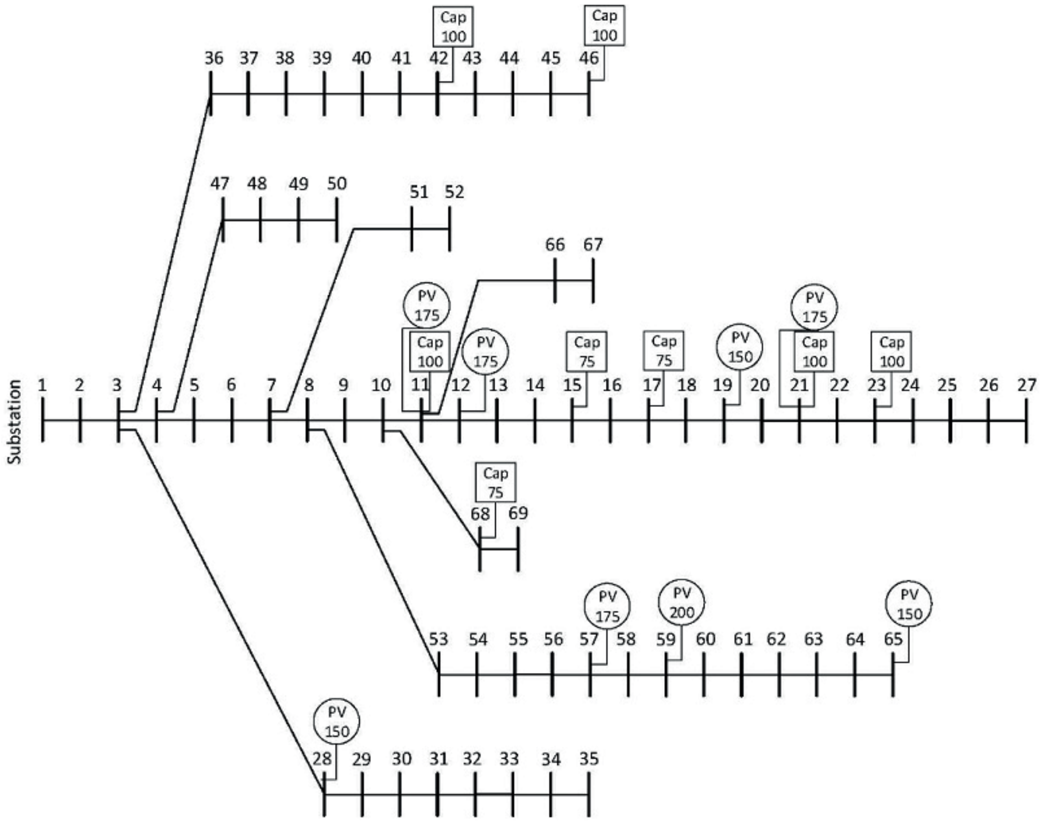

Figure 1 - Case 1.Connecting PV panels and capacitors to the electrical network with different options for the power output ranges.

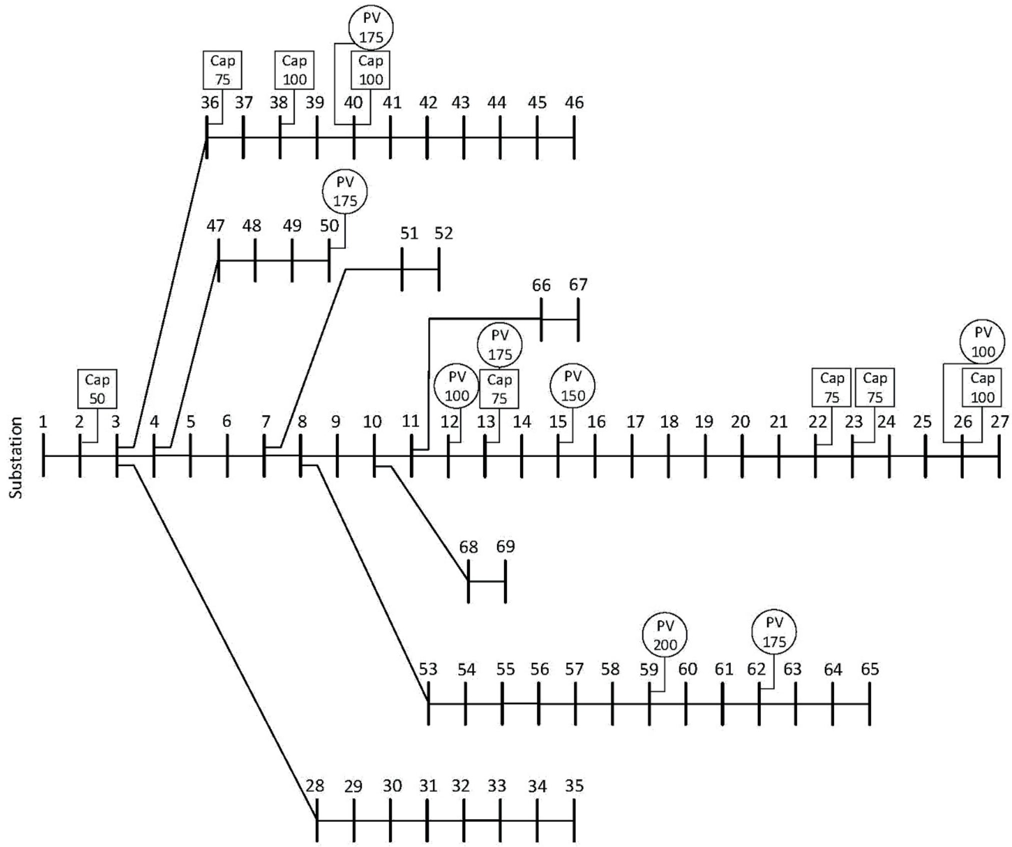

Figure 2 - Case 2. Connecting PV panels and capacitors to the electrical network with different options for the power output ranges.

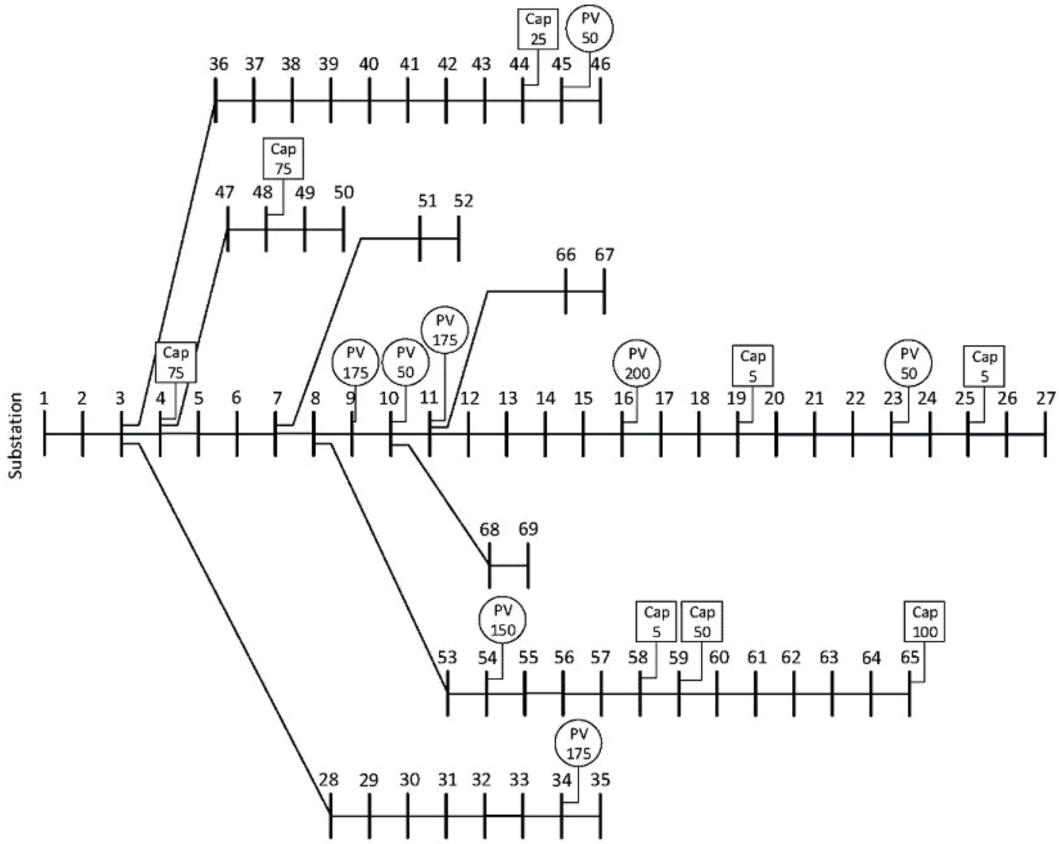

Figure 3 - Case 3. Connecting PV panels and capacitors to the electrical network with different options for the power output ranges.

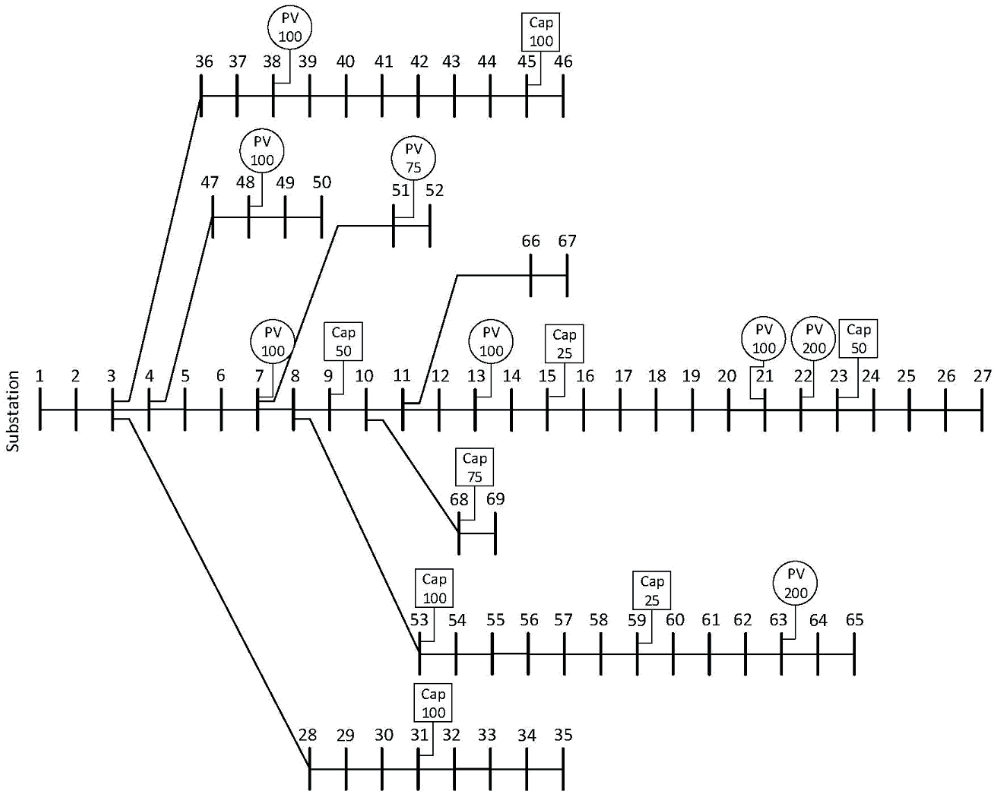

Figure 4 - Case 4. Connecting PV panels and capacitors to the electrical network with different options for the power output ranges.

Cases 1, 2, 3 and 4 differed in the range of variation of the output power for PV - panels: 150 kW - 200 kW, 100 kW - 200 kW, 50 kW - 200 kW, 25 kW to 200 kW, for capacitors: 75 kVar - 100 kVar , 50 kVar - 100 kVar, 25 kVar - 100 kVar, 5 kVar up to 100 kVar. Based on the simulation results, it can be seen that search agents in the form of moths with a population of 16 units and several flame sources (PV - panels, and capacitors) of 16 units chose different connection points that have, as well as different power of PV - panels and capacitors. Table 2 summarizes the results.

Table 2 Summary results of the total power of PV - panels, and capacitors for different options

Case 1		Case 2		Case 3		Case 4	
ΣP	1350 kW	ΣP	1250 kW	ΣP	975 kW	ΣP	1025 kW
ΣQ	725 kVAr	ΣQ	650 kVAr	ΣQ	525 kVAr	ΣQ	340 kVAr

From the analysis of the simulation results, it can be noted that the MFO optimization algorithm for option 1 chose the highest unit power of PV - panels, and capacitors. At the same time, the optimization consisted of smooth regulation of the output of active and reactive power relative to the central nodes of the loads. Since with an increase in the range of power generation by PV panels and capacitors, their unit power decreased. In this case, the criterion for the effectiveness of different optimization options is the maximum reduction in power and voltage losses. Figures 5 and 6 show the results of optimization modeling for reducing voltage deviation and power losses for different options.

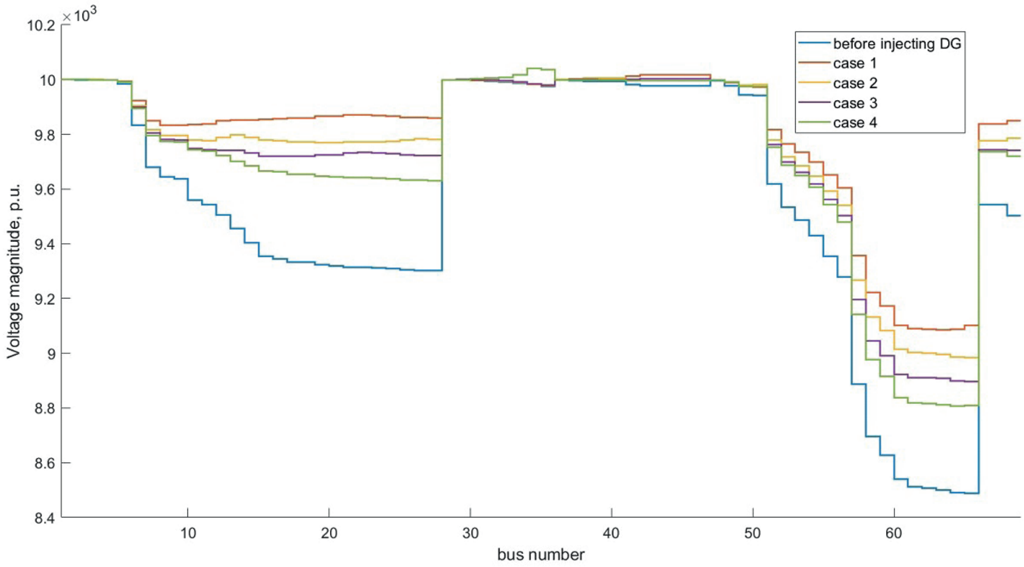

Figure 5 - Change in voltage deviation at load nodes with different connection options for PV-panels and capacitors

Analysis of the change in the voltage profile relative to each node shows that the voltage drop before connecting PV - panels and capacitors at a remote section of the investigated network is 15% or exceeds the permissible voltage deviations of 5%. Studies of the efficiency of optimization of flow distribution modes with the connection of PV - panels, and capacitors for 4 options have shown that the first option is the most effective. Option 2,3 and 4 also show their effectiveness, however, in terms of the voltage deviation level, they have a difference in deviation of 0.2 kV for each option on a remote section of the electrical network. At the same time, all 4 options for connecting PV - panels and capacitors show voltage equalization at remote points of power consumption, which can be used to regulate the voltage in the daily profile as «counter-regulation».

The change in the value of active power losses for different cases relative to each node of the distribution network shows that after modeling with the MFO optimization algorithm, the reduction in losses averaged 30%. At the same time, the most effective is the first option, which has a power output limitation range P = 150 ÷ 200 kW, Q = 75 ÷ 100 kVar, and a total maximum injection for the active power of 1350 kW, for reactive power of 725 kVar. Other options 2, 3, and 4 are less effective than option 1, especially in branched radial branches, the difference in efficiency is 0.1-0.2 p.u of active power losses. Thus, the results of optimization modeling according to the criteria for maximum reduction of power and voltage losses have shown that the first option is the most effective. It should be noted that the effectiveness of the first option in comparison with other options lies in the peculiarities of the operation of the MFO optimization algorithm, which, under conditions of limited power output P, Q (150-200 kW, 75-100 kVar), the population of moths M_i, (16 units) and the number of flame sources F_i (16 units) set the maximum volumes of unit power of PV panels and capacitors.

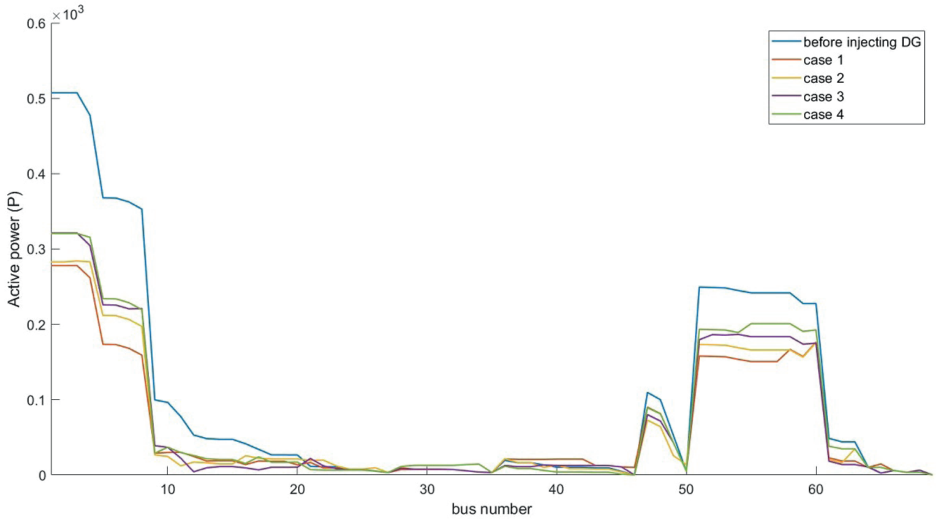

Figure 6 - Change in power losses in load nodes with different connection options for PV-panels and capacitors.

Conclusion. The studies on optimization of modes with the MFO algorithm on a test circuit of 69 nodes showed that out of 4 options for the range of limitations for the output of active and reactive power, the first option is the most effective. The results obtained are useful for finding the optimal connection points for sources of active and reactive power, which ensure the maximum reduction in power losses and voltage deviations in load nodes under conditions of a limited number and uniform power of PV panels and capacitors. The results of optimization modeling of modes with the connection of PV-panels and capacitors showed that the use of distributed generation of reactive power in electric networks allows regulating the voltage according to the «counter law» of control, the voltage at the terminals of the near and remote power consumers is entered within the permissible limits.

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MOTHFLAMEOPTIMIZATIONАЛГОРИТМІН ҚОЛДАНЫП МҰНАЙ КЕН ОРНЫНДАҒЫ ЭЛЕКТР ЖЕЛІЛЕРІНІҢ ҚУАТ ЖӘНЕ КЕРНЕУ ШЫҒЫНДАРЫН ТӨМЕНДЕТУ

Аннотация. Электр энергиясының таралуы режимдерінде электр желілерінің орталық және шалғай аудандары үшін оны оңтайландырудың заманауи әдістері кеңінен қолданылады. Тиімді тәсілдердің бірі - таратылған генерациясының интеграциясы. Қазақстанда жаңартылатын энергияны енгізуді ынталандыру бойынша бірқатар шаралар қабылданды, оның бірі - күн энергиясы. Таратылған генерация ретінде мұнай кен өндіру секторында PV - панельдерін пайдалану кернеуді реттеуге мүмкіндік береді, бұл 10 / 0,4 кВ тарату желілеріндегі қуат пен кернеу шығынын азайтады. Сонымен қатар режимдерді оңтайландырудың қосымша құралы ретінде аз қуатты конденсатор банктерін пайдалануға болады. Алайда, электр тарату желілеріндегі күрделі міндеттердің бірі - таратылатын генерация көздерінің қуатының саны мен көлемінің шектеулеріне негізделген қуат пен кернеудің ысыраптарын тиімді төмендету үшін PV панельдері мен конденсаторларының қосылу нүктелерін таңдау. Бұл мәселені шешу үшін ең тиімді әдіс. Бұл мақалада мұнай кен орындарының электр желілерінде таратылған генерация көздерінің (PV панельдері мен конденсаторлары) оңтайлы қуат коэффициентін табу үшін эвристикалық Moth-Flame Optimization алгоритмін қолданып IEEE 69 сынақ тізбегіндегі ағынның таралуын оңтайландыруды модельдеу нәтижелері талқыланады. Жаңа эвристикалық оңтайландыру алгоритмін қолдану MFO шектеулер жағдайында қуаттың шығынын және жүктеме түйіндеріндегі кернеудің ауытқуын азайту үшін тарату жұмысының тиімділігін арттыратын активті және реактивті қуат көздерін қосудың оңтайлы нүктелерін табуға мүмкіндік береді.

Түйінді сөздер: электр қуатының шығыны, мұнай кен орнындағы тарату электр желілері, мұнай кен орындарын электрмен жабдықтау, эвристикалық оңтайландыру алгоритмдері, MFO алгоритмі.

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СНИЖЕНИЕ ПОТЕРЬ МОЩНОСТИ И НАПРЯЖЕНИЯ ЭЛЕКТРИЧЕСКИХ СЕТЕЙ НЕФТЯНЫХ МЕСТОРОЖДЕНИЙ С ИСПОЛЬЗОВАНИЕМАЛГОРИТМА MOTHFLAMEOPTIMIZATION

Аннотация. Современные способы оптимизации режимов потокораспределения мощности для снижения технологического расхода электроэнергии на ее передачу широко используется для центральных и отдаленных районов электрических сетей. Одним из эффективных способов является интеграция распределенной генерации. В Казахстане предпринят ряд мер по стимулированию ввода возобновляемой энергетики, одной из которых является солнечная энергетика. Использование PV – панелей в нефтяных месторождениях в качестве распределенной генерации позволит регулировать напряжение, что снизит потери мощности и напряжения в распределительных сетях 10/0,4кВ. При этом дополнительным средством для оптимизации режимов могут быть использованы маломощные конденсаторные батареи. Однако одной из сложных задач в распределительных электрических сетях является выбор точек подключения PV-панелей и конденсаторов для эффективного снижения потерь мощности и напряжения, исходя из ограничений количества и объемов мощности источников распределенной генерации (PV-панелей и конденсаторов). Для решения данной задачи наиболее эффективным является метод, основанный на алгоритме Moth - flameoptimization. В настоящей статье рассмотрены результаты моделирования оптимизации потокораспределения в тестовой схеме IEEE 69 узлов с применением эвристического алгоритма Moth-Flame Optimization для поиска оптимального соотношения мощности источников распределенной генерации (PV-панелей и конденсаторов) в электрических сетях нефтяных месторождений. Применение нового эвристического оптимизационного алгоритма MFO позволяет в условиях ограничений найти оптимальные точки подключения источников активной и реактивной мощности с целью максимального снижения потерь мощности и отклонения напряжения в узлах нагрузок, что повышает эффективность эксплуатации распределительных электрических сетей.

Ключевые слова: потери электроэнергии, распределительные электрические сети на нефтяных месторождениях, электроснабжение нефтяных месторождений, оптимизационные эвристические алгоритмы, алгоритм MFO.

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