



THE METHODOLOGY FOR DESIGN OF AUTONOMOUS POWER SUPPLY SYSTEM OF OIL PRODUCING COMPANY OPTIMIZED ON LENGTH AND NUMBER OF GENERATION CENTERS

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Abstract: Improving energy efficiency and reducing the cost of creating an electrical complex of autonomous power supply for an oil-producing enterprise is an urgent problem and requires a rational solution. The goal is the construction of energy-efficient electrical systems of autonomous power supply for oil-producing enterprises, leading to a reduction in the unit cost of electricity per unit of production. A methodology for constructing an autonomous power supply system for an oil producing enterprise, optimized in length and number of generation centers is present. The results presented in the work were obtained using methods of the theory of electric and magnetic circuits, theory of electric drive, methods of optimization of power supply systems, methods of mathematical and computer modeling. The configuration of the power supply system of oil producing enterprises and the efficiency of its work is analyzed. To test the efficiency of the methodology, the power supply system of an oil producing enterprise is simulated in the RTDS software package. The results of the work were introduced and used in the creation of energy-efficient electrical systems for autonomous power supply to oil-producing enterprises based on autonomous diesel generators and optimized by the length of power lines and the number of generation centers. Implementation of the results of the work allows reducing the specific energy consumption per unit of extracted products and reducing the cost of building an energy-efficient electrical complex of autonomous power supply for oil-producing enterprises.

Keywords: autonomous power supply system; oil producing enterprise; methodology; electric centrifugal pumps; optimization.

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Introduction

Mechanized oil production in the world is carried out in various ways. In Russia, 54% of operating oil wells are equipped with electric centrifugal pumps, 41% use sucker rod pumps [1]. These pumps, as a rule, are equipped with three-phase asynchronous electric motors, but recently there has been a tendency to install synchronous electric motors [2-4]. The power of motors mounted on sucker rod pumps is lower than that of centrifugal pumps [5-7]. This is due to the fact that the performance of centrifugal pumps is higher.

There are several options for equipment for oil wells [8-10]:

1. One well – one powerful submersible centrifugal pump, on which a powerful electric motor is installed. This engine is powered by its own single-transformer substation 10 (6) / 0,4kV.
2. Several wells at one site with sucker-rod pumps with medium power engines. The motors are powered by their own one-two-transformer substation. 10 (6) / 0,4kV.
3. Several wells on the same site with submersible centrifugal pumps with small average power engines. The motors are powered by a cluster transformer substation 10 (6) / 0,4kV.

Power supply of transformer substations of wells can be carried out both from a centralized power supply system and from autonomous generators. Autonomous generators are

used in cases: remoteness from the centralized power supply system (PSS), lack of power, low quality electricity of a centralized PSS [11-13]. Analysis of existing power supply systems for transformer substations in wells that are powered by a centralized power supply system showed that power is supplied through a trunk circuit. This is due to the fact that the radial power supply circuit is more expensive.

The analysis of power supply systems from autonomous generators according to the scheme of one generator – one well showed low generator load and high operating costs. This issue was considered in detail in works [14-16]. This problem led to the creation of generation centers, on which several generators are installed and from which a group of transformer substations for wells is fed.

When creating generation centers to power a group of transformer substations for wells, the following problems arise:

1. Determining the number of generation centers.
2. Determining the configuration of the power supply system of transformer substations of wells from one generation center.
3. Organization of mutual reservation between generation centers.

To solve these problems, we propose a methodology for designing an electric power supply system for an oil production complex that is optimal according to the criterion of minimum length and the number of generation centers.

Materials and methods

The main procedures for designing the power supply system of an oil production complex that are optimal according to the criterion of minimum length and number of generation centers:

1. Formation of the source data system: coordinates, power and utilization factors of electrical equipment, parameters of electric lines.

2. Building a Steiner tree.

Let a set of nodes $P = \{p_1, p_2, \dots, p_n\}$ located on one plane be given: it is required to find a tree $T = (X, U)$ with many vertices X and many edges U for which $P \in X$ the total length of the edges U is minimal. Using this method, you can enter an unlimited number of additional nodes.

Let $P = \{p_n\}, i = 1, 2, \dots, n$ be the set of conclusions of the elements of the power supply system. We construct a basic orthogonal grid passing through given conclusions (points) p_i .

The tree construction algorithm includes the following operations. We introduce auxiliary variables:

g_{ij} – the weight of the connection between the given conclusions (points, vertices) i and j , in which the features consisting in the presence of various sections, places of laying, etc. for the electrical connection are taken into account.

$$g_{ij} = \mu_0 \cdot l_{ij} \cdot C \quad (1)$$

μ_0 – raw data connection features;

C – linear cost of the power line, rub / m;

l_{ij} – the length of the electrical connection, which is according to the formula for the orthogonal metric:

$$L_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

2.1. Number clockwise, in a spiral fashion, the points (terminals of the electrical circuit) of the set $P = \{p_n\}, i = 1, 2, \dots, n$.

2.2. Determine the weight of the connections between all given points of the set $P = \{p_n\}, i = 1, 2, \dots, n$ by the formula (1).

2.3. Compose a matrix of compound weights $G = |g_{ij}|$.

2.4. Determine the minimum matrix element $G = |g_{ij}|$. With the same value of the minimum connection weights, the element with the lowest value of the output number (point) is selected. To each element of the matrix $G = |g_{ij}|$ matches two points.

2.5. Build a tree fragment connecting two points p_i and p_j a minimum matrix element G

for which $g_{ij} = \min$.

2.6. To all points of the orthogonal grid through which the fragment of the tree passed, assign the lowest of the numbers of the endpoints of the fragment.

2.7. Operations 2.2-2.6 should be performed for the remaining points until fragments for all points $p_i, i = 1, 2, \dots, n$ are constructed and until everyone receives number 1.

At the end of the solution, we obtain a single tree connecting all points of the set $P = \{p_n\}, i = 1, 2, \dots, n$ and having the least weight of the connections.

3. Locate the center of generation.

To solve the problem by the method of constructing the optimal Steiner tree with subsequent binding of the generation center to it, a special algorithm was developed:

3.1. To find the center of electrical loads, transfer the resulting wiring of electrical circuits to a two-dimensional coordinate system.

3.2. Create a table with the coordinates and power of each consumer of electric energy

3.3. According to equations (3) and (4), determine the center of electrical loads:

$$X_{CEL} = \sum_{i=1}^{\infty} \frac{x_i \cdot P_i \cdot k_u}{P_i \cdot k_u} \quad (3)$$

$$Y_{CEL} = \sum_{i=1}^{\infty} \frac{y_i \cdot P_i \cdot k_u}{P_i \cdot k_u} \quad (4)$$

3.4. Locate the center of electrical energy generation. Its location will be on the edge of the obtained graph closest to the load center.

4. Checking the electrical network for long-term permissible currents. In case of a negative result, the zone is divided by $n+1$ (where n is the number of the site). Further, procedures 3, 4 must be repeated for each zone.

5. Configuration of the power supply system of the oil producing enterprise according to the options:

- Steiner tree.
- Hamiltonian cycle.

Next, determine the root mean square value of the current, the average length of overhead power lines, the average resistivity of overhead power lines throughout the power supply system.

6. Checking the electrical network for voltage losses, which should be no more than 5% in normal mode. If the voltage loss test is negative, increase the number of zones by one, then repeat procedures 2-6.

7. Determine the connection points of redundant jumpers between highways receiving power from neighboring generation centers by the method of combinatorics of distance comparison.

Results and discussions

An example of constructing a power supply system for an oil producing company that is optimal according to the criterion of minimum length and number of generation centers for the *Ratka* region of the *Rumaila* field (*Iraq*), which has 20 oil wells (*Ru-013, Ru-033 ... Ru-321*). *Rumaila (Iraq)* is one of the five largest deposits in the world. We compose a matrix of connection weights for the corresponding oil wells (fig. 1).

	Ru-033	Ru-064	Ru-083	Ru-093	...	Ru-286	Ru-300	Ru-321
Ru-033	0	113,3578	50	87,46428	...	68,00735	50	60,20797
Ru-064		0	82,76473	31,62278	...	65,76473	63,63961	74,33034
Ru-083			0	51,47815	...	71,58911	31,62278	11,18034
Ru-093				0	...	58,5235	38,07887	42,72002
...
Ru-286						0	40,31129	72,11103
Ru-300							0	32,01562
Ru-321								0

Fig. 1. Compound Weights Matrix

We determine the minimum matrix element: *Ru-083 - Ru-321* = 11.18 connecting the conclusions of *Ru-083, Ru-321*. We build a fragment of the tree *Ru-083, Ru-321* and assign the

number Ru-083 to all points of the fragment. Similarly, we determine the minimum weight of the remaining electrical connections and complete the corresponding fragments of the tree (fig. 2).

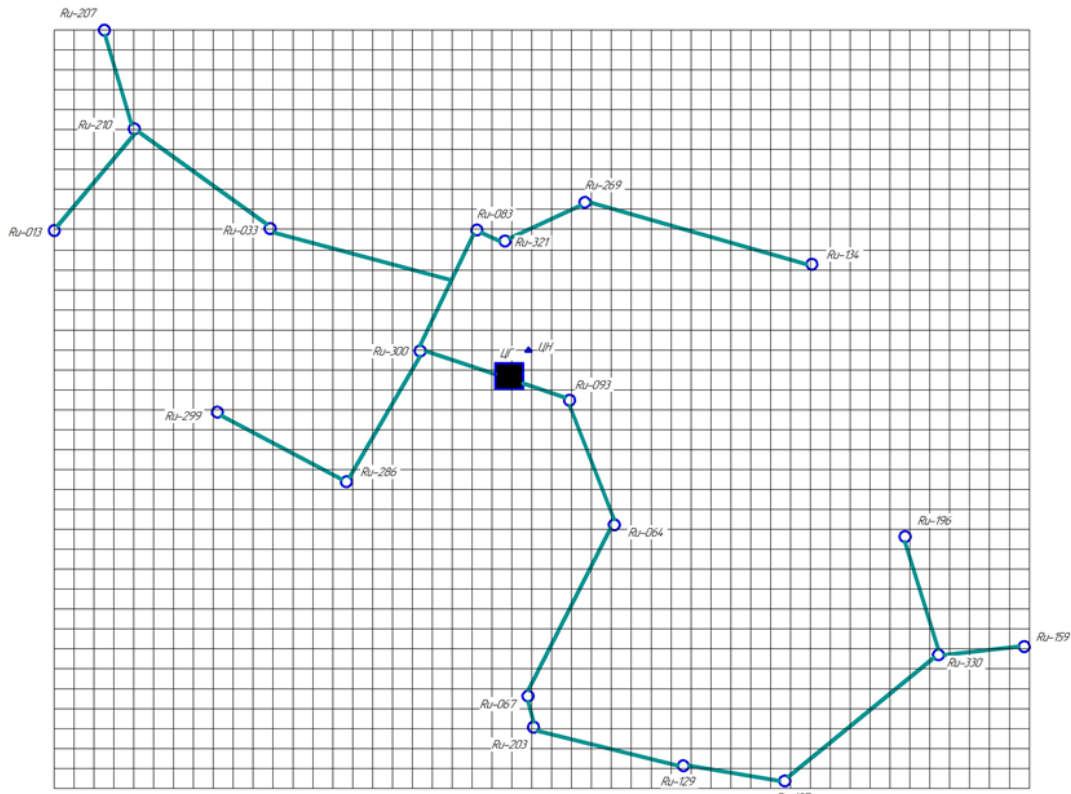


Fig. 2. The power supply system of the Ratka region of the Rumaila field (Iraq) for the Steiner tree

Next, we divide the electrical loads into uniform zones (fig. 3). Limitations under this option will be: uniform power of consumer groups, the cost of electrical equipment of substations (switches, cable lines, etc.).

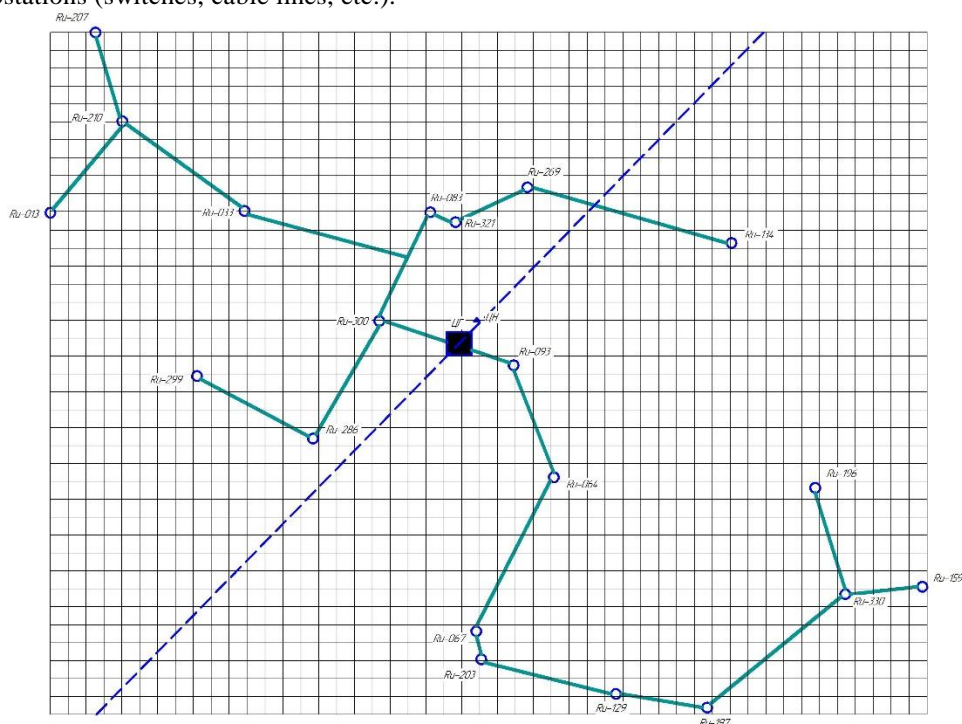


Fig. 3. Division of electrical loads into uniform zones

As a result of the division of the formed zone, two subsets are determined for which the algorithm with the Hamiltonian cycle is applicable (Fig. 4).

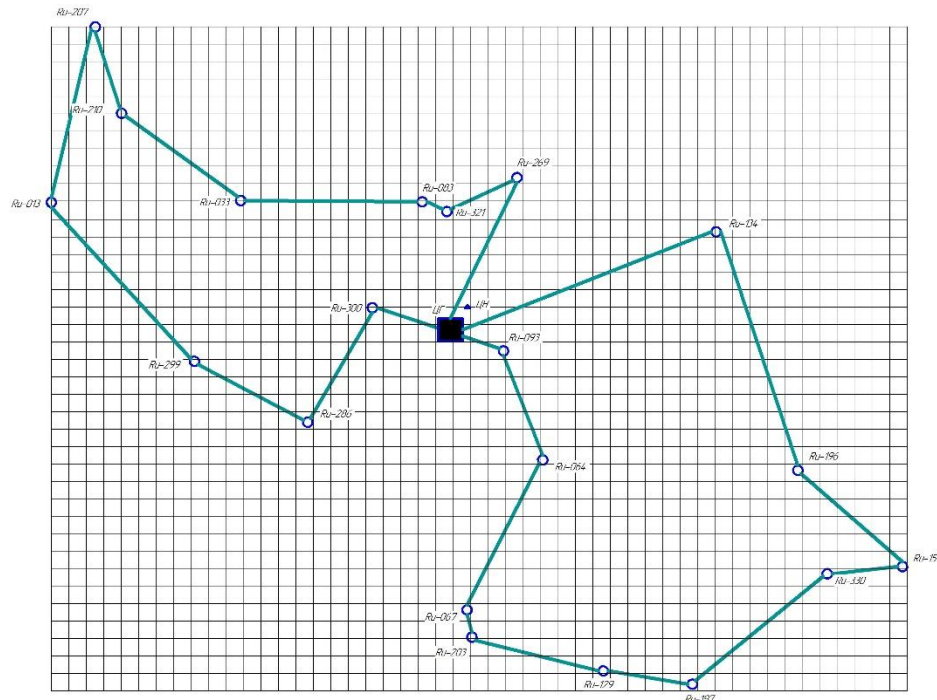
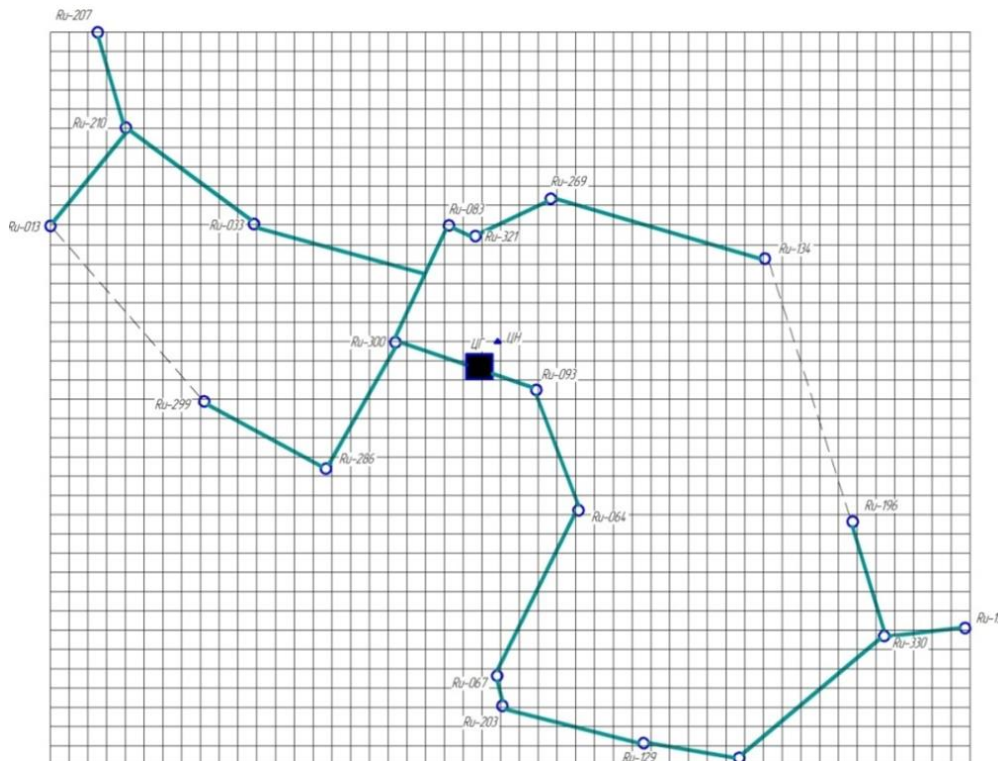


Fig. 4. The power supply system of the Ratka region of the Rumaila field (Iraq) according to the Hamilton cycle

From the obtained options for the power supply system of the Ratka region of the Rumaila field (Iraq) (fig. 2 and fig. 4), the power supply system for the Steiner tree with double-circuit overhead power lines (fig. 5) is less expensive based on the cost of the structure.



Dotted lines indicate reserve jumpers.

Fig. 5. Center for electricity generation in the Ratka region of the Rumaila field (Iraq)

To check the received power supply system of the Ratka region of the Rumaila field (Iraq) for voltage losses, we simulated the power supply of the oil producing enterprise in the *RTDS* software package (Fig. 6).

Overhead power lines are presented as a «*PI Section Model*». This module simulates

self and mutual resistances, inductances and capacitances.

The load is presented in the form of a «*Dynamic Load*» block with specified power parameters, with the possibility of change during the simulation.

The power source is given in the form of a «*Three Phase Source*» block, presented as an infinite power source.

Transformers are presented in the form of a «*Power Transformers*» unit with all relevant technical specifications.

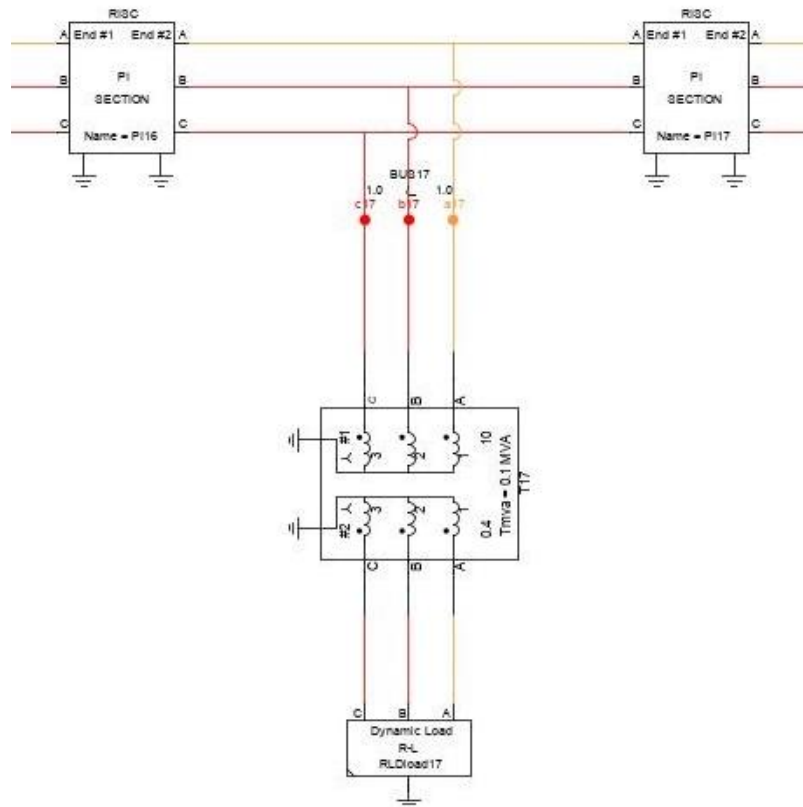


Fig. 6. Modeling of the power supply system in the RTDS software package

The simulation results of the power supply system in the RTDS software package are presented in Table 1.

Table 1.

Simulation results				
№	Oil well	$\Delta U_{sim.} \%$	$\Delta U_{calc.} \%$	$\Delta U\%$ <i>IEEE141-1993</i>
1	Ru-093	1,9	1,82	5
2	Ru-064	2,63	2,47	5
3	Ru-067	2,93	2,78	5
4	Ru-203	2,99	2,81	5
5	Ru-129	3,18	3,02	5
6	Ru-197	3,35	3,21	5
7	Ru-330	3,6	3,45	5
8	Ru-159	3,75	3,56	5
10	Ru-196	3,87	3,63	5
11	Ru-300	2,93	2,75	5
12	Ru-286	3,08	2,89	5
13	Ru-299	3,17	3,01	5
14	Ru-033	3,22	3,09	5
15	Ru-210	3,47	3,33	5
16	Ru-013	3,61	3,42	5
17	Ru-207	3,51	3,29	5
18	Ru-083	3,1	2,91	5
19	Ru-321	3,13	2,97	5
20	Ru-269	3,2	3,07	5
21	Ru-134	3,35	3,18	5

Conclusions

Modeling the power supply system of an oil company in the Ratka region obtained using the algorithm for constructing an energy-efficient power supply system showed that the voltage deviation at all points of the network does not go beyond the boundary values under normal and post-accident conditions, the largest voltage loss at the far Ru-196 well is 3,87%, which is acceptable.

The error voltage of calculation results on standard *IEEE* 141-1993 and voltage deviations simulation results of power supply system is 4%. That is, the modeling of the power supply system of the oil company reflects the high convergence of the research results.

Thus, the developed methodology for designing the power supply system of the oil production complex determines the number of generation centers, the configuration of the power supply system for transformer substations of wells from one generation center, organizes mutual reservation between the neighboring generation centers according to the criterion of the minimum length and number of generation centers, ensuring a minimum cost for this power supply system.

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