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MODEL DEVELOPMENT AND CALCULATIONS FOR 35/10 KV ELECTRICAL SUBSTATIONS IN TURKESTAN REGION USING RASTRWIN3 PROGRAM

Abstract: The city of Turkestan, Kazakhstan is experiencing growth leading to an increased need for electricity. In order to meet this demand the city is upgrading its infrastructure specifically focusing on improving its 35/10 kV substations. Engineers are utilizing calculation software like RastrWin3 to design and analyze these substations.

This software offers capabilities, for modeling substations. Using RastrWin3 the ability to import data from sources like drawings AutoCad, GIS maps and other relevant resources. This imported data serves as the foundation for constructing the substation model. Engineers can easily incorporate components such as transformers, feeders, circuit breakers and busbars into the model. Each element of the model can be assigned parameters like voltage, current, resistance and power to represent real world conditions. Additionally, load profiles can be generated for analysis purposes to capture fluctuations, in energy demands throughout the day and year.

Numerical calculation software plays a role, in the design and analysis of substations. It provides engineers with a toolset to achieve the following objectives:
1. Construct models of substations.
2. Simulate the behavior of substations under operational conditions.
3. Resolve issues that may arise in electrical substations.
4. Enhance the design and optimization of substations.

One notable software in this domain is RastrWin3 which offers capabilities for calculations and simulations related to electric substations. Engineers can utilize this program to evaluate power systems, in emergency and transient modes. Accounting for various factors such as non-linearity, power and reactive power losses, as well, as the influence of capacitive coupling.

Various types of loads such, as consumer loads, substation auxiliary loads and loads from protection and automation devices are considered in the modeling process. The software RastrWin3 is utilized to design and analyze 35/10 kV substations, in Turkestan. This software assists in enhancing the precision of substation design reducing the time needed for designing and developing substations improving substation efficiency and lowering maintenance costs.

Keywords: numerical calculation; energy indicators; distribution of electrical networks; RastrWin3.

Introduction

RastrWin3 software is specifically developed to tackle calculation, analysis and optimization challenges related to networks and systems. It finds application, in over 150 organizations, across Russia, Kazakhstan, Kyrgyzstan, Belarus, Moldova, Mongolia and Serbia. The demonstrates how the RastrWin3 program can be used to determine the operating conditions of networks. Specifically they discuss analyzing the 110 kV substation mode, which involves considering components, like transformers, switches, disconnectors, reactors, capacitors and protective and automation devices. According to the authors in the RastrWin3 software is an powerful tool, for analyzing networks numerically. It can handle stability analysis of networks of any size and complexity regardless of voltage (from 0.4 to 1150 kV). In they explain how RastrWin3 utilizes an algorithm as an optimization methodology to find solutions that minimize or maximize specific target functions while adhering to operational constraints. This algorithm effectively manages the nonlinear connections within electrical grids resulting in enhanced system performance [1-4].

In the paper [5] the authors delve into the considerations regarding the reliability of grids when there is an increase in generation. They highlight that as the share of generation grows it leads to a decline in grid reliability. Additionally, they explore how IT solutions can be applied to enhance power grid reliability and efficiency in [6]. By implementing IT solutions risks associated with accidents and failures can be reduced, while resource utilization efficiency can be improved.

The article discusses the use of the RastrWin3 program for modeling a 35/10 kV electrical substation. The authors demonstrate the capabilities of the program in modeling the operation of various substation components, such as transformers, switches and reactors.

The paper studies the impact of distributed generation on the operation of 35/10 kV electrical substations. The authors show how the RastrWin3 program can be used to analyze this influence.

Furthermore [7, 8] discusses an approach, for processing of power transfer analysis specifically designed for large scale power systems. When contemplating expansion of transmission networks it becomes crucial to take into account and control constraints.

This could involve optimizing the structure of the network and planning, for network expansion [9]. The methods used to model DC and AC network models are likely discussed in [10]. The objective seems to be incorporating types of networks into power system modeling. [11, 12] presents a method based on homotopy to determine equilibrium points that should be applied when solving problems related to the application of information technology, for calculations in controlling 35/10 kV substations. This may be connected to strategies aimed at ensuring the stability of the power supply system.

Research methodology

Step-down transformer Ps 100/10/10kV "Nursat", "Yassy" provides power supply to consumers of the first, second and third categories of the city of Turkestan, receives power from the substation 110/35/6kV "Shardara". In the substations "Nursat", "Yassy" has two working power transformers T1 and T2. The power of the T1 power transformer is 6300 kVA, the power of the T2 transformer is 4000 kVA. This substation does not have a capacity reserve, that is, two 6.3 and 4 MVA transformers operate with almost loads close to nominal capacities, and a small fraction of the daily schedule operate in overload mode of approximately 7%. Substations included in the network section of the Turkestan region for the power supply of the city of Turkestan do not contain reactive power compensation devices, which could reduce the loss of active power during transmission from the source to consumers. In addition, the location of

substations on the network section and the scheme of their connections using overhead power lines contributes to increased power losses due to the long transmission path of electricity. However, this factor was not taken into account during the construction of the network. The 110/10/10kV substation "Yassy" was put into operation in 2017. The connection scheme of the new 110/10/10kV substation "Nursat", "Yassy" to the electric grid has significantly reduced the flow of power from the source to the end consumers. It is also possible to connect substations 10/10 kV "Nursat", "Yassy" according to the new scheme.

When modeling generators, it is possible to simulate the Qmax(V) dependence taking into account the stator current limitation.

The interface language is Russian. A student license has been obtained to work in the program, that is, the number of nodes in the network scheme is limited to 60 nodes, but less than 60 nodes are used in this work. The system requirements for working in the program are not high, which allows you to work in it on most computers.

For further calculations of the operating modes of the district electric network, the Rastr-Win3 software package was selected.

When it comes to developing and calculating models for substations with RastrWin3, it is not just electrical engineering. The process also includes IT aspects that make IT relevant to the project. Understanding its features, functionality and user interface falls under the realm of software applications and user interaction.

Collecting substation information including equipment specifications, network configurations and operational parameters requires data management and manipulation techniques.

Computers with sufficient processing power and memory may be required to perform modelling using RastrWin3. Understanding the hardware requirements and how to optimise them is critical.

Documentation and reporting; effective presentation of project and modelling results relies on IT tools to create documents, develop presentations and use communication channels.

In general, substation work using RastrWin3 focuses on engineering issues, but the process relies heavily on IT aspects. Using software applications, data analysis techniques and suitable hardware, models can be created efficiently. Analyse substations in the Turkestan region.

Calculation of the operating mode of the district electric network

Before calculating the operating mode of the electrical network, the node number was assigned to each bus at each substation. The diagram with node numbers has the form in accordance with Figure 1. Before constructing the diagram in the RastrWin3 program, it is necessary to calculate and enter the initial data. RastrWin3 has a number of features: power lines are represented by branches bounded by two adjacent nodes, transformers are defined as branches, where the nodes bounding these branches are the ends of windings, three-winding transformers are defined as a star with three branches, two of which have a transformer coefficient. In the circuit of a three-winding transformer in RastrWin3 there is a central node that has a voltage, as well as a high-voltage winding. All the parameters of the transformers in this work are reduced to the high voltage side.
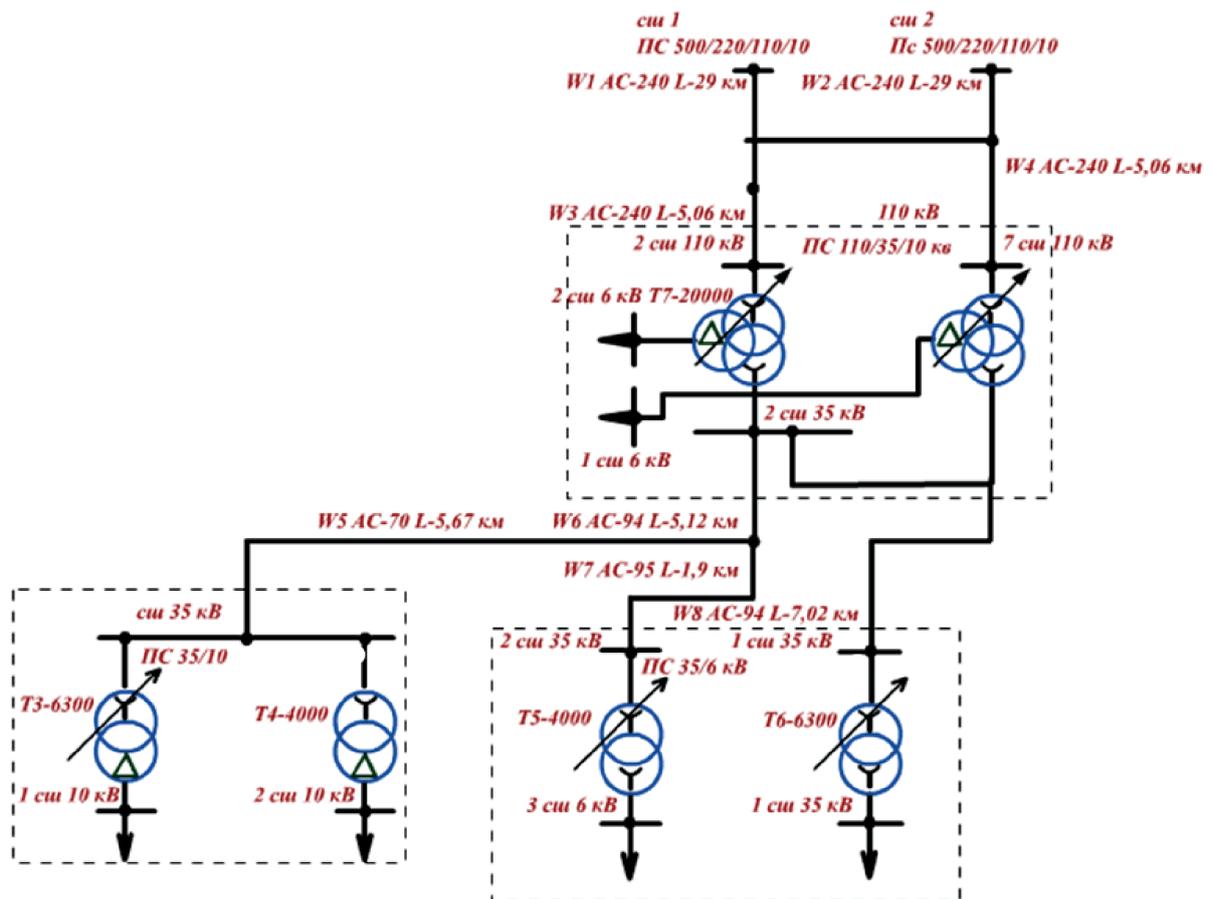
Figure 1. Contains the initial data for the description of nodes (nominal bus voltages U, kV,
active P, MW, and reactive Q, Mvar, load connected to substation buses, bus voltage angle φU, deg)
in the software package

Table 1. Node parameters in the Rastrwin 3 software package for describing
network parameters used in calculating modes

№ node	U_{nom}, kV	R, MW	Q, Mvar	Note
1	2	3	4	5
1.1	6	2,95	1,385	-
1.3	6	2,95	1,385	-
1.4	35	-	-	-
1.5	35	-	-	-
2.1	6	5	1,46	-
2.2	6	2,3	1,34	-
2.3	35	-	-	-
2.4	35	-	-	-

Node parameters are entered in a special RastrWin3 table "Nodes according to Figure 2.
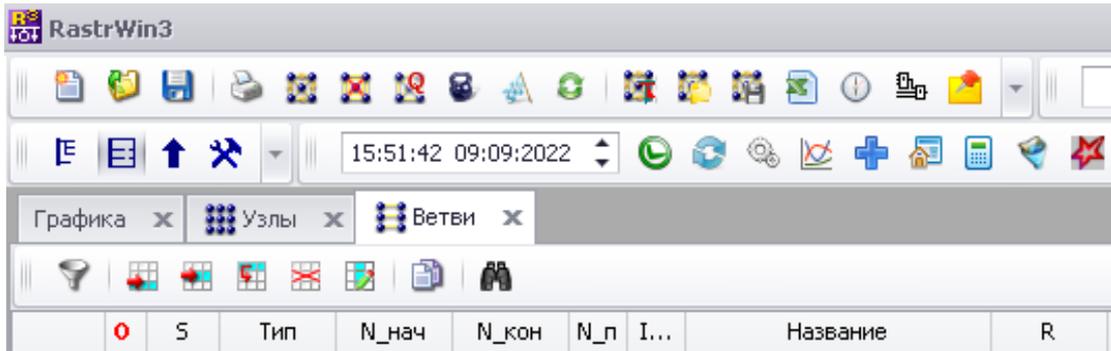
Figure 2. Node parameters are entered in a special RastrWin3 table
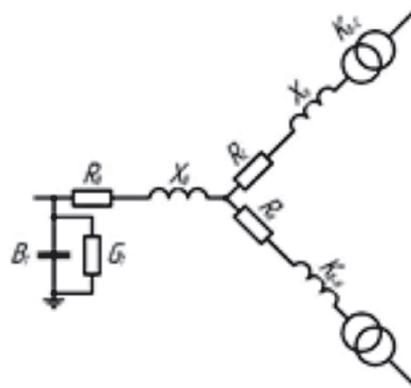
Figure 3. Entering data into the "Nodes" table in the RasrtWin3 program

To calculate the modes of the electrical network, the software package uses a U-shaped replacement circuit of power lines (in accordance with Figure 4) and an L-shaped replacement circuit of a three-winding transformer of transformers (in accordance with Figure 5), a two-winding transformer (in accordance with Figure 6).

Network equipment (lines and transformers are characterized by parameters: R-active resistance Ohms, X reactive resistance, ohms, G - active conductivity, Cm, B - reactive (capacitive) conductivity, Cm. For the possibility of calculations, the parameters of each element of the network are set.
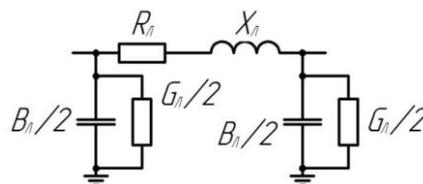
Figure 4. The replacement circuit of the power transmission line.
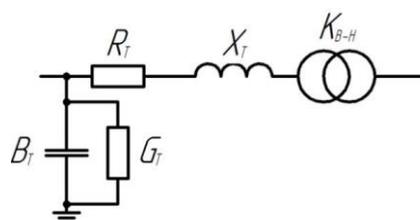
Figure 5. Replacement circuit of a two-winding transformer

To calculate the parameters of the power line. The active resistances of the overhead power-er line R_L, ohms, medium voltage windings of the three-winding transformer RC, ohms, low voltage windings of the three-winding transformer RN, ohms, are calculated according to the equations, respectively:

$$R_L = r_0 \, L \tag{1}$$

$$R_C = R_H = \frac{\Delta P_{K3} \cdot U_{rat}^2}{2 \cdot S_{ratT}^2} \tag{2}$$

where $\Delta P_{кз}$ – loss of transformer short circuit experience, Вт; U_{rat} – voltage of high voltage windings of transformers, B; $S_{rat\,T}$ – rated power of transformers, BA.

Reactive resistances of an overhead power line X_L, Ohm, high voltage windings of a three-winding transformer X_B, Ohm, medium voltage windings of a three-winding transformer X_C, Ohm, low voltage windings of a three-winding transformer X_H, Ohm, [13, 14, 15] calculated according to the equations, respectively:

$$X_{Л} = x_0 \cdot L, \quad X_B = \frac{u_{BK3} \cdot U_{rat}^2}{100 \cdot S_{rat}}, \quad X_B = \frac{u_{CK3} \cdot U_{rat}^2}{100 \cdot S_{rat}}, \quad X_B = \frac{u_{HK3} \cdot U_{rat}^2}{100 \cdot S_{rat}}. \tag{3}$$

where $u_{B\,кз}$, $u_{C\,кз}$, $u_{H\,кз}$, – the short-circuit voltages of the windings of high, medium, and low voltage are calculated according to the formulas (5), (6), (7) accordingly.

The active conductivity of power transmission lines with a voltage of 110 kV and below is not taken into account in the calculations of modes according to. The active conductivity of BT power transformers, MCM, is calculated by the equation:

$$G_T = \frac{\Delta P_{XX}}{U_{rat}^2} \cdot 10^6, \tag{4}$$

where ΔP_{xx} – is the losses in the transformer during the idling experiment, W. The reactive (capacitive) conductivity of overhead power lines with a voltage of 35 kV and below is not taken into account when calculating modes. The reactive conductivity of power transmission lines with a voltage of 110 kV and above VL, MCM, transformers W, MCM, are calculated according to the formulas, respectively:

The Ct transformation coefficients of power transformers are calculated by the equation:

$$B_L = b_0 \cdot L \tag{5}$$

$$B_T = \frac{i_{xx} \cdot S_{ratT}^2}{100 \cdot U_{rat}^2} \tag{6}$$

where $U_{rat\,H(C)}$ – rated winding voltage of the low (medium) voltage of the power transformer, V;

$U_{rat\,B}$ – rated voltage of the high voltage winding of the power transformer, V.

When modeling the operating mode, it is necessary to take into account that transformers have devices for regulating voltage under load (RPN) or a switching device without excitation (PBV). This equipment allows you to change the transformation coefficients in order to ensure optimal voltage on the secondary windings. The voltage of the RPN stages for transformers TDTNGU-20000/110/35/10-U1 and TDTN-20000/110/35/6-U1. The on-load tap-changer of these transformers is located on high-voltage windings, the number of turns of which changes during operation. The voltage regulation range is ±16% (±9 steps with step ΔU_{rpn}=1.778%).

Resistances of high-voltage windings XV, Ohm, RV, Ohm for each tap changer stage of a three-winding transformer, resistances of two-winding transformers XT, Ohm, RT, Ohm are calculated according to the equations respectively:

$$X_B = \frac{u_{B\kappa3}}{100} \cdot \frac{[U_{Brat}(\pm\Delta U_{rpn}/100)]}{S_{Trat}}, \tag{7}$$

$$R_B = \Delta P_{\kappa3} \cdot \frac{[U_{Brat}(\pm\Delta U_{rpn}/100)]}{2 \cdot S_{Trat}^2}, \tag{8}$$

$$X_T = \frac{u_{B\kappa3}}{100} \cdot \frac{\left[U_{Brat}\left(\pm\frac{\Delta U_{rpn}}{100}\right)\right]}{S_{Trat}}, \qquad R_T = \Delta P_{\kappa3} \cdot \frac{[U_{Brat}(\pm\Delta U_{rpn}/100)]}{2 \cdot S_{Trat}^2} \tag{9}$$

Branch voltages RPN $U_{BH\ i\pm n}$, kV, in increments of 1,778% calculated by the equation:

$$U_{BHi \pm n} = U_{BHrati} \pm 0{,}01778 \cdot n \cdot U_{Brati}, \tag{10}$$

where n is the number of the RPN stage.

The transformation coefficients are calculated according to the equation (2). Table 3 shows the calculation results.

Table 2. Voltages and resistances at the RPN stages

№ steps	$U_{BH\ i\pm n}$, kV	RB, Ohm	XB, Ohm	$K_{T\ B\text{-}C}$ for T1, T2	$K_{T\ B\text{-}H}$ for T1, T2	$K_{T\ B\text{-}C}$ for T3, T4	$K_{T\ B\text{-}H}$ for T3, T4
1	2	3	4	5	6	7	8
-9	96,5977	1,481	50,155	0,399	0,068	0,399	0,114
-8	98,6424	1,545	52,3	0,39	0,067	0,39	0,112
-6	102,7318	1,675	56,727	0,375	0,064	0,375	0,107
-5	104,7765	1,743	59,007	0,367	0,063	0,367	0,105
-4	106,8212	1,811	61,333	0,36	0,062	0,36	0,103
-3	108,8659	1,881	63,703	0,354	0,061	0,354	0,101
-2	110,9106	1,953	66,119	0,347	0,06	0,347	0,099
-1	112,9553	2,025	68,579	0,341	0,058	0,341	0,097
0	115	2,099	71,084	0,335	0,057	0,335	0,096
1	117,0447	2,175	73,635	0,329	0,056	0,329	0,094
2	119,0894	2,251	76,23	0,323	0,055	0,323	0,092
3	121,1341	2,329	78,87	0,318	0,054	0,318	0,091
4	123,1788	2,409	81,555	0,313	0,054	0,313	0,089
5	125,2235	2,489	84,285	0,307	0,053	0,307	0,088
6	127,2682	2,571	87,06	0,303	0,052	0,303	0,086
7	129,3129	2,655	89,88	0,298	0,051	0,298	0,085
8	131,3576	2,739	92,745	0,293	0,05	0,293	0,084
9	133,4023	2,825	95,654	0,289	0,049	0,289	0,082

Calculation of parameters for transformers TMN-6300/35/10-U1 (T6, T9, T10), TMN-6300/35/6-U1 (T3) is performed similarly to the calculation for transformers TDT-NG-20000/110/35/6-U1, TDTNGU-20000/110/35/10-U1. But it is necessary to take into account that for 35 kV transformers on high-voltage windings the on-load tap-changer with regulation range ±10 (±4 stages with step ΔUrpn = 2,5%) is installed. Table 3 shows the results of calculations.

Table 3. Voltages and resistances at the on-load tap-changer stages of T3 transformers

№ steps	$U_{BH\,i\pm n}$, кВ	R_T, Ohm	X_T, Ohm	$K_{T\,B\text{-}H}$ for T3
1	2	3	4	6
-4	31,5	1	11,813	0,349
-3	32,375	1,056	12,478	0,34
-2	33,25	1,114	13,161	0,331
-1	34,125	1,174	13,863	0,322
0	35	1,235	14,583	0,314
1	35,875	1,297	15,322	0,307
2	36,75	1,361	16,078	0,299
3	37,625	1,427	16,853	0,292
4	38,5	1,494	17,646	0,286

Similarly, the calculation of parameters for transformers T4 was made, table 2 shows the results of calculations for T4, table 2 for T5. Transformer T4 has a PBV with ±2 steps in increments $\Delta U_{pпн}$=2,5%.

Table 4. Voltages and resistances at the stages of the PBV transformer T4

№ steps	$U_{BH\,i\pm n}$, кВ	R_T, Ohm	X_T, Ohm	$K_{T\,B\text{-}H}$ for T4
1	2	3	4	5
-2	33,25	2,211	20,729	0,331
-1	34,125	2,329	21,835	0,322
0	35	2,45	22,969	0,314
1	35,875	2,574	24,132	0,307
2	36,75	2,701	25,323	0,299

The RastrWin3 program uses a special "Branches" dialog box to describe branches (power lines and transformers) (as shown in Figure 6). When entering the parameters of network elements, in addition to active, reactive resistances and conductivities, it is necessary to set the initial N_{start} and N_{fin} nodes of the branch (for power lines, the number of the initial and final node does not matter, for transformers, the initial node is the node to whose voltage the resistance is reduced).
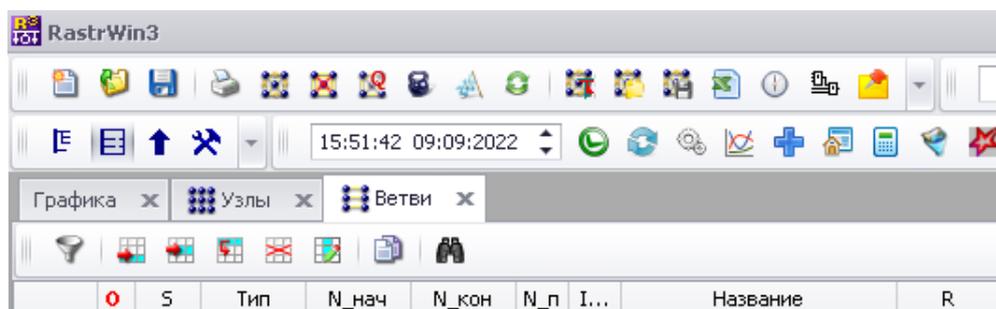
Figure 6. Entering data into the "Branches" table in the RasrtWin3 program

Voltage losses in a two-winding transformer ΔU_{Ti}, kV, are calculated by the equation:

$$\Delta U_T = \frac{P_i \cdot R_{Ti} + Q_i \cdot X_{Ti}}{U_B} \cdot 10^{-3},$$
(11)

where P is the active load of the transformer, W Q is the reactive load of the transformer, Var; R_{Ti} – active resistance of the transformer, Ohm; X_{Ti} – reactance of the transformer, Ohm. U_B – voltage on the high voltage windings in this mode of operation of the network, B.

As a result of the check, the program displays a message stating that the network contains two unconnected islands. This means that the whole circuit consists of two parts that are not electrically connected to each other, since the sectional switches (voltage 6, 10 and 35 kV) of each substation are in the off state. This message does not mean that an error was made when entering schema parameters. Therefore, it is allowed to calculate the operating mode of the electrical network. To calculate the mode, use the "Mode" command in the "Calculations" tab (in accordance with Figure 7), or the F5 key.

Figure 7. Command "Mode"

The calculation of the operating mode of the district electrical network was made. As a result, voltages (in kV) and voltage angles (in degrees) on substation buses are indicated near each node, directions and modules of active (in MW) and reactive (in Mvar) power flows are indicated at the beginning and end of each line (in accordance with figure 8).

Figure 8. Calculation of the operating mode of the district electrical network in the RastWin3 software package

In the RAstrWin3 software package, the scheme of the district electrical network was modeled and the operating mode was calculated. The direction and module of reactive power flows can be observed on the diagram in the working area (in accordance with Figure 9), table 6 displays the losses, where ΔP is the longitudinal losses of active power in the branch (transformer, power line), MW, ΔQ is the longitudinal losses of reactive power in branches, Mwar. The calculated loss is displayed in the "Branches" table in RastrWin3.

With known losses of active ΔP_y^x, MW, and reactive ΔQ_y^x, MW, powers, the total losses of active ΣP, MW, and reactive ΣQ, MW, powers are calculated according to the formulas, respectively (the index x indicates the number of the beginning of the branch, y is the number of the end of the branch):

$$\Sigma P = \Sigma \Delta P_{y}^{x},$$
$$\Sigma Q = \Sigma \Delta Q_{y}^{x} \tag{12}$$

The calculation of total losses was made using the mathematical package MS Excel. The total losses of active and reactive power are, respectively, ΣP_{oth}=1.206286 MW, ΣQ_{oth}=8.585647 Mvar. To assess the losses in each branch, a diagram of the dependence of active power losses ΔP=f(x-y) (in accordance with Figure 6) and reactive power ΔQ ,=f(x-y) on the branch number (in accordance with Figure 9) was constructed.
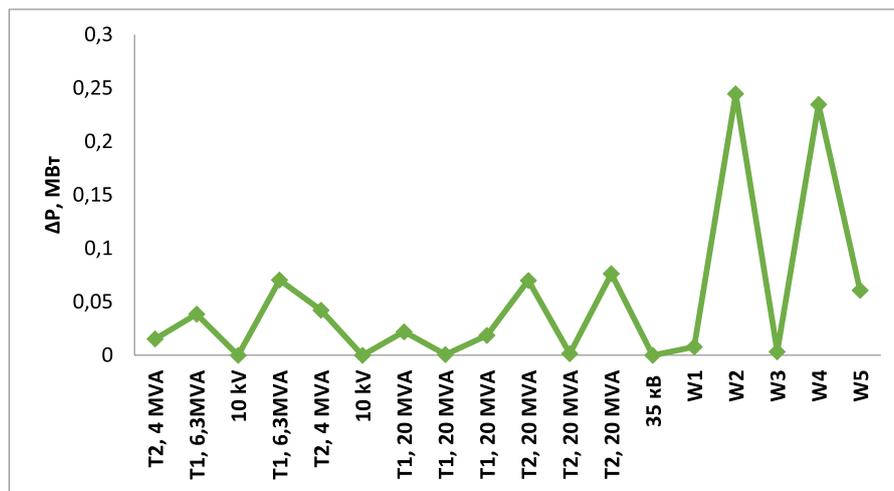
Figure 9. Diagram ΔP=f(x-y)

From the analysis of the diagram of active power losses in individual branches, it can be seen that the largest losses are in the branches W3 (0.192791 MW), W7 (0.244578 MW), W9 (0.234559 MW). These losses are due to the heating of the conductors during the flow of load currents through them. As can be seen from the diagram of the district electrical network (in accordance with Figure 10), all losses are formed in overhead power lines. The RastrWin3 software package allows you to calculate the maximum current in the elements of an electrical network. For branch 6.1-1 (line W3) the maximum mode current is I_{max}W3=139 A, for branch 3.3-3 (line W7) the maximum mode current is I_{max}W7=185 A, for branch 5.2-3 (line W9) the maximum mode current is I_{max}W9 \u003d 227 A.
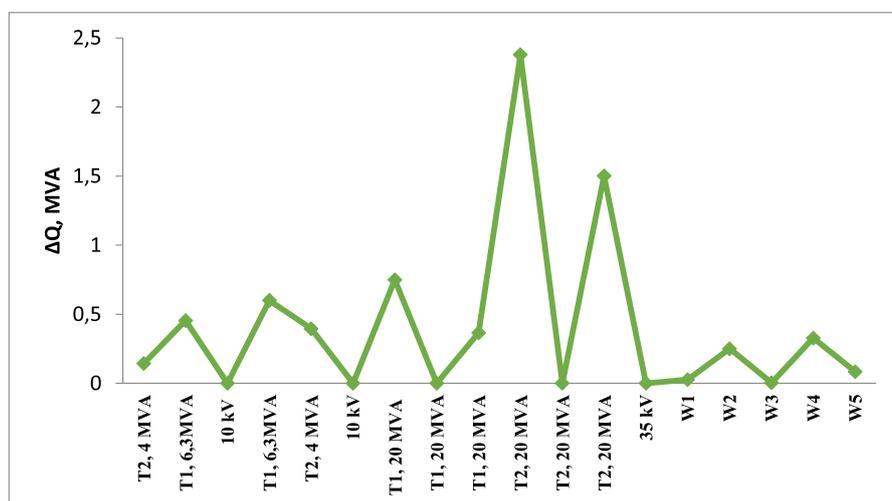
Figure 10. Diagram ΔQ=f(x-y)

From the analysis of the diagram of reactive power losses in separate branches we can see that the greatest losses are in branches 5.6-5.6.1 (2.377476 MVA), 5.6.1-5.2 (1500684 Mvar). According to [3], the permissible current under the condition of heating in wires of AC-70 (line W7) is equal to $I_{dopAS-70}$=265 A, AC- (line W9) is equal to $I_{dopAS-95}$=330 A, AC-240 (line W3) is equal to $I_{dopAS-240}$=610A. The most loaded is line W7. The load factor of line KZ is calculated by the formula:

$$К_{ЗW7}=I_{maxW7}/ I_{допAC-70},$$

$$К_{ЗW7}=185/265=0,698.$$

(13)

It is necessary to provide measures for unloading the W7 line. When the load of this line decreases, the load on the transformer T2 will decrease, the line W3 will be unloaded, therefore, losses in the electrical network will decrease. The RastrWin3 software package calculates the voltages at the beginning of the branches and at the end of each power line. Based on the data obtained, the calculation of voltage losses in each line is made as a percentage $\Delta U\%$, %, where table 8 displays the calculation results. U_{start} – voltage module at the beginning of the power line, kV, Window - voltage module at the end of the power line, kV, U_{fin} – rated voltage of the power line, kV.
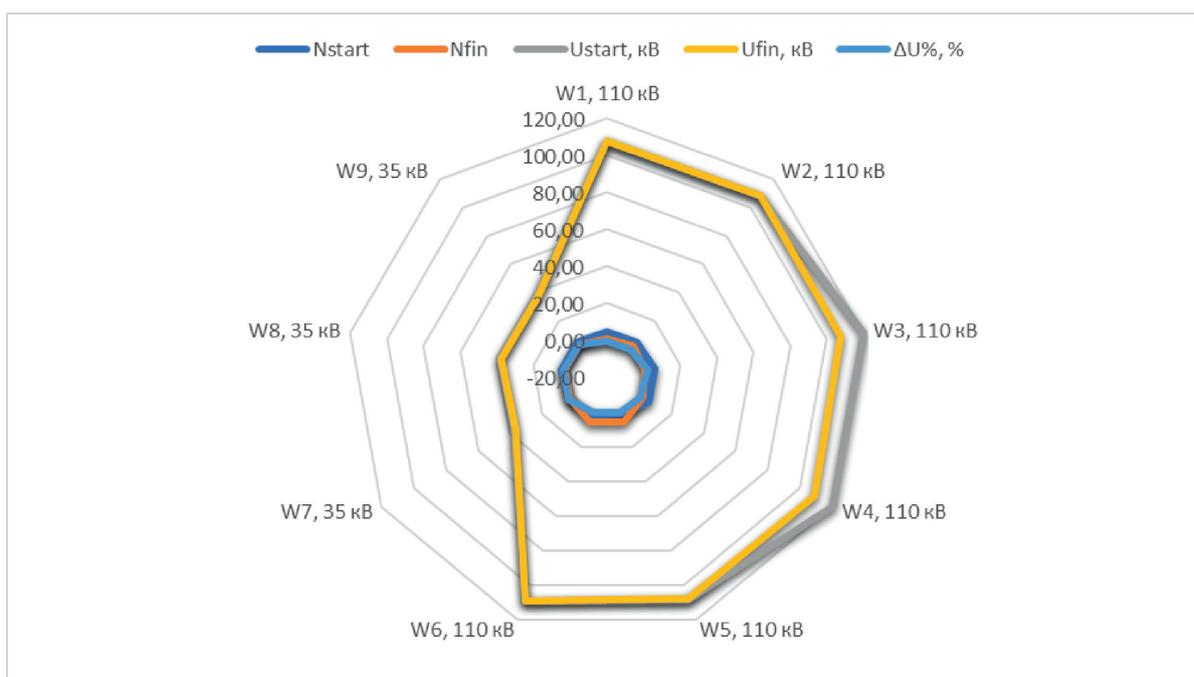
Figure 11. Results of stress calculations Nstart Nend Unstart, kV Ufin, kV ΔU%, %

The diagram of voltage losses in power lines W1-W7 has the form in accordance with Figure 12. Voltage losses are represented by a modular value. When analyzing the diagram of Figure 11 and Table 8, it was found that the greatest voltage losses have power transmission lines W7, W9, W3. One of the reasons for the increased losses is the operation of the overhead line W7 at increased load, since it simultaneously feeds two transformers of the substation 10/10 kV "Nursat" and "Yassy".
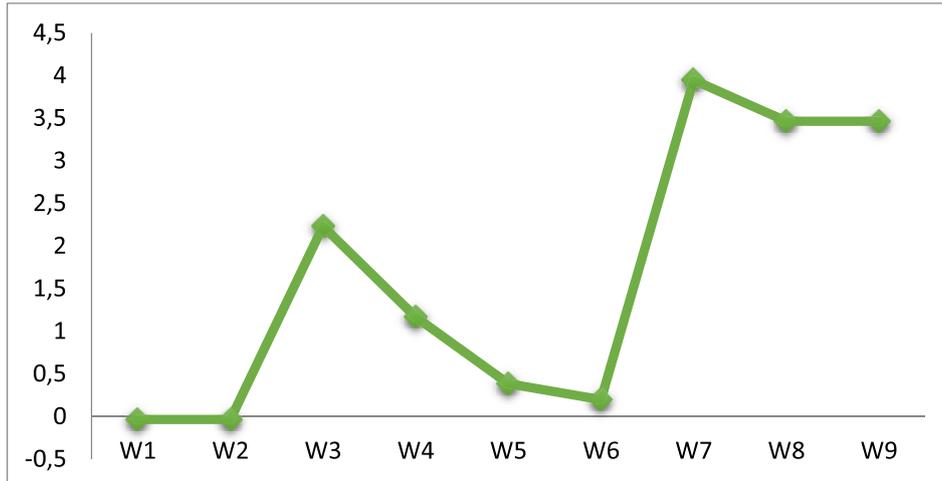
Figure 12. Voltage losses in lines

Conclusion

The application of information technology to the calculation of 35/10 kV substations has greatly improved the design, analysis and operation of these facilities. Engineers now rely on numerical calculation software such as RastrWin3 as a tool for working with 35/10 kV substations. These tools have brought a number of benefits including increased design accuracy, reduced design time, improved efficiency and reduced maintenance costs.

1) The authors analysed the structure of the networks in the study area. This included examining the substations within the site. In particular, the focus was on two transformers operating with overload at the 10/10 kV Nursat and Yassy substations.

2) It's been decided to use the RastrWin3 software package to analyse the functioning of the network section. Before carrying out any reconstruction works, a model of this section in the RastrWin3 program was created. Our calculations are based on determining how this district electricity network operates in steady state.

3) The authors used the software package RastrWin3 where the voltage levels at both the start and end points of each transmission line branch and modelling can be calculated providing an accurate representation and analysis of substations.

From the data collected, the percentage of voltage loss (ΔU%) in each line was calculated. After analysing the study, it was found that there were voltage losses on transmission lines W7, W9 and W3. One of the factors contributing to these higher losses is the operation of the line under high load conditions, as it provides electricity to the 10/10 kV substations of Nursat and Yassy.

It is possible to utilize the model for future direction:

- Integration with Smart Grid technologies for real-time monitoring and dynamic control of substations.

- Development of advanced models that incorporate climate data and renewable energy for greater resilience.

- Open source platforms and data sharing to facilitate collaboration and accelerate progress in this area. Overall, this project is an example of the close interaction between electrical engineering and information technology. By combining the capabilities of both fields, we can develop innovative solutions for a more efficient and sustainable energy system in the Turkestan region and beyond.

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