The Study of the Power Supply System of the Existing Gas Fields in Western Siberia using the Theory of Experimental Planning

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Abstract. Nowadays most of the gas fields in Western Siberia are at the final stage of development. To extend the cost-effective gas production at the final stage of development modern technologies are introduced at the fields. One of these technologies is the technology of distributed gas compression. As a result, a multiple increase in the electrical load is observed and new power transmission lines and substations are being constructed to provide electricity to gas fields. For example, at Vyngapurovsky gas field MCU (9 PCs) were to be put into operation and the 6 kV OHL with a length of 22 km were needed to be built, at Yamburg gas field at the moment MCU (52 PCs) are to be set up and it is required to build the 10 kV OHL with a length of 480 km. Thus, the purpose of this paper is to conduct an experimental study of the existing supply and distribution grids of the gas fields' power supply system in Western Siberia. To achieve this goal the following tasks have been solved: the method of the mathematical models development was selected; the main influencing factors on the voltage class were identified; variation ranges of the selected factors were defined; the optimization of the power supply schematic diagrams for the choice of voltage with minimal discounted costs was completed by the computer program PRON. The problems have been solved using the empirical method (measurement, comparison) of the study, the method of experiment planning (full factorial experiment), and computer programming methods. The analysis shows that all distribution grids of the power supply system in Western Siberia need to be converted to a higher voltage class of 20 kV or the additional overhead lines should be built.

1. Introduction

According to the Standart of Orfanization of Gazprom NTP 1.8-001-2004 [1], existing power supply systems for gas fields use a voltage class of 6/10 kV for a supply and distribution grid. At the end of the gas field's life, the estimated electrical load increases, which leads to the reconstruction of the external power supply system. Sometimes it is necessary to switch to a higher voltage class than 6/10 kV.

The peculiarity of the gas fields' power supply system makes it impossible to conduct real experiments on them. Therefore, changes in the parameters of these systems are carried out using mathematical modeling methods.

In the 80s, 90s and 2000s, the design of the power supply system for gas fields in Western Siberia was carried out without taking into account the electrical load at the final stage of development, which led to a brake on the introduction of modern technology for distributed gas compression [2-4].

The purpose of this paper is to perform an experimental study of the existing supply and distribution grids of the existing gas fields' power supply system in Western Siberia for the possibility of connecting MCUs to them.
To achieve this goal, a number of tasks have been solved:
- the method of developing mathematical models was selected;
- the main influencing factors on the voltage class were determined;
- the ranges of variation of the selected factors were defined;
- the computer program PRON has been developed to determine the optimal voltage class at the minimum discounted cost;
- power supply schematic diagrams for voltage selection with minimal discounted costs in the PRON program were carried out.

2. Experimental section
The author has developed a software product PRON. It is a program for calculating the optimal stress class of gas fields, which takes into account its entire life cycle. PRON is based on the derived mathematical models of the supply and distribution grid of voltage classes 6, 10, 20, 35, 110, 220, 330 kV.

Table 1. The main levels and intervals of variation factors

| Factor | Name of the factor | Basic zero level, \( x_{0} \) | Range of variation, \( \Delta x \) | Upper level, \( \langle+\rangle \) | Lower level, \( \langle-\rangle \) |
|--------|-------------------|-----------------|-----------------|-----------------|-----------------|
| x1     | Number of CGPP (PCs) | 10.5 | 4.5 | 15 | 6 |
|        | Distance from the power source to the consumer, L, km | 105 | 45 | 150 | 60 |
| x3     | The coefficient of increase in the electric load, \( k_{\text{incr}} \), a.u. | 3 | 2 | 5 | 1 |
| x4     | Load distribution coefficient for OHL, \( k_{\text{distr}} \), a.u. | 0.775 | 0.225 | 1 | 0.55 |

Gas field with average electric capacity (from 7 to 75 MV)

| Factor | Name of the factor | Basic zero level, \( x_{0} \) | Range of variation, \( \Delta x \) | Upper level, \( \langle+\rangle \) | Lower level, \( \langle-\rangle \) |
|--------|-------------------|-----------------|-----------------|-----------------|-----------------|
| x1     | Number of CGPP (PCs) | 3.5 | 1.5 | 5 | 2 |
|        | Distance from the power source to the consumer, L, km | 45 | 30 | 75 | 15 |
| x3     | The coefficient of increase in the electric load, \( k_{\text{incr}} \), a.u. | 3 | 2 | 5 | 1 |
| x4     | Load distribution coefficient for OHL, \( k_{\text{distr}} \), a.u. | 0.775 | 0.225 | 1 | 0.55 |

Gas field with low electric capacity (up to 7 MV)

| Factor | Name of the factor | Basic zero level, \( x_{0} \) | Range of variation, \( \Delta x \) | Upper level, \( \langle+\rangle \) | Lower level, \( \langle-\rangle \) |
|--------|-------------------|-----------------|-----------------|-----------------|-----------------|
| x1     | Number of CGPP (PCs) | 4.5 | 2.5 | 7 | 2 |
| x2     | Distance from the power source to the consumer, L, km | 11.5 | 8.5 | 20 | 3 |
| x3     | The coefficient of increase in the electric load, \( k_{\text{incr}} \), a.u. | 2.5 | 1.5 | 5 | 1 |

Distribution grid – “Trunk circuit with one through trunk”

| Factor | Name of the factor | Basic zero level, \( x_{0} \) | Range of variation, \( \Delta x \) | Upper level, \( \langle+\rangle \) | Lower level, \( \langle-\rangle \) |
|--------|-------------------|-----------------|-----------------|-----------------|-----------------|
| x1     | Number of gas clusters N, PCs. | 6 | 4 | 10 | 2 |
| x2     | Distance from the power source to the consumer, L, km | 10.25 | 9.75 | 20 | 0.5 |
| x3     | The coefficient of increase in the electrical load during the period of falling production, \( k_{\text{incr}} \), a.u. | 5.5 | 4.5 | 10 | 1 |
| x4     | Load distribution coefficient for OHL, \( k_{\text{distr}} \), a.u. | 0.7 | 0.15 | 0.85 | 0.55 |
Mathematical models of the supply and distribution grids of gas fields were obtained on the basis of the theory of experimental planning. In the experiment, the object of research is the external power supply system of a gas field. The method consists in planning of the full factorial experiment (FFE) of type \(2^k\), where \(k\) is the number of considered factors. All possible combinations of factor levels are implemented in the experiment. The parameter for optimizing the external power supply system is the voltage class.

The experiment is carried out by changing the factors of the power supply system, resulting in the optimal voltage class. The optimal voltage is determined by the minimum discounted cost. The optimal voltage class with the minimum discounted costs is found by changing the factors of the power supply system and determining the discounted costs for each voltage class.

For each influencing factor, in Table 1, the ranges of change (variation) are selected, allowing to cover a significant number of power supply schematic diagrams of the complex gas preparation plans (CGPP) and gas well clusters.

The determination of the coefficient of increase in the electric load for the supply and distribution grid was given by the author in the article “The Assessment of the dynamics of the electric load in the gas fields of Western Siberia, taking into account the entire life cycle”.

The coefficient of increase in the electrical load is:

1. For the power supply grid:
   - in the first period of a gas field's life - \(k_{\text{incr}} = 1\) a.u.;
   - in the second period of a gas field's life - \(k_{\text{incr}} = 1.63\) a.u.;
   - in the third period of a gas field's life - \(k_{\text{incr}} = 3.45\) a.u.

2. For the distribution grid:
   - in the first/second period of a gas field's life - \(k_{\text{incr}} = 1\) a.u.;
   - in the third period of a gas field's life – \(k_{\text{incr}} = 10\) a.u.

### 3. Results

With the help of PRON program, the existing supply and distribution grids of gas fields in Western Siberia have been tested according to the criterion of optimal voltage class, taking into account the coefficient of increase in electrical load in different periods of the field's life cycle. Table 2 shows the parameters of the existing supply grid of a number of gas fields in Western Siberia.

**Table 2.** Technical characteristics of the existing grid at the CGPP of the existing fields of Western Siberia.

| #  | Name of the power transmission line | Number of CGPP, PCs | The length of the trunk line, km | Acceptable voltage class, kV | Optimal class voltage, kV|
|----|-----------------------------------|---------------------|---------------------------------|-----------------------------|--------------------------|
|    |                                   |                     |                                 |                             | the first period \(k_{\text{incr}} = 1\) | the second period \(k_{\text{incr}} = 1.63\) | The third period \(k_{\text{incr}} = 3.45\) |
| 1  | OHL SS 6/35 kV – SS 35/6 kV CGPP 51 | 1                   | 8.95                            | 35                          | 20                       | 35                       | 35                       |
|    | The Fifth section of the Achimov deposits, CGPP 51 |                     |                                 |                             |                          |                          |                          |
| 1  | OHL Vyganpur – Peschanaya          | 1                   | 25.71                           | 110                         | 20                       | 35                       | 110                      |
|    | Vyngapurovsky gas field            |                     |                                 |                             |                          |                          |                          |
| 1  | OHL Tarko - Sale CGPP              | -                   | 15.26                           | 110                         | 20                       | 35                       | 35                       |
|    | Komsomolsky gas field              |                     |                                 |                             |                          |                          |                          |
| 1  | OHL Bazovaya-PGF 9-1,2             | 10                  | 111.81                          | 110                         | 110                      | 110                      | 110                      |
|    | Medvezhye gas field                |                     |                                 |                             |                          |                          |                          |
| 1  | OHL Yamburg                        | 10                  | 104.8                           | 110                         | 110                      | 110                      | 110                      |
|    | Yamburg gas field                  |                     |                                 |                             |                          |                          |                          |

where \(k_{\text{incr}}\) is the coefficient of increase, the definition of which is given in the article “The Assessment of the dynamics of the electric load in the gas fields of Western Siberia, taking into account the entire life cycle”
Table 3 shows the estimation of discounted costs for each supply grid of the external power supply system from Table 4 for voltage class 6, 10, 20, 35, 110 kV (for low-power gas fields).

**Table 3.** Calculated values of discounted costs of existing supply lines of the existing fields’ power supply system in Western Siberia (low power).

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 6 kV  | 10 kV | 20 kV | 35 kV | 110 kV |
| Gas fields with low electric power (up to 7 MV) |                                   |       |       |       |       |       |
| 1             | OHL 35 kV SS 6/35 kV – SS 35/6 kV | 1.9   | 0.9   | 0.5   | 0.6   | 1.2   |
|               | CGPP 51 I1, p                     |       |       |       |       |       |
| 2             | OHL 35 kV SS 6/35 kV – SS 35/6 kV | 3.3   | 1.5   | 0.8   | 0.8   | 1.3   |
|               | CGPP 51 II1, p                    |       |       |       |       |       |
| 3             | OHL 35 kV SS 6/35 kV – SS 35/6 kV | 7.5   | 3.1   | 1.6   | 1.2   | 1.5   |
|               | CGPP 51 III I, p                  |       |       |       |       |       |

**Vyngapurovsk gas field**

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 20 kV | 35 kV | 110 kV |
| 1             | OHL 1 Vyganpur – Peschanaya I, I,p | 4.8   | 2.1   | 0.9   | 1.0   | 1.7   |
| 2             | OHL 1 Vyganpur – Peschanaya II, I,p | 8.7   | 3.5   | 1.6   | 1.2   | 1.8   |
| 3             | OHL 1 Vyganpur – Peschanaya III, I,p | 20.1  | 7.5   | 3.3   | 2.1   | 2.1   |

**Komsomolsky gas field**

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 20 kV | 35 kV | 110 kV |
| 1             | OHL 1 Tarko - Sale CGPP I, I,p     | 2.9   | 1.3   | 0.75  | 0.8   | 1.4   |
| 2             | OHL 1 Tarko - Sale CGPP II, I,p    | 5.2   | 2.2   | 1.1   | 1.0   | 1.5   |
| 3             | OHL 1 Tarko - Sale CGPP III, I,p   | 11.9  | 4.6   | 2.1   | 1.4   | 1.7   |

**Table 4.** Calculated values of discounted costs of existing supply lines of power supply system at operating gas fields in Western Siberia (medium and high power).

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 20 kV | 35 kV | 110 kV | 220 kV | 330 kV |
| Gas fields with average electric capacity (from 7 to 75 MV) |                                   |       |       |       |       |       |
| Medvezye gas field |                                   |       |       |       |       |       |
| 1             | OHL 1 Bazovaya-PGF-9-1,2          | 41.2  | 19.7  | 11.7  | 19.6  | 33.1  |
| 2             | OHL 1 Bazovaya-PGF-9-1,2          | 62.6  | 29.0  | 13.9  | 20.4  | 34.1  |
| 3             | OHL 1 Bazovaya-PGF-9-1,2          | 124.4 | 56.0  | 20.3  | 22.8  | 37.1  |

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 20 kV | 35 kV | 110 kV |
| 2-1           | The difference in the costs of the second life period from the first one | 21.4  | 9.3   | 2.2   | 0.8   | 1.0   |
| 3-1           | The difference in the costs of the third period of life from the first one | 83.2  | 36.3  | 8.6   | 3.2   | 4.0   |

**Gas fields with large electrical capacity (more than 75 MV)**

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 20 kV | 35 kV | 110 kV | 220 kV | 330 kV |
| Yamburg gas field |                                   |       |       |       |       |       |
| 1             | OHL Yamburg the first period of life | 37.5  | 17.9  | 11.4  | 19.0  | 32.0  |
| 2             | OHL Yamburg the second period of life | 56.6  | 26.3  | 13.5  | 19.8  | 33.0  |
| 3             | OHL Yamburg the third period of life | 111.8 | 50.6  | 19.7  | 22.1  | 36.0  |

| Period of life | Name of the power transmission line | Discounted costs for the voltage class, billion rub. |
|---------------|-----------------------------------|-----------------------------------------------|
|               |                                   | 20 kV | 35 kV | 110 kV | 220 kV | 330 kV |
| 2-1           | The difference in the costs of the second life period from the first one | 19.1  | 8.4   | 2.1   | 0.8   | 1.0   |
| 3-1           | The difference in the costs of the third period of life from the first one | 74.3  | 32.7  | 8.3   | 3.1   | 4.0   |

- minimum discounted costs
There is the estimation for voltage classes 20, 35, 110, 220, 330 kV (for medium-capacity gas fields) in Table 4.

Thus, analyzing Table 4, it can be concluded that the higher the voltage class, the smaller the difference in discounted costs. It is seen that for the 6 kV voltage class, the difference in discounted costs in the subsequent life cycle periods is large relative to the first period, and for 110 kV, the difference is smaller and then it converge to almost zero. This suggests that the higher the voltage class, the more the supply grid of the external power supply system is adapted to the growth of the electrical load, i.e., to the development of the gas field.

Table 5 shows the parameters of the existing distribution grid (the number of gas well clusters, the length of the main line, the accepted voltage class for electricity transmission) of some existing gas fields in Western Siberia. With the help of PRON program, the optimal voltage class of the existing distribution grid was selected for each life period (taking into account the load gain coefficient), the results are presented in Table 5. Table 5 shows that the most progressive voltage class for the distribution grid of gas fields is 20 kV.

Table 5. Technical characteristics of existing power distribution lines for gas well clusters of operating fields in Western Siberia.

| #   | Name of the power transmission line | Number of clusters, PCs | Power trunk length, km | Accepted voltage class, kV | Optimal voltage class, kV | The first period kincr = 1 | The second period kincr = 1 | The third period kincr = 10 |
|-----|-----------------------------------|-------------------------|------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 1   | OHL Cluster K-5A22                | 6                       | 9.79                   | 10                        | 20                        | 20                        | 20                        | 20                        |
| 2   | OHL Cluster K-5A23                | 7                       | 16.4                   | 10                        | 20                        | 20                        | 20                        | 20                        |
| 3   | OHL Cluster K-5A24                | 5                       | 12.94                  | 10                        | 20                        | 20                        | 20                        | 20                        |
| 4   | OHL Cluster K-5A25                | 5                       | 10.49                  | 10                        | 20                        | 20                        | 20                        | 20                        |
|     | The First section of the Achimov deposits, CGPP 31 |                       |                        |                           |                           |                           |                           |                           |
| 1   | OHL Cluster 1                     | 8                       | 15.62                  | 6                         | 20                        | 20                        | 20                        | 20                        |
| 2   | OHL Cluster 3                     | 6                       | 10.28                  | 6                         | 20                        | 20                        | 20                        | 20                        |
| 3   | OHL Cluster 18A                   | 4                       | 10.96                  | 6                         | 20                        | 20                        | 20                        | 20                        |
| 4   | OHL Cluster 32                    | 11                      | 15.19                  | 6                         | 20                        | 20                        | 20                        | 20                        |

Thus, analyzing the values of discounted costs, it can be concluded that the voltage class of 20 kV is optimal for the distribution grid of the gas well clusters' external power supply system. With a tenfold increase in the electrical load, the difference between the values of the discounted costs is minimal. This means that the distribution grid with a voltage of 6/10 kV is not adapted to increase of the load by 10 times (there is no reserve) and additional capital costs are required for power supply. The values of the discounted costs of the grid with a voltage of 6/10 kV with an increase in the electrical load become comparable to the values of the discounted costs for the voltage class 35 and 110 kV. For the distribution grid of gas well clusters, the minimum discounted costs are inherent in the 20 kV voltage class.

Table 6 shows the results of calculations of discounted costs for each distribution grid of the power supply system from Table 5 for the voltage class 6, 10, 20, 35, 110 kV.
Table 6. Estimated values of discounted costs of existing power distribution lines for gas well clusters in existing fields of Western Siberia.

| #  | Name of the power transmission line | Discounted costs for the voltage class, million rub. |
|----|-----------------------------------|--------------------------------------------------|
|    |                                   | 6 kV | 10 kV | 20 kV | 35 kV | 110 kV |
|----|-----------------------------------|------|-------|-------|-------|--------|
|    |                                   | 25  |
| 1  | OHL Cluster K-5A 22               | 143.03 | 138.83 | 135.1 | 215.85 | 408.61 |
| 2  | OHL Cluster K-5A 23               | 227.43 | 217.56 | 211.52 | 321.3 | 565.42 |
| 3  | OHL Cluster K-5A 24               | 174.42 | 170.06 | 165.62 | 249.17 | 470.04 |
| 4  | OHL Cluster K-5A 25               | 145.99 | 142.71 | 139.04 | 214.35 | 415.27 |

The Fifth section of the Achimov deposits, CGPP 51

The first and the second periods of life

| #  | Name of the power transmission line | Discounted costs for the voltage class, million rub. |
|----|-----------------------------------|--------------------------------------------------|
|    |                                   | 6 kV | 10 kV | 20 kV | 35 kV | 110 kV |
|----|-----------------------------------|------|-------|-------|-------|--------|
|    |                                   | 25  |
| 1  | OHL Cluster K-5A 22               | 603.99 | 374.13 | 279.64 | 340.69 | 841.79 |
| 2  | OHL Cluster K-5A 23               | 1116.33 | 688.07 | 444.08 | 491.72 | 1063.87 |
| 3  | OHL Cluster K-5A 24               | 679.54 | 414.01 | 296.26 | 353.67 | 826.67 |
| 4  | OHL Cluster K-5A 25               | 557.19 | 341.57 | 256.94 | 315.23 | 771.6  |

The first and the second periods of life

| #  | Name of the power transmission line | Discounted costs for the voltage class, million rub. |
|----|-----------------------------------|--------------------------------------------------|
|    |                                   | 6 kV | 10 kV | 20 kV | 35 kV | 110 kV |
|----|-----------------------------------|------|-------|-------|-------|--------|
|    |                                   | 25  |
| 1  | OHL Cluster 1                     | 224.36 | 213.11 | 207.06 | 321.68 | 556.98 |
| 2  | OHL Cluster 3                     | 148.81 | 144.34 | 140.46 | 222.82 | 419.57 |
| 3  | OHL Cluster 18A                   | 146.06 | 143.93 | 140.39 | 209.58 | 416.77 |
| 4  | OHL Cluster 32                    | 231.53 | 216.9  | 210.47 | 338.5  | 565.38 |

The third period of life

| #  | Name of the power transmission line | Discounted costs for the voltage class, million rub. |
|----|-----------------------------------|--------------------------------------------------|
|    |                                   | 6 kV | 10 kV | 20 kV | 35 kV | 110 kV |
|----|-----------------------------------|------|-------|-------|-------|--------|
|    |                                   | 25  |
| 1  | OHL Cluster 1                     | 1191.59 | 739.34 | 473.38 | 519.44 | 1128.24 |
| 2  | OHL Cluster 3                     | 632.19 | 391.04 | 288.41 | 348.79 | 852.35 |
| 3  | OHL Cluster 18A                   | 490.02 | 296.44 | 228.4  | 285.2  | 697.33 |
| 4  | OHL Cluster 32                    | 1405.93 | 880.08 | 551.9  | 593.4  | 1281.48 |

- - minimum discounted costs

4. Discussion

The experimental study of existing power supply systems has showed:
1. The number of gas well clusters in the distribution grid varies from 2 to 15 PCs. The length of the power transmission line of the distribution grid is from 3 to 16 km.
2. The optimal voltage class of a distribution grid is 20 kV.
3. The optimal voltage class of the supply grid of low-power gas fields (up to 7 MV), taking into account the increase in loads, is 35 kV and 110 kV;
4. The optimal voltage class of the supply grid of medium-capacity gas fields (from 7 to 75 MV) is 110 kV.

5. Conclusion

The voltage class at all the considered operating supply and distribution grids of gas fields in Western Siberia is not optimal, and the implementation of distributed gas compression technology will require additional capital investments for the construction of new power transmission lines and substations.

Thus, for the external power supply system of new gas fields in Western Siberia, it is recommended to use a voltage class of 110 kV for electricity transmission, and for a distribution grid it should be 20 kV. These voltage classes have a sufficient reserve of power for the transmission of electricity, taking into account the entire life cycle of the field (the growth of the electric load) at the lowest discounted costs.
References

[1] The Standards of Organization of Gazprom NTP 1.8-001-2004 Norms of technological design of objects of gas-producing enterprises and underground gas storage stations of LLC “VNIPIgazdobycha” 2004 Moscow

[2] Sarancha A V and Ogay V A 2016 Application of modular compressor units of Russian production in the production of low-pressure Cenomanian gas Academic Journal of Western Siberia Vol 12 1 (62) pp 21-22

[3] Minlikaev V Z, Dikamov D V, Arno O V et al 2015 Application of mobile compressor units at the final stage of development of gas deposits J. Gas industry 1 (717) pp 15-17

[4] Arno O B 2015 Technical and technological solutions and innovations at different stages of the life cycle of Yamburg deposits Sc. J. of the Russian newspaper society 2-3 pp 7-14