Designing Power Supply Systems with Account to the Entire Life Cycle of the Gas Field as Exemplified by the Existing Fields in Western Siberia

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Abstract. This article deals with designing a power supply system that would take into account all life cycle periods of a gas field. The goal of the research is to study the process flows of the existing gas fields in Western Siberia to improve their power supply systems taking into account their entire life cycles. To achieve this goal, we strove to determine the key technology used to prolong the profitable gas extraction in the third life cycle period, the process flows of Western Siberia gas fields during various life cycle periods, as well as the duration of each of the development periods at the existing gas fields in Western Siberia and the duration of the entire gas field life cycle, and determined the electrical load for each of the life cycle periods. The research problems were solved using the theoretical experiment methods (analysis and synthesis), and the empirical methods (metering, comparison). The results of the research show that the yearly average electrical load of a gas field significantly increases over its life cycle.

1. Introduction
As the gas field is being developed, its gas output decreases and power consumption grows due to the commissioning of gas booster stations (GBS). The problem of prolonging the life of a gas field is especially pressing at the end of its operation, during the decreasing output period. This problem is solved by installing mobile compressor units (MCU) within the gas collection process flow. This requires the reconstruction of the existing power mains.

The power supply systems at the Yamburgskoye, Byngapurovskoye, and Medvezhye gas fields in Western Siberia were designed without any technical or economical feasibility assessments that would take into account the entire life cycles of these fields. The incorrect selection of the key power supply system parameters at the design stage is the main reason for the inefficient operation of the power supply system.

2. Statement of problem
Power supply systems of the gas fields in Western Siberia were designed without any attention to their final life cycle stages.

Currently, design documentation on power supply mostly contains the data on electrical load during the first and sometimes the second periods (depending on the designer's competence) and does not consider the electrical loads of the third life cycle period of a gas field. This leads to the need for large-scale reconstruction of power supply systems and, subsequently to large capital costs.

Currently, the majority of large gas fields in Western Siberia are at the final development stage of the Cenomanian deposit, i.e. the third life cycle period or the 'decreasing output' period [1].
For example, the distributed gas compression with MCUs is used to prolong the profitability of the low-pressure Cenomanian gas extraction at the Vyngapurovskoye [2], [3] and Yamburgskoye OGCF [4], [5], [6].

At the Vyngapurovskoye gas field, a total of 9 MCUs were put into operation. Their power consumption ranges between 0.45 MW and 1 MW, which helped increase the extraction of the accumulated gas. However, this requires the following power supply reconstruction works to be performed at the Vyngapurovskoye gas field:
- the renovation of the existing 22 km 6kV overhead power lines (OPL);
- the construction of a new 6 kV indoor switchgear (ISG);
- the construction of a new 6 kV automated voltage control unit (AVCU).

The situation at the Yamburgskoye OGCF is much worse. To implement distributed gas compressing at the field, 52 1-MVA MCUs are put into operation. This requires the following power supply reconstruction works to be performed at the Yamburgskoye OGCF:
- The construction of a 410 km 10 kV power line;
- The construction of a 124-169.2 km 35 kV power line;
- The construction of two 10/35 kV substations (SS);
- The construction of 4-5 35/10 kV SS;
- The reconstruction of the existing 110 kV SS for the complex gas treatment facility No. 2 (CGTU2), CGTU4, and CGTU6 — the construction of a 35 kV indoor switchgear (ISG).

One of the key problems of the power supply in the gas industry is the development of the best power supply layouts. This problem can be broken down into the following objectives:
- selecting the power source type (autonomous or centralized power supply);
- selecting the power supply mains layout (loop, radial, etc);
- determining the number and the power output of transformer substations;
- selecting the voltage class to transfer power from the source to the consumers taking into account the prospective load increase;
- locating substations on the premises of the gas field.

Nowadays, almost none of the gas field power supply systems comply with the modern technical and economic standards at the end of their life cycles. Our goal is to research the process flows of the existing gas fields in Western Siberia to improve their power supply systems taking into account their entire life cycles.

This required to solve the following problems:
1. Determining the main technology used to prolong the profitability of gas extraction throughout the third life cycle period;
2. Determining the process flow layouts at the gas fields of Western Siberia in various life cycle periods;
3. Determining the duration of each of the development periods of the existing gas fields in Western Siberia;
4. Determining the duration of the entire life cycle of a gas field;
5. Determining the electrical load in each of the life cycle periods.

3. Theory
The first three problems were solved by the study of literature [7], [8], [9] on gas field development.

Currently, all of the gas fields go through four life cycle periods:
1. Increasing output: the period of pilot operation (PO).
2. Stable output.
3. Decreasing output.
4. Gas field decommissioning.
During the first (PO) period, the gas field is arranged, gas wells are commissioned, and the field is prepared for the second period. During this period, 10-15% of the gas reserves are extracted.

During the second period, the main volume of the gas reserves is extracted. In this period, gas booster stations (GBS) are put into operation. This period lasts until drilling new gas wells and increasing the capacities of the GBS becomes unfeasible. During this period, 60-70% of the gas reserves are extracted.

During the third period, some geotechnical actions are taken to preserve the well stock in the face of possible problems like well flooding, the destruction of the bottom hole area with the ejection of abrasive sand particles on the surface, and the destruction of wellhead equipment. The decreasing output period lasts until the extraction is marginally profitable. In this period, another 10-15% of the gas reserves are extracted.

In the fourth period, the gas field is decommissioned. The decommissioning is the final life cycle stage of a gas field (same as with any other complex system) The final stage is characterized by the drop in gas extraction and extraction profitability, as well as the reduction of reliability and sustainability of the industrial processes [8].

During periods 1-3, the gas production output, average formation pressure, and bottom hole pressures decrease over time.

In the first periods, the reservoir energy is used to extract the gas, and in the following periods, the reservoir energy decreases, which leads to the introduction of external power sources.

To maintain the gas outputs, gas compressors are installed at the gas field in the second period, and during the third period, the compressors are used more intensively, and brand-new technology is applied.

To intensify gas extraction at the final stages of the field life cycle, the distributed compression technology is used which is based on mobile compressor units (MCU) [9], [10] installed at the well clusters.

Thus, the process flows at the gas fields in Western Siberia are transformed three times over the life cycle:

- Deposit-Well-Gas Collection System (GCS)-Complex Gas Treatment Unit (CGTU)-Main Pipeline;
- Deposit-Well-GCS-GBS-CGTU-Main Pipeline;
- Deposit-Well-MCU-GCS-GBS-CGTU-Main Pipeline;

The transformation of the process flow leads to the changes in the equipment of the gas field.

Each of the life cycle periods is characterized by its specific power consumption.

In the third period, the installation of MCUs at the gas well clusters results in a drastic change in electrical loads, power supply solutions, and the power distribution system of the gas field.

The list of key gas field equipment across various life cycle periods is shown in Table 1.

| No. | Gas field development periods |
|-----|-------------------------------|
|     | Increasing output | Stable output | Decreasing output |
| 1   | Gas well clusters   | Gas well clusters | Gas well clusters |
| 2   | -                 | -              | MCU             |
| 3   | -                 | GBS            | GBS             |
| 4   | CGTU              | CGTU           | CGTU            |
| 5   | Gas air cooling units (ACU) | ACU        | ACU             |

Table 1. Equipment list.

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The list of key gas field equipment across various life cycle periods is shown in Table 1.
Our fourth problem is solved by metering yearly power consumption for each of the life cycle periods and performing basic calculations.

Each of the life cycle periods is characterized by its specific yearly average electrical load. The results of yearly power consumption metering for each of the gas field life cycle periods and the yearly utilization time for gas fields (7650 hours of continuous operation) allowed us to calculate the yearly average electrical load using the following formula:

\[ P_{\phi} = \frac{W_{32}}{T_M}, \text{ MW} \]  

(1)

Table 2 shows yearly average electrical loads for each of the life cycle periods of the existing gas fields in Western Siberia.

**Table 2.** Rated electrical load in each of the periods.

| No. | Gas field              | Rated electrical load per gas field life cycle periods in MW |
|-----|------------------------|------------------------------------------------------------|
|     |                        | First | Second | Third |                                    |
| 1   | Medvezhye              | 2.84  | 5.48   | 5.48  |                                    |
| 2   | Urengoyskoye           | 8.77  | 11.42  | 11.42 |                                    |
| 3   | Yamburgskoye           | 13.18 | 18.05  | 49.25 |                                    |
| 4   | Vyngapurovskoye        | 1.50  | 2.43   | 5.34  |                                    |
| 5   | Komsomolskoye          | 1.19  | 3.13   | 3.13  |                                    |
| 6   | Western Tarkasalinskoye| 1.44  | 2.06   | 2.64  |                                    |
| 7   | Gubkinskoye            | 1.59  | 2.75   | 2.75  |                                    |
| 8   | Yubileynoye            | 2.45  | 4.24   | 5.68  |                                    |
| 9   | Yamsoyevskoye          | 2.56  | 4.47   | 4.47  |                                    |
| 10  | Yuzhno-Russkoye        | 3.22  | 4.23   | 4.99  |                                    |
| 11  | Byngoyakhinskoye + Yetypurovskoye | 2.34 | 3.11   | 3.11  |                                    |

The fifth problem was solved using the yearly gas extraction diagrams for the fields in question. Table 3 shows the duration of the development stages in the gas fields in Western Siberia. The periods were determined using the yearly gas extraction diagrams and thus, these data may differ from their actual duration.
Table 3. The duration of the development stages in the gas fields in Western Siberia.

| No. | Gas field          | Increasing output | Stable output | Decreasing output |
|-----|--------------------|-------------------|---------------|-------------------|
| 1   | Medvezhye          | 4                 | 21            | 34                |
| 2   | Urengoykskoye      | 4                 | 15            | 68                |
| 3   | Yamburgskoye       | 4                 | 14            | 200               |
| 4   | Vyngapurovskoye    | 2                 | 11            | 35                |
| 5   | Komsomolskoye      | 3                 | 9             | 42                |
| 6   | Western Tarkasalinskoye | 4     | 11            | 73                |
| 7   | Gubkinskoye        | 2                 | 12            | 39                |
| 8   | Yubileynoye        | 8                 | 12            | 38                |
| 9   | Yamsoveyskoye      | 2                 | 15            | 42                |
| 10  | Yuzhno-Russkoye    | 4                 | 15            | 21                |
| 11  | Vyngayakhinskoye   | 3                 | 14            | 41                |
| 12  | Yety-Purovskoye    | 3                 | 8             | 25                |

The average duration of the period in years

- Increasing output: 3.6 years
- Stable output: 12.7 years
- Decreasing output: 44 years

The average duration of a gas field life cycle is 60.3 years.

4. Research results

Thus, when designing power supply systems for new gas fields, it is necessary to take into account all of their life cycle periods rather than just one.

The experience of operating gas fields at the final stages of their life cycles shall be used in the designing of new gas fields.

If some parameters like the power source, power supply layout, the number and power output of transformer substations, substation location on the gas field premises that were selected during the gas field design stage do not take into account the third life cycle period but can be adjusted (e.g. charge the transformer power output or the number of substations, etc) during the operation of the field, the voltage class as the key power supply system parameter depending on the electrical load must be selected taking into account all of the gas field life cycle periods.

If the voltage was selected correctly from the very beginning, the power supply system will be more reliable (due to the increased trip sensitivity of relay protection and automation or PSP). This helps reduce the discounted costs, the consumption of nonferrous metals, and power losses, as well as increase the radius of power supply mains while using the same power or the transferred power if the distance is the same, which is very important for the gas industry.
5. Conclusions
1. The prolongation of the third life cycle period of a gas field is mostly achieved through the distributed gas compression with electric MCUs.
2. Throughout the entire life cycle, the process flow and energy consumption of a gas field change.
3. We compared the yearly average electrical load shift for each of the life cycle periods at the existing gas fields of Western Siberia with the first-period data to identify the load increase, which is as follows:
   - in the second life-cycle period, it is between 1.37 and 2.63 p.u. (due to the commissioning of GBS);
   - in the third period, it is between 3.03 and 3.74 p.u. (due to the commissioning of GBS and MCU).
4. The duration of each of the development periods of the existing gas fields in Western Siberia is as follows:
   - the increasing output period lasts for 2-8 years, 3.6 years on average;
   - the stable output period lasts for 8-21 years, 12.7 years on average;
   - the decreasing output period lasts for 25-73 years, 44 years on average;
5. The average duration of an entire gas field life cycle is 60.3 years.
6. The correct voltage class that takes into consideration the entire gas field life cycles will help install MCU in time to preserve the gas well stock, prevent their waterflooding, and reduce the costs of renovating the entire power supply system.

6. References
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