Power supply and control systems for subsea production complexes in Arctic offshore fields

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Abstract. The subsea type of arrangement is no alternative for remote deep-sea oil and gas fields of the Arctic shelf. One of the main factors determining the level of reliability of year-round production of hydrocarbons using subsea production complexes is the availability of effective control and power supply systems. In this article the current state of subsea production complexes is studied, possible ways to develop power supply and control systems are analyzed in order to increase their efficiency and reliability when used in deep-water remote fields of the Arctic shelf.

1. Introduction

The interest in the Arctic over the past 10 years, during a period of high prices for hydrocarbons, was primarily due to the enormous oil and gas reserves in this region. At the same time, according to experts, up to 40% of oil reserves and 70% of gas reserves are located in the Russian Arctic. The availability of their development is determined by the distance from the shore, the depth of the water and the so-called Arctic factors, which are often decisive when choosing the type of field development.

Currently, a combined type of arrangement (platform + SPC) is often used for the development of offshore deep-water hydrocarbon deposits. In the Russian Arctic, when developing deep-water remote deposits, it is impossible to use both stationary and floating platforms due to the long ice period, extreme natural and climate conditions and the presence of massive ice formations of various nature. Therefore, the subsea type of arrangement of oil and gas fields in this region of the World Ocean is the most preferable, and often the only possible one.

Ensuring year-round, stable production of hydrocarbons for several decades with the use of SPC requires reliable and efficient control and power supply systems. Therefore, the development of SPC control and power supply systems, taking into account the increase in their reliability and survivability under the active influence of Arctic factors, is an important problem, the solution of which will allow us to start developing hydrocarbon resources in deep-water remote areas of the Arctic shelf.

2. Power supply systems

Most of the problems that arise during the operation of the field during its combined development are related to the technological platform. In addition, the cost of ice-class technological platforms is up to 50% of all capital expenditures for the development of an offshore field [1].

Therefore, the next step in the strategy for the development of Arctic deposits is the development of a subsea type of their arrangement. This type of offshore field development is characterized by the following features:

1. Subsea placement of wellheads.
2. In the production and in-field transportation systems the multiphase flow technology is used.
3. Equipment for pretreatment of well products is placed subsea. It should be noted that the design of the equipment for subsea arrangement is fundamentally different from the equipment for shore arrangement. Its production requires more precise technologies and often new materials.
4. Maximum use of automated machinery in the organization of control and maintenance.
5. The power supply of the equipment is provided from external sources, which can be located either on the shore or on a remoted autonomous platform.

In a typical subsea production complex, the electric power system provides power generation, power distribution and its transmission to the equipment included in the SPC. To ensure continuous production in a subsea field, it is important that all systems are well designed. Figure 1 shows the process of designing a power supply system [1].

![Figure 1. Power supply system design process.](image1)

It is important to consider a real case. A schematic diagram of power supply from the shore of an offshore field with alternating current at a distance of 600 km is shown in Figure 2 [1].

![Figure 2. Schematic diagram of power supply for remote subsea production complex.](image2)

The need for power supply for a fully electric subsea production system for a large remote gas condensate field is shown in Table 1.

| Consumer                                      | Individual load | Quantity | Total load   |
|-----------------------------------------------|-----------------|----------|--------------|
| Christmas tree (for 1 well)                   | 15 kW           | 32       | 480 kW       |
| Subsea compressing station (for 1 well)       | 5 MW            | 32       | 160 MW       |
| Subsea gas treatment                          | 20 MW           | 1        | 20 MW        |
| Waterpump                                     | 10 MW           | 4        | 40 MW        |
| Subsea control system                         | 20 kW           | 1        | 20 kW        |
| Total load without compressing / treatment    |                 |          | 0.5 MW       |
| Total load with compressing / treatment        |                 |          | 220.5 MW     |
From the data presented, it is clear that when implementing a subsea type of equipment for a large remote field, it is necessary to ensure a high demand for electricity. Modern technologies for long-distance transmission of electrical energy using high-voltage and low-frequency alternating current require the presence of a high-voltage frequency converter directly at the field. Unfortunately, there are currently no industrial models of such subsea type converters on the market. Therefore, to place them, it is needed to install the platform. Obviously, at the same time, many of the advantages of the subsea type of arrangement disappear.

Thus, a large gas-condensate field with a subsea type of arrangement will require about 220 MW of electricity during its compressor operation.

Currently, high-voltage AC transmission is used for power transmission to offshore facilities. Electrical equipment for converting voltage to levels acceptable to consumers, such as submersible centrifugal electric pump drives or multiphase pumps, currently already exists. Using two criteria – the power consumption and the distance from the shore to the consumers of electricity (SPC systems in offshore fields), it is possible to distinguish the areas of preferred use of various technologies of electricity transmission [1].

![Figure 3. Applicability of various power supply technologies for SPC.](image)

Since many Arctic offshore fields are located at different distances from the shore, it is needed to have a classification of power supply systems such as power consumption as a function of distance. Currently, there is a division according to 2 criteria: the distance and power mentioned above.

![Figure 4. Typical configurations of subsea AC power supply systems.](image)

1. For fields located at a distance of up to 30 km from the source of electricity (shore station or platform), with an installed equipment capacity of up to 10 MW, a 1st type system can be recommended, in which the transformers and speed control drives are located in the surface position, and the electrical signal to the underwater equipment goes with the required frequency and voltage.

2. For fields located at a distance of 20-140 km, with an installed equipment capacity of up to 100 MW, electricity supply can be carried out according to the 2nd type scheme, in which the AC frequency control drives are presented in the surface version. Electricity in the form of high-voltage current and...
the required frequency is transmitted via subsea cables to the field, where step-down transformers are installed that convert the voltage to a value sufficient for consumers.

3. For fields located at a distance of 50-300 km, with an installed equipment capacity of more than 100 MW, the optimal power supply 3rd type scheme should include:
   a. Low-frequency surface-mounted alternating-current (AC) generator;
   b. Surface step-up transformer;
   c. Subsea power cable;
   d. Subsea step-down transformer;
   e. Subsea AC frequency control drive.

4. For power supply of SPC facilities of offshore fields located at distances of more than 300 km, with an installed capacity of more than 100 MW, DC and high-voltage power transmission systems are promising.

Most of the implemented subsea production systems, which required the transfer of electricity, are located from the shore or from the platform at a distance of 5-50 km. However, recent subsea developments allow the transmission of electricity and control signals for hydrocarbon production control to fields located at distances of 120-160 km. While these developments still rely on traditional power supply solutions, they create technical solutions for new long-range power transmission technologies, such as high-voltage underwater cables (over 10 kV) for AC and DC transmission, or the use of fiber-optic data cables. While subsea connectors and electrical equipment operating at 32 kV voltages already exist, reliable 100 kV electrical equipment and connectors still need to be developed and certified for subsea using.

Thus, the main advantage of high-voltage DC transmission lines is the ability to transmit large amounts of electricity over long distances with less loss than AC lines. Depending on the line voltage and the current conversion method, the losses can be reduced by up to 3% per 1000 km.

3. Control systems
An equally important feature is the control system of a subsea production complex. Moreover, it is the most important system in the structure of the subsea production complex, since it is the only source of information on the progress of technological production processes, gathering and interfield transportation of hydrocarbons in the combined type of offshore field development and also on the effectiveness of the processing system in the subsea development. The structural design of the control systems should ensure continuous monitoring of the equipment, work management and failure diagnostics both with and without removing the equipment to the surface. In fields located in freezing seas with a limited navigation period, it is not always possible to bring equipment to the surface.

Therefore, for such cases, increased requirements for operational readiness and other reliability indicators should be imposed on the control systems.

![Figure 5. Scheme of the control system of SPC (FMC Technologies).](image-url)
3.1. Types of control systems

There are several types of control systems, including hydraulic, electrohydraulic, multiplex and electrical. These control systems are given in Figures 6, 7, 8, 9 and 10 respectively. The potential advantages and disadvantages are also listed in Tables 2, 3, 4, 5 and 5 respectively.

![Figure 6. Scheme of the hydraulic control system.](image)

**Table 2. Advantages and disadvantages of the hydraulic control system.**

| Advantages | Disadvantages |
|------------|---------------|
| 1. Low tech solution | 1. Best suited to shallow water |
| 2. High level of reliability | 2. Slow to respond |
| 3. Easy to understand | 3. Large umbilical |
| 4. Easy to fault find |    |
| 5. Easy to service |    |
| 6. Cheap |    |

![Figure 7. Scheme of the piloted hydraulic control system.](image)

**Table 3. Advantages and disadvantages of the piloted hydraulic control system.**

| Advantages | Disadvantages |
|------------|---------------|
| 1. Subsea accumulation | 1. Not suited for ultra-deep water or long step outs |
| 2. Mechanical or electrical pilot valve operation | 2. Slow to respond |
| 3. Valve sequencing can be used | 3. Large umbilical |
Figure 8. Scheme of the electro hydraulic control system.

Table 4. Advantages and disadvantages of the electro hydraulic control system.

| Advantages                  | Disadvantages                                           |
|-----------------------------|---------------------------------------------------------|
| 1. Smaller umbilical         | 1. Not suited for ultra-deep water or long step outs    |
| 2. Faster response           | 2. Increased number of subsea electrical connections     |
| 3. Simplified control pod    | 3. Requires separate electrical umbilical or multicore  |

Figure 9. Scheme of the electro hydraulic multiplexed control system.

Table 5. Advantages and disadvantages of the electro hydraulic multiplexed control system.

| Advantages                  | Disadvantages                                           |
|-----------------------------|---------------------------------------------------------|
| 1. Long step out and deep water | 1. Increased number of subsea electrical connections   |
| 2. Faster response           | 2. Higher voltage connections                           |
| 3. Simplified umbilical      | 3. More complex subsea components                       |
| 4. Capable of complex control| 4. More difficult to support                           |
| 5. Improved surveillance     |                                                         |

Figure 10. Scheme of the all-electric control system.
Table 6. Advantages and disadvantages of the all-electric control system.

| Advantages                                      | Disadvantages                                      |
|------------------------------------------------|----------------------------------------------------|
| 1. Ultra-deep water and extremely long step-outs | 1. Complex electro-mechanical devices              |
| 2. Zero emissions                               | 2. Power electronic devices subsea                 |
| 3. Suitable for harsh environments              | 3. High voltage distribution systems               |
| 4. Subsea processing                            | 4. Harder to control failure modes                 |
| 5. Easily expandable                            | 5. Greater level of technical support              |
| 6. More autonomous                              | 6. Higher intervention costs                       |
| 7. Lower operating and maintenance costs        | 7. Installation costs                              |

All-electric control systems are by far the most promising direction for the development of subsea technologies. The use of such systems reduces the environmental impact by eliminating the possibility of dumping hydraulic system fluid into the sea, reducing the size and cost of umbilicals, and monitoring the technical condition of subsea equipment components in real time. The use of all-electric control systems is becoming particularly relevant in the development of subsea technologies for field production: subsea separation units, compressor stations and multiphase pumps. For example, electrically driven gate valve from FMC Technologies are identified as the main elements of the shut-off and control valves for subsea compression systems of the Asgard field.

Table 7. Overview table of control systems.

| System type              | Cost | Maintenance / reliability         | Flexibility | Step out | Depth     |
|--------------------------|------|----------------------------------|-------------|----------|-----------|
| Hydraulic                | Low  | Low technical threshold. Most components topside | Limited     | Short    | Shallow   |
| Piloted hydraulic        | Low  | Low technical threshold. Most components topside | Limited     | Short    | Shallow   |
| Electro hydraulic        | Low  | Increased complexity.           | Limited     | Short    | Shallow   |
| Electro hydraulic multiplexed | Low  | More complex, subsea equipment. | Expandable  | Long     | Deep      |
| All-electric             | Low  | More complex, subsea equipment. | Expandable  | Very long| Ultra-deep|

3.2. Control systems selection criteria

The choice of a control system for a particular field is a complex process in which several factors must be taken into account. The combination of these factors will determine the type of control system suitable for a selected project. The following criteria should be taken into account:

1. Type of development:
   a. Combined
   b. Subsea
   c. Re-development (Development of the existing field according to the new plan);
   d. New development (New field);
2. The cost of installing and operating the control system;
3. Water depth;
4. Distance from the shore;
5. Environmental conditions of the region (for example, the presence of ice).
6. Availability and reliability of equipment.
4. Conclusion

Currently, there is an experience in implementing modern power supply and control systems for the subsea development of fields on the Arctic and subarctic shelf, such as the Kirinskoye gas condensate field (the Sea of Okhotsk), the Ormen Lange and Snøhvit fields (Norwegian Sea). The experience of their operation has shown that the further development of this type of arrangement of remote deep-water deposits requires deep research to implement new technical solutions in the following areas:

- development of highly efficient technologies and techniques for transmitting high-power energy over extremely long distances and its conversion at the field to operating parameters (voltage and frequency), which are used in subsea equipment;
- creation of reliable control systems and monitoring of the technical condition of the subsea production complex equipment on the basis of all-electric multiplex technologies.

In addition to the problems discussed in this article related to energy supply and control of SPC facilities, there are also important tasks for the development of a subsea type of arrangement:

- technical provision of this type of arrangement with the necessary equipment and technologies for subsea treatment of hydrocarbons for long-distance transportation (separation, compression, multiphase pumps);
- improvement of technologies for multiphase transportation of hydrocarbons through salient pipelines and their calculation methods;
- development of tools and methods for year-round remote control and maintenance of SPC facilities.

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