The powering of subsea facilities for remote offshore oil and gas fields

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Abstract

The development of offshore fields is supported by drilling and production equipment which requires high performance and a reliable power supply. Russian offshore fields that can be developed using subsea technologies are located at up to 650 km from onshore infrastructures under extreme ice conditions. Requirements for the equipment capacities of power supplies may vary from dozens of kilowatts to hundreds of megawatts. It has been recognized that these days one of the most reliable and safe techniques for powering subsea oil and gas facilities is power transmission from an onshore power supply source through a subsea cable. Different systems of high voltage power supply have been considered: direct high voltage current transmission, alternating current and low frequency alternating current transmission. They have been compared in terms of loss minimization during power transmission and conversion, and the provision of reliability and safety of unattended operating. It has been concluded that high voltage direct current transmission at long distances ensures the sufficient reduction of cable losses as compared to alternating current transmission, but subsea DC-AC conversion (as subsea equipment usually uses alternating current) requires the development of a subsea converter.
Keywords: electric power supply system, subsea production facilities, losses, converter station.

1 Introduction

The development of offshore fields when using subsea equipment for production, processing and transportation demands power supplies. The majority of Russian offshore fields are located rather far from onshore infrastructure being

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characterized by extreme ice conditions and water depth of up to 400 m. Thus, providing these offshore fields with a reliable power supply is important. The capacities of different subsea equipment may be from dozens of kilowatts to hundreds of megawatts, and all of them need power supplies.

2 The main equipment for subsea production facilities

The top power consumers within the Subsea Production Facilities (SPF) are the following:

1) Multi-phase transport module comprising one or more multi-phase pumps, with pump capacity up to 2 MW.
2) Injection module comprising one or more injection pumps, with pump capacity up to 2.5 MW.
3) Compressor station comprising one or more subsea compressors, with compressor capacity up to 20 MW.

The total scheme of subsea equipment for expected upcoming Russia offshore fields has to contain several subsea production centres with a radial gathering system that includes a centralized manifold. For preliminary research of such SPF the electric power supply system (EPSS) may be assumed at about 250 MW.

3 The ways of Electric Power Transmission to SPF

One of the most reliable and safe version for subsea oil and gas facilities power supply is electric power transmission from onshore power supply via a submarine cable. Electric Power Transmission may use DC high voltage (Fig. 1), AC high voltage (Fig. 2) or low frequency AC high voltage (Fig. 3).

At first sight, AC power transmission seems to be more cost-efficient as compared to DC transmission so as the latter need two converter stations: onshore station for converting industrial frequency voltage into DC voltage and subsea station for converting DC voltage into industrial frequency voltage. So we'll study the AC version more scrupulously.

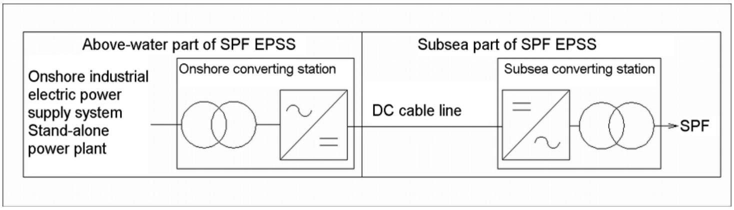

Figure 1: EPSS with DC transmission.

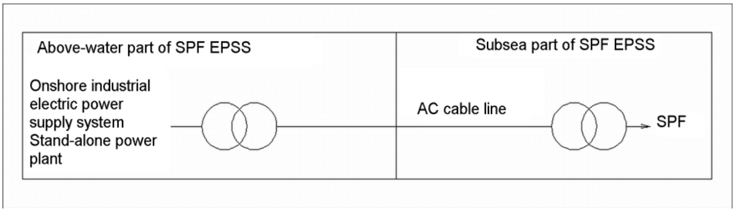

Figure 2: EPSS with AC transmission.

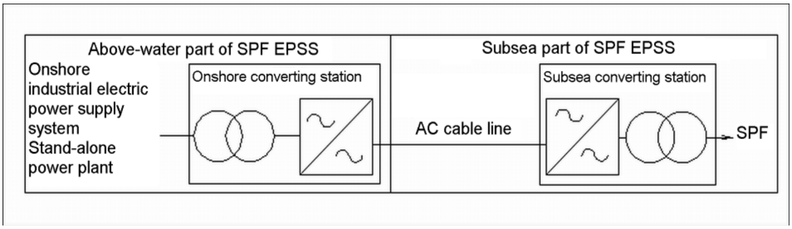

Figure 3: EPSS with low frequency AC transmission.

4 The analysis of losses

To get a more detailed analysis we will review the AC transmission to SPF. Full power S transmitted via AC line comprises active P and reactive Q components:

$$S = \sqrt{P^2 + Q^2}$$

Fig. 4 shows active power P delivered to SPF versus distance ***l*** for various AC frequencies when onshore power supply voltage is 200 kV. For calculations we assume that submarine cable capacitance is about 0.22 µF/km (cross area 1000 mm^2 [1]).

The curves show that if the distances to SPF longer than 50 ÷ 60 km no significant active power may be delivered at industrial frequency. Alternative current losses may be reduced by installation of power factor correction units (e.g. static VAR compensators). But in case of submarine cable length reaching kilometres several VAR compensators along the cable line would be needed.

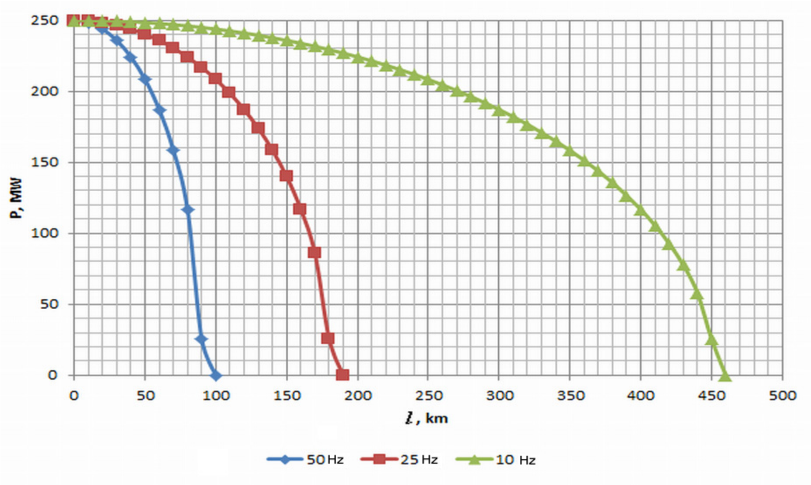

Figure 4: Curves of active power delivered to SPF versus distance between onshore power supply and SPF at transmission voltage of 200 kV and frequencies of 10, 25 and 50 Hz.

The allowable distance increases as soon as frequency f decreases, but the cable length does not exceed 250 km even for f = 10 Hz. As a result, advantages of AC over DC are doubtful because of very high weight and size parameters of both onshore and particularly subsea transformer and reactor equipment.

Now, let's evaluate losses in a SPF EPSS cable line with DC transmission (Fig. 1) as a function of output voltage U_{OUT} of onshore conversion station. In this case we assume that the power of onshore grid is much more than 250 MW, so introduction of new DC transmission will not result in perceptible growth of short-circuit currents at bus-ties of other power system elements.

At the table 1 voltage drop ΔU in a cable line for various cross-section areas S is shown. An addition power ΔP_{DC} that requires ensuring the power consumption at SPF and subsea converting station input voltage U_{IN} are shown too.

It should be noted that DC cables of all cross-section areas (from 1000 to 3000 mm^2) for specified voltages (from 100 to 300 kV) are available at the world market [2–5]. Today, long DC transmissions with submarine cables exist [3] and even a Pacific DC transmission that is 1330 km long. But they all are conventional DC transmissions with onshore converting stations at both ends.

As it can be seen from the Table 1, for U_{OUT} = 100 kV with a cable area of 3000 mm^2, the usage results to 25% power losses in the cable line; for 2000 mm^2 areas and less, which require such currents for power transmission, all 100 kV voltage drops at active resistance of the cable line and power transmission becomes impractical (that is why no EPSS with a voltage lower than 200 kV is provided in Fig. 4).

Further selection of U_{OUT} should be done on the basis of two contradictory requirements. On one hand, growth of this voltage leads to cable line losses decreasing and for U_{OUT} = 300 kV and S = 3000 mm^2 the losses fall to 2%, which corresponds to the allowable industrial overhead power transmission lines losses. On the other hand, problems of cable insulation and division of input direct voltage between concrete actuators becomes harder.

Table 1: DC cable line parameters for length 650 km.

U_{OUT}, kV	S, mm^2	R, Ohm	I_{DC}, A	P_{DC}, MVA	ΔU, kV	ΔP_{DC}, %	U_{IN}, kV
100	1000	22.75	-*	-*	-*	-*	-*
	2000	11.38	-*	-*	-*	-*	-*
	3000	7.58	3372	335	25	25	75
200	1000	22.75	1509	302	34	17.2	166
	2000	11.38	1354	271	15	7.2	185
	3000	7.58	1316	263	10	5.0	170
250	1000	22.75	1113	278	25	10.1	225
	2000	11.38	1050	263	12	4.8	238
	3000	7.58	1032	258	7.8	3.1	242
300	1000	22.75	894	268	20	6.7	280
	2000	11.38	861	258	10	3.1	290
	3000	7.58	852	256	6.5	2.3	293
* – demanded current exceeds cable capacity							

5 High voltage DC cable transmission advantages

The advantages of high voltage DC cable transmission are as follows:

1. In the case of a DC transmission voltage drop and electric power losses, this corresponds to the allowable losses of industrial overhead power transmission lines. Losses for AC transmission with the same length of cable line will be much bigger;
2. The DC cable line length is limited by the active resistance only;
3. The bifilar design of a two-core DC cable [2, 3] fully prevents the magnet field from coming outside of cable sheath, thus its influence on sea fauna is excluded;
4. The ageing of cable insulation in case of direct current is far less than in the case of alternating current [1];
5. DC lines are able to increase power transmission via AC lines with the same insulation and core size by 41%. This reduces capital expenses for cable line construction.

Still, even at the initial stage of EPSS design a number of serious problems appear. The most significant of these are as follows:

1. Arrangement of equal high DC voltage for all separate feeders;
2. The controlled initial start of converting equipment on a subsea converting station;
3. Arrangement of auxiliary power supplies at a rated operation mode of EPSS SPF;
4. Transmission of information signals between the subsea and the onshore converter stations for distance approximately of 600 km (selection of optical or galvanic channel, signal amplification systems, etc.);
5. The providing of subsea unit insulation for a voltage of hundreds of volts along with required cooling.

6 Certain examples of EPSS circuits for SPF

The onshore converting station may be a conventional matured design in a form of a controllable rectifier. One of the versions of EPSS block-diagram is shown at fig. 5. This circuit functions as described below.

At first the onshore converting substation has to be activated in over-regulated (inverter) mode. Then it is required to arrange subsea converting station with auxiliaries power supply from onshore system. Subsea auxiliaries supply is required to test all control units and to bring all safety switch drivers to their correct initial position. All signals of readiness come into a collector and when all "yes" are available, a signal for smooth increasing of control angle α will be delivered to input of control system (CS) of onshore converter station. Growing output voltage is transmitted to subsea converting station via submarine DC cable.

To transmit an information signal from onshore to SPF the choice between optic and galvanic fibres has to be made. Today, the maximum achievable distance for fibre optic information transmission without amplifiers-repeaters is

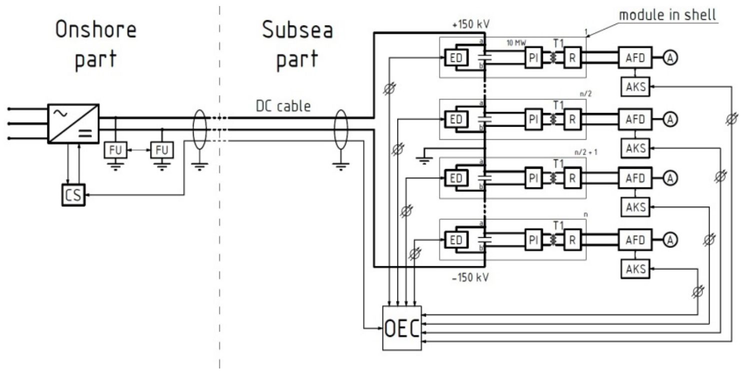

Figure 5: SPF electric power supply system block-diagram. FU – filtering unit; CS – control system; ED – equalizing device; PI – power inverter; R – rectifier; T1 – power high-voltage (for overall SPF voltage) transformer; AFD – adjustable frequency drive; OEC – optoelectronic converter; A – actuator; ACS – actuator control system.

425 km [6]. In fact, there is a method for high-frequency information signals transmission via AC transmission lines. But transmission of high-frequency signals for long distances via high voltage cable is impractical so as attenuation for 220 kV cables is more than 2.5 dB/km even at relatively low frequency (about 100 Hz [7]).

The next step of design is arrangement of uniform division of high input voltage among loads (load feeders). Actually there are only two known methods of DC voltage division: via series-connected capacitors or via series-connected large capacity storage batteries. Selection should be made both according to reliability indices and according to weight and size parameters. So as equipment at each feeder consumes about 10 MW it's necessary to use storage units with maximum specific capacitance. Today, Li-ion batteries have the best indices for this parameter. But they have not been widely proven to be sufficiently reliable. The main reasons for failures are defects in cooling system and balancing system of the charging units. Both failure reasons may be eliminated through careful engineering. Powerful equalizing devices (ED) and onshore converting station signal feedback give the opportunity to effective regulation of voltage in feeders. Thus the rated voltage U_{DC} may be achieved by control of angle α in all cases: when consummation in SPF sharply changes during operation and even in the case of failure of one or more circuits in one of the halves (+150 kV or –150 kV).

As it is shown in Table 1, at the selected voltage of ±150 kV voltage drop at subsea converting station input is ≈ 2% for the cable cross-section area 3000 mm^2 and ≈ 3% for cable cross-section area 2000 mm^2. This drop may be ignored and all subsea converting station equipment may be reasonably divided into 26 units (modules) of 10 MW each with DC input voltage ≈ 10 kV.

As for the arrangement of the electric power supply for various auxiliaries in the rated mode, the task is divided into two parts:

1. Power supply for power inverter auxiliaries.
2. Power supply for auxiliaries located inside the shell.

The block-diagram for power inverter auxiliaries is shown in Fig. 6. All auxiliaries have to be connected directly to power terminals "a – b". Such structure gives the opportunity to get rid of IGBT series connection in auxiliaries inverter branches and as a result increases the reliability. The number of auxiliaries inverters may be more or less than 4 pieces as shown in Fig. 6 and shall be selected during detailed engineering. The power supply unit for the power inverter shall be a common one. Such a matrix circuit, as presented in Fig. 6, is also acceptable for power inverter design.

As for power supply for switcher drivers and other ancillary mechanisms, they shall be isolated from "earth" for an overall voltage of ±150 kV (see Fig. 5). Therefore it is reasonable to provide them in locations where such isolation has already been done, i.e. from the secondary sides of a T1 transformer. The EPSS circuit for one subsea converting station module including power part and auxiliary power supplies is shown in Fig. 7.

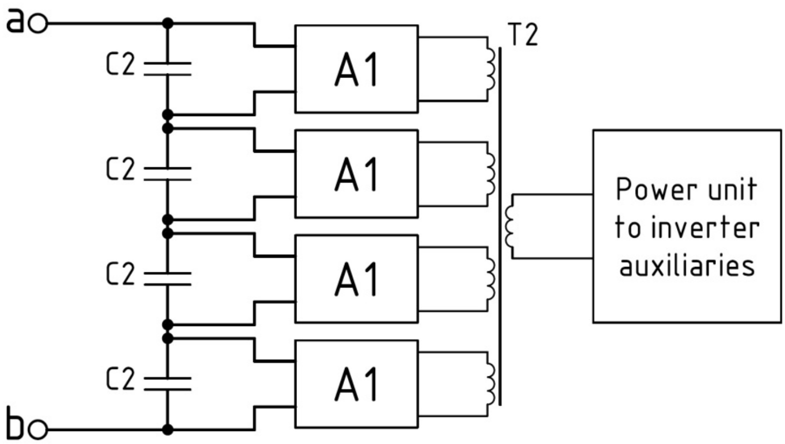

Figure 6: Block-diagram for power inverter auxiliaries in the shell. A1 – auxiliaries inverter; T2 – multi-winding transformer.

7 Conclusion

To summarize the presented analysis of the challenges connected with the design of SPF EPSS and subsea converting equipment for remote offshore fields we should note the following major tasks that should be solved during SPF EPSS development:

1. Arrangement of reliable and regular division of DC high voltage between the subsea converting station modules in case of power consummation changes by modules and even in case of failure of one or more modules.

2. Guaranteeing of high reliability of all maintenance-free electrical equipment of SPF EPSS.
3. Arrangement of initial SPF EPSS equipment start that requires transmission of starting control pulses from the onshore converting station to the subsea converting station and back as well as initial electrical power supply of the subsea converting station auxiliaries.
4. Guaranteeing of insulation of SPF EPSS units for voltage of hundreds volts together with efficient cooling system.
5. It should be noted that notwithstanding the technical complexity of the above-mentioned tasks they may be solved by using proven engineering and technological solutions applied in the area of power converting equipment and submarine shipbuilding.

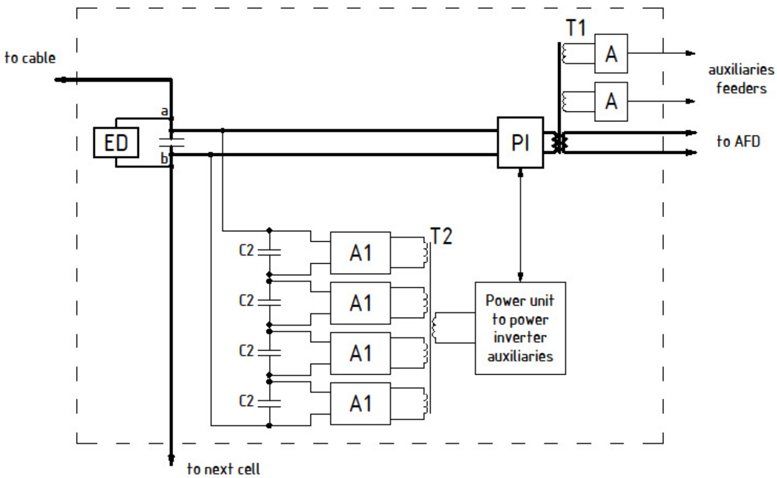

Figure 7: Overall structure of EPSS for a single subsea converting station module.

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