Schematic overview of the all electric subsea boosting system where templates A and B have each 8 well slots and are installed initially.

(57) Abrégé/Abstract:
The present invention relates to an all electric subsea boosting system for well fluid boosting by compressing hydrocarbon gases and/or pumping hydrocarbon liquids where said system comprises one or more subsea boosting stations and one or more long step-out power supplies.
Title: ALL ELECTRIC SUBSEA BOOSTING SYSTEM

Schematic overview of the all electric subsea boosting system where templates A and B have each 8 well slots and are installed initially

Abstract: The present invention relates to an all electric subsea boosting system for well fluid boosting by compressing hydrocarbon gases and/or pumping hydrocarbon liquids where said system comprises one or more subsea boosting stations and one or more long step-out power supplies.
Published:
— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
"All electric subsea boosting system"

The present invention relates to an all electric subsea boosting system for well fluid boosting by compressing hydrocarbon gases and/or pumping hydrocarbon liquids comprising one or more subsea boosting stations and one or more long step-out power supplies. A boosting station may consist of compressor(s) and/or single or multiphase pump(s).

An offshore gas field may be developed with seabed installations which are tied back to a terminal onshore or an existing platform. The seabed installation comprises of one or more production templates where each template produces well fluid through manifold headers which are connected to one or more pipelines. Said pipelines transport well fluid to an onshore terminal or an existing platform (receiving facility) for further processing. Processed gas and condensate are exported to the market. One or more umbilicals for power, control and utility supplies are installed from the receiving facility to said subsea installations.

For the initial production phase, well fluid may flow to the receiving facility by means of the reservoir pressure. Later in the production phase, or at start-up of the production, well fluid boosting is required in order to maintain the production level and to recover the anticipated gas and condensate volumes. The conventional solution for such well fluid boosting facility is an offshore platform. However, a subsea boosting system may be an alternative to or in combination to said platform solution.

The present invention seeks to provide an all electric subsea boosting system to replace or assist the use of an offshore platform.
That the system is all electric means that it is controlled and operated with electrical power, and does not have a hydraulic system for assisting opening and closing of valves.

In accordance with the present invention, this object is accomplished in an all electric subsea boosting system where said system comprises one or more subsea compression stations and one or more long step-out power supplies.

An all electric subsea boosting system in accordance with the present invention has a number of advantages compared to a booster platform solution.

Said system is safe to human injuries and fatalities due to remote operation, reliable, cost effective, environmental friendly and comprises few parts which make the system less complicated and easy to operate.

The present invention will now be described and with reference to the accompanying drawings in which:

**Fig. 1** shows a schematic overview of the all electric subsea boosting system in accordance with the present invention.

**Figure 2** shows a subsea main power system single line diagram.

**Figs. 3 and 4** show a typical all electric subsea boosting station layout in accordance with the present invention.

**Figure 5** shows a boosting station process flow diagram.

**Figure 6** shows a schematic overview of main modules and parts in a subsea boosting station according to the present invention.
**Figure 7** shows a typical power and control architecture for a subsea boosting system.

**Figure 1** illustrates the all electric subsea boosting system. Said system comprises one or more subsea boosting stations and one or more long step-out power supplies.

The long step-out power supply is defined from the connection point at the receiving facility to and including the main subsea transformer.

Such long step-out power supply comprises the following subsea components:

- Subsea main transformer with pressure compensation system
- High voltage penetrator(s)
- Umbilical termination head
- Combined or separate power and control umbilical, including:
  - Main electrical supply
  - Utility power (optional)
  - Fibre optic lines for control signals
- Barrier lines (optional)

The boosting station is connected directly to at least one subsea production template and is designed for boosting well fluid from said production templates. Well fluid from the production templates is routed via one of the template manifold headers, via the infield flow lines and to connectors on the suction side of the boosting station.

The boosting station is connected to export pipelines with flow lines to each pipeline. Compressed gas will be transported in said export pipelines to the receiving facility.
Figure 2 shows a main power system single line diagram for a subsea boosting system.

High voltage power, control and utilities are supplied from receiving facilities with one or more power and control umbilicals.

The high voltage (HV) power cables will be connected to the subsea main step-down transformer and the transformer will be installed on the subsea boosting station with the umbilical attached.

The single line diagram shows the power distribution system for the main subsea electrical consumers.

Figures 3 and 4 show a typical subsea compression station layout.

The subsea boosting station, comprises the following modules and parts:

- One or more compressor trains and/or single or multiphase pump(s)
- One or more circuit breaker modules
- Inlet and outlet manifolds
- Inlet coolers
- Inlet sand trap
- Parking location for main transformer and power umbilical termination head
- Required installation tools
- High voltage electrical system
- Process system
- Utility power system
- Control system
- Barrier system
The compressor train is the main equipment required for compressing the well stream. The compressor train comprises the following modules and parts:

- Compressor module
- Compressor Variable Speed Drive (VSD)
- Anti-surge valve and actuator
- Anti-surge cooler
- Separator/scrubber module
- Pump module
- Pump VSD
- Remote and manually operated valves
- Interconnection piping
- Control system including control modules

Common to the compressor trains is a power and control umbilical connection system and a valve manifold fitted with flow line connection systems.

The station power distribution system consisting of removable circuit breaker modules and variable speed drive modules are arranged together at one end of the station structure adjacent to the subsea main transformer. The actual mating mechanism for the high voltage wet mate connectors will be dependent upon the chosen power connection system.

The piping manifold is formed to provide a balanced symmetrical routing through each of the compressor trains. Emphasis is given to avoid high stress levels, ensuring flexibility for connection operations.

The modules are provided with local guiding/docking and are locked into position by dedicated mechanisms.

Intervention for ROV is designed for minimum top and one side access.
Access to modules for vertical removal/installation is provided from the top and sides of the protective structure.

Smaller removable modules such as control pods, control valves and certain instrumentation units are provided as individual units and/or included within one of the main modules as removable items, these modules/items are run on dedicated intervention running tools.

The compressor is directly driven by a high-speed motor. The electrical motor is cooled with hydrocarbon gas with a pressure regulated to be equal to or as close to the suction pressure as possible. Said gas source can either be conditioned gas supplied to the subsea compression station from an external source, discharge gas from the compressor module or suction gas to the compressor module. Said hydrocarbon gas for electrical motor cooling might be conditioned prior to entering into the electrical motor and said hydro-carbon gas might also be replaced by other suitable gases. Alternatively the motor may be fully canned with main cooling from the gas flow.

The compressor is able to meet the design operational conditions over the production period with declining production wellhead pressure. Re-bundling of the compressor can be performed as part of a maintenance program.

A magnetic bearing system is used for each of the subsea compressor modules.

The system includes magnetic radial and axial bearings as well as run-down bearings.

Material properties of the compressor unit is suitable for operation with relevant content of H₂S and CO₂.
The compressor and material properties are designed for the liquid fractions and solids content coming with the gas stream from the upstream separator. The size and distribution of the liquid droplets and solids particles is dependent on the separator design.

The boosting station manifold is equipped with a remote operated isolation valve facilitating by-pass of the compression trains.

The boosting system is designed to handle the continuous fines/sand production. The rotating equipment is protected against wear and degradation from solids. This will ensure high efficiency, long life and reliability.

The compressor(s) have anti-surge control recycle line designed for full recycle flow at maximum continuous speed (105%). The anti-surge control valve is electrical actuated, axial stroke and is located close to the compressor discharge at high point. An anti-surge re-cycle cooler is included downstream of the anti-surge valve in the re-cycling pipe loop.

The compressors have a discharge pipe equipped with a remote operated isolation valve. A non-return valve is fitted in the compressor discharge pipe upstream of the isolation valve.

The boosting station is able to handle liquid backflow from the downstream export pipeline. The boosting station is isolated and pressurised to avoid liquid ingress due to back-flow from multiphase export pipelines.

The separator separates liquid/solids from the gas which in turn is ingested into the pump and compressor, respectively.

The separator is designed to separate liquids and solids from the gas flow to avoid excessive erosion of the compressor. Right separator design is chosen to
secure that solids are not clogged or fixed anywhere in the separator or its internals.

The condensate pumps are able to handle the liquid production and boost it up to the required discharge pressure. The pumps are variable or fixed speed driven.

The pumps are able to handle the continuous and intermittent sand production in the liquid stream from the separators.

The boosting station has tie-in connection for well fluid discharge. Each of these are equipped with ROV (remotely operated vehicle) operated valves for routing of the well fluid to the different pipelines.

**Figure 5** shows a subsea boosting station process flow diagram.

The process in the subsea boosting station is envisaged in the following paragraphs.

The well fluid from a tied-in production template is distributed to a separator equipped with an electric actuated isolation valve in the inlet pipe. The well stream is further routed via the compressor by-pass line before compressor start-up and the by-pass valve is closed when the compressor(s) are brought into operation.

The need for inlet/input coolers will depend on required compressor inlet temperature and the physical location of the compressor station in relation to the production template(s) and the heat transfer from the connecting flow lines to the seawater. The cooling required is dependent on the well stream inlet temperature, the required inlet temperature to the boosting system and the hydrate formation temperature. Additional cooling in the in-field flow lines from the production templates is possible.
The compressor allows recirculation for anti-surge protection and start-up/shut-down operations. The recycle cooler and recycle loop is designed for full recycle flow at compressor maximum continuous speed (105%).

Most of the solids are removed in the separators. Sand/fines/solids entering the boosting station will be separated out in the separator and transported via the liquid pump to the discharge pipeline. However, a sand trap for accidental sand production may be used to remove sand from the inlet well fluid.

Gas demisting and gas-liquid separation is performed by use of scrubbers. Tolerance to sand/solids/fines in the well stream is made acceptable with regard to entrainment, clogging in demisting equipment and drainage system and also accumulation in vessel bottom. Continuous production of fines is handled in the boosting station, without jeopardizing operation and performance.

Terrain induced slugging and transient slugging may be expected. The separation vessel is designed to have safe and efficient handling of liquid slugs. The slug handling philosophy is to accumulate the specified slug volumes in the separator units. The liquid slugs entering the boosting station will accumulate in the separator before being pumped to the station discharge by the liquid pumps.

The design also ensures stable operation for moderate slugging with minimum use of liquid level control devices and minimum impact on compressor operation due to inlet pressure transients. The internals are designed for the thrust and vibration caused by the expected slugging.

The liquid boosting system consists of single or multiphase condensate pumps with fixed or variable speed drives. The pump discharge pipes are equipped with a non-return valve upstream of the discharge isolation valve.
Anti-surge control is made possible by monitoring the compressor suction flow rate, temperature, pressure together with compressor discharge pressure and temperature.

5 The well stream is inhibited by MEG injection at the wellheads to prevent hydrate formation.

The MEG, condensate and water is separated out in the separator in the boosting station and pumped to the station discharge header by the condensate pumps. Sufficient MEG content will ensure hydrate prevention of these parts of the system.

The gas separated out in the separator will have none or only small quantities of MEG.

15 A schematic overview of main modules and parts in a subsea boosting station pilot set-up used for tests in the intended environment is shown in Figure 6.

The subsea facilities comprise remotely actuated valves to control the flow of produced gas and the injection of chemicals. The remotely operated valves are electrically actuated

Local instruments (transmitters) is provided to measure pressure, temperature, gas flow rate and record the anti-surge valve position.

25 The different types of valves, the condition monitoring system and the transmitters are interfaced via the subsea control modules.

Interfaces with subsea variable speed drives and circuit breakers, distributed control system and emergency shut down systems are foreseen.
A typical power and control supply architecture use for the boosting system architecture is shown in Figure 7.

Interface and closing of control loops between the variable speed drives circuit breakers and compressors control system may be via the receiving facilities control system main bus. All information, alarms and interlocks between the two systems should be handled by the distributed control system.

The receiving facilities distributed control system controls all control loops defined "slow". This is typically opening and closing of manifold valves and condition monitoring systems. The subsea control system has inter-connection links to handle potential subsea shutdown requirements.

Dynamic control loops, which requires quick response, are the anti-surge controller and the magnetic bearing controller. These loops shall be closed subsea if required.

Anti-surge algorithms are identically implemented for all compressor stages. The control algorithms include features for suction and discharge pressure override, i.e. limiting the discharge pressure or increasing the suction pressure.
PATENT CLAIMS

1. A subsea boosting system for a subsea installation, for boosting well fluid pressure when compressing hydrocarbon gasses and pumping hydrocarbon liquids, said system comprising at least one long step-out power supply and at least one subsea boosting station, each boosting station comprising at least one separator for separating gas and liquid phases, at least one gas compressor and at least one liquid pump, both arranged after said separator, the system further comprising inlet and outlet manifolds and at least one high voltage electric system, and each long step-out power supply terminating in a power umbilical termination head attached to a main transformer in a boosting station, said system being characterized in that each subsea boosting station further comprises electrically actuated valves, an all electric utility power system and an all electric control system.

2. The system of claim 1, characterized in that at least one of said subsea boosting stations further comprises circuit breaker modules and a barrier system.

3. The system of claim 2, characterized in that said at least one subsea boosting station further comprises at least one inlet cooler and an inlet sand trap.

4. The system of claim 1, characterized in that said at least one subsea boosting station comprises at least one compressor module, at least one compressor VSD, at least one anti-surge valve and actuator, at least one anti-surge cooler, at least one separator and/or scrubber module, at least one pump module, at least one pump VSD, remotely and manually operated valves, interconnection piping and control system including control modules.

5. The system of claim 1, characterized in that each long step-out power supply comprises a subsea main transformer with pressure compensation.
system, high voltage penetrators, an umbilical termination head and a power and control umbilical including main electrical supply, utility power, and fibre optic lines for control signals.

6. The system of claim 4, characterized in that each compressor module comprises at least one compressor which is directly driven by a variable speed controlled (=VSD) high-speed electric motor with magnetic bearings, said motor being cooled by hydrocarbon gas.

7. The system of claim 4, characterized in that said anti-surge cooler is designed for heat transfer by convection with the sea water.

8. The system of claim 4, characterized in that said separator and/or scrubber module is designed to absorb liquid slugs, ensure sufficient gas and liquid levels for safe operation of compressor and pump modules by level control, and prevention of internal solid buildups by possible re-circulation of liquid.

9. The system of claim 4, characterized in that said liquid pump(s) is designed to be solid tolerant and can be operated either with variable speed by means of a variable speed drive or operated on fixed speed with control of discharge flow and pressure by a regulating valve, said valve discharging liquid back to the separator/scrubber module.

10. The system of claim 9, characterized in that said liquid pump(s) is designed with an electrical motor cooled by hydrocarbon gas or a liquid.

11. The system of claim 6, characterized in that said control system including control modules is designed for control and monitoring of at least one subsea compression train, further for control of all other functions on the boosting station, and to include direct communication with a receiving facility and any local closed loop required to operate the boosting station in a safe and operational friendly manner.
Figure 1: Schematic overview of the all electric subsea boosting system where templates A and B have each 8 well slots and are installed initially.
Figure 2: Typical subsea main power system single line diagram
Figure 3: Typical subsea boosting station layout
Figure 4: A subsea boosting station layout
Figure 5: Boosting Station Process Flow Diagram
Figure 6: A schematic overview of main modules and parts in a subsea boosting station
Figure 7: Typical power and control supply architecture use for the boosting system
Schematic overview of the all electric subsea boosting system where templates A and B have each 8 well slots and are installed initially.