Power Requirements for Offshore Hydrocarbon Production from the Brent System

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The paper reviews the techniques adopted to produce the power required to recover, process, and distribute hydrocarbons from a number of northern North Sea Shell-Esso fields included in the Brent System. There are six different combined drilling and production platforms, together with seabed and floating storage facilities with a design throughput of up to 770,000 bbl per day of oil and 1000 mmscfd of natural gas. The main energy demands have been identified as crude oil export pumping, compression of gas for sale, or re-injection and water injection to maintain reservoir pressure. To meet the power requirement 42 gas turbines of both industrial and aero derivative types have been installed. These have been selected to meet the specific applications and are used both for direct mechanical drives and electrical power generation. The merits of the various prime movers including electric motors are discussed with the relative advantages of reliability and flexibility developed. The paper outlines the design criteria used in the lay-out of the gas turbines and concludes with a description of the electrical system studies which predicted the motor and turbine inter-relationships when accelerating the various pumps and compressors to running speed.


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ABSTRACT

The paper reviews the techniques adopted to produce the power required to recover, process and distribute hydrocarbons from a number of northern North Sea Shell-Enso fields included in the Brent System.

There are six different combined drilling and production platforms, together with seabed and floating storage facilities with a design throughput of up to 770,000 barrels per day of oil and 1,000 MMscfd of natural gas.

The main energy demands have been identified as crude oil export pumping, compression of gas for sale or reinjection and water injection to maintain reservoir pressure.

To meet the power requirement forty-two (42) gas turbines of both industrial and aero derivative types have been installed. These have been selected to meet the specific applications and are used both for direct mechanical drives and electrical power generation.

The merits of the various prime movers including electric motors are discussed with the relative advantages of reliability and flexibility developed.

The paper outlines the design criteria used in the lay-out of the gas turbines and concludes with a description of the electrical system studies which predicted the motor and turbine inter-relationships when accelerating the various pumps and compressors to running speed.

INTRODUCTION

Shell U.K. Exploration and Production operating on behalf of the Shell and Enso 50/50 joint venture have designed six combined drilling and oil production platforms. These have now been positioned in the northern North Sea for the extraction of hydrocarbons from the three oil fields known as Brent, Cormorant and Dunlin. The platforms are joined by a network of submarine pipelines to other neighbouring facilities, to the Shetland Islands oil terminal at Sullom Voe and to the Scottish gas terminal at St. Fergus. The configuration of the proposed field development and the pipeline system is shown in Fig 1.
for either reinjection or export through the pipeline to shore.

PRODUCTION PROCESS FOR A TYPICAL PLATFORM

Oil and gas under natural pressure flow from the reservoir up through production wells to the wellhead. The production flow from each individual well is controlled by the arrangements of valves known as the "Christmas tree". Some formation water will be produced in addition to the gas and oil.

BRENT D


KEY
A DRILLING POWER MODULE
B MAIN GENERATION
C SUB-MAIN GENERATION AND EMERGENCY FACILITIES

DIMENSIONS
LENGTH 73.64m
WIDTH 46.40m
HEIGHT 34.50m

Fig 2
The product then passes through the four stages of separation each providing successive pressure reduction. Where the different physical properties of oil, gas, and water enable them to be drawn off for separate treatment.

The partially stabilized crude is cooled and passed to the storage cells in the base of the platform structure, for the final phase of water settlement. Oil booster pumps, located in the utilities leg, lift the crude oil from storage and feed the transfer pumps for transport via the subsea pipeline, either to a tanker loading facility known as Spar, or to the Brent System main oil export pumps and the shore terminal at Sullom Voe.

Gas System

Gas recovered from the separators passes through compression equipment which is used both to inject excess gas into the reservoir to maintain pressure, and export sufficient gas to meet the contract quantities.

The system comprises three stages of centrifugal compression, natural gas liquid removal, desalting, and further compression using a large reciprocating machine.

Gas recovered from the second, third, and fourth stages of separation is cooled, the condensed liquids being removed in scrubbers, and compressed to the pressure of the first stage separator. The gas then passes through a treatment plant to produce a gas which is nearer to the sales specification and finally it is dried in a triethylene glycol contactor. The treated gas is boosted by the reciprocating compressor for reinjection into the formation or into the pipeline for transport to the shore terminal at St. Fergus. Fuel gas for the turbines is removed during the treatment stages.

Water Injection

The platform is equipped with pumps for injection of water into the formation. This process is carried out to help maintain the reservoir pressure and thus improve the recovery of oil and gas.

Sea water is fed to the desalinator column where it is stripped of dissolved gases by vacuum extraction. Any residual oxygen is removed by the injection of sodium sulphite. The desalted water is filtered before being passed to the seven water injection pumps.

POWER REQUIREMENTS FOR A TYPICAL PLATFORM - BRENT 'C'

The crude produced from the Brent field contains large quantities of associated gas. (The gas/oil ratio is 2,000 cu ft per barrel) hence on Brent 'C' platform the power required to compress the gas from the separator pressure to sales gas pressure is in the order of 13.5MW (18,000 hp). Hence, two compressor trains are installed, to give some operational flexibility during the pre and post production plateau periods and two prime movers each of 7.5MW (9,900 hp) were required.

The water injection rate requires an input of 22.88 MW (30,550 hp) which has been conveniently spread into seven pumping units each of 3.66MW (4,800 hp).

Crude oil pumping requires 3 booster pumps and 3 transfer pumps each of 0.45MW (600 hp) two of each type are operated for full production.

Other production power requirements consist of a wide variety of smaller pumps and compressors all of which are electric motor driven.

Figure 3 - Illustrates the magnitudes of the mechanical and electrical loads installed on each platform of the Brent system.

SELECTION OF PRIME MOVERS - MECHANICAL AND ELECTRICAL DRIVES

The design options were either to use gas turbines to drive the individual pumps and compressors above 2.5MW directly or to generate electric power centrally and distribute this power via the subsea pipeline.

The decision in favour of central power generation on the Brent platforms was made for the following reasons:-

1. The overall operational reliability of a process comprising a relatively small number of base loaded gas turbines supplying a number of large induction motors was greater than that if each of the larger drives was powered by a gas turbine.

2. The space demand and overall weight were less: also the smaller number of inlet and exhaust ducts led to fewer restrictions being imposed on the platform layout design.

3. The operational flexibility available by varying the speed of the gas turbine was recognised but this could be reproduced by using the turn-down capabilities of the driven machines, together with varying the number of machines on line.

4. The design of a mechanical transmission system between very large slow speed reciprocating compressors and gas turbines was outside the experience of Shell's engineering staff and their consultants.

5. The overall thermal efficiency of both systems was comparable.

6. The operating philosophy that, in the event of the loss of one generator, production of oil and gas could be maintained by reducing the quantity of water injection and operating the remaining machines in their peak mode.

SELECTION OF GAS TURBINES FOR MAIN GENERATORS

A review of the features of the aero derivative and industrial type gas turbines resulted in the selection of the former type for this application. The decision was based on:-

1. The reduced weight and space demands of the aero derivative: it must be remembered that although many parts of both types are common the industrial machine requires greater maintenance area and heavier lifting equipment for the more bulky components.

2. The advantage of rapid change out of the gas generator portion on the aero derivative set. It was recognized that longer periods between major overhauls may be available with the industrial machine but when heavy maintenance is required a set could be unavailable for service for an extended period.

1 Certain types of aero derivative gas turbines can be operated in either the base load or peak modes. Base load can be defined as the load beneath which normal operation produces no increase in engine life or time between overhauls (TBO). Conversely, operation in the peak regime produces an increase in power coupled with a decrease in TBO. The parameters which determine the limits of the two operational modes are gas generator speed and exhaust temperature.
3. The peaking facility is not available for heavy duty machines.
4. The gas generator chosen was established on a world-wide basis and had given good service in Shell Group companies.

SELECTION OF GAS TURBINES FOR OTHER APPLICATIONS

In addition to main generation, turbines are required for the submain generators. Those provide electrical power for the platform during the construction hookup phase, production start-up, and during maintenance periods. They are designed for dead platform or "black start" conditions and can use liquid or gas fuel. It was the object of the design exercise to provide sets which are operationally simple and the criteria of reliability and robustness are paramount for this duty. A variety of types have been installed with outputs ranging from 0.5MW to 5MW.

Three mechanical drive units on Brent 'G' supply power to three single stage pumps arranged in series, used to export the whole of the Brent crude output to Concorant 'A'. It is essential that the operation of these pumps is independent of the normal activities on the platform since a failure on one platform would jeopardise the operation of the remaining Brent platforms, hence the use of platform electrical power supplies is undesirable. The turbines are designed, however, to use fuel gas from the platform with automatic change-over to liquid fuel in the case of non-availability of gas.

The four main export pumps for the total Brent system are located on Concorant 'A'; again these pumps are independent of platform operations. The size of these pumps, 1,000M/Bbl/day, is very large, enabling the gas turbine drivers to be standardised with those of the main generator, in addition the chosen design speed of 50,000rpm eliminated the need for a gear unit. Three pumps operating in series will be required to transport the maximum output of the fields to the onshore stabilisation plant.

Brent Spar is a combined floating oil storage and tanker mooring buoy (which will serve as an anchorage when the subsea line to Sullom Voe and the onshore treatment facilities are available). In the meantime, it is used to fill dedicated oil tankers, which shuttle between the field and UK refineries, with Brent crude. The platform export pumps are used to move the crude into storage and the four electrically driven Spar pumps transfer the crude into the tanker via fixed and flexible hoses. Four liquid fuelled gas turbines, one to normally used as standby, are available to generate the required power during non-pumping periods. One set is kept on line to provide essential supplies.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>TYPE</th>
<th>SITE (GB)</th>
<th>RATING (MW)</th>
<th>EFFICIENCY</th>
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MAIN GENERATION

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<table>
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<th>SUB MAIN GENERATION</th>
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<td>SOLAR</td>
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<tr>
<td>PIRON</td>
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MECHANICAL DRIVES

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<th>RATING (MW)</th>
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TABLE 1 - APPLICATION OF GAS TURBINES ON THE BRENT SYSTEM

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</table>

In view of the rigorous conditions prevailing in northern North Sea, particular attention has been paid to various aspects of the turbine installation.

Combustion Air Filtration System

Each turbine is fitted with a three stage combustion air filtration system, similar to that shown in Fig 1, which is capable of reducing the salt content of the air to a value of not greater than 0.03ppm. In addition each generator and main oil line pump has a damper system which isolates the turbine at the inlet and exhaust ducts allowing warm air to be circulated through the machine during periods when the equipment is not required for production purposes.

![Fig 4](image-url)
Frost and Ice Protection
A study of statistical weather data and operating experience to date has shown that ice formation on the combustion air filters of turbines in these latitudes in the North Sea is not a problem. However, as a safety precaution, blow-in doors, actuated on differential pressure, are installed downstream of the filter/coalescer stages and the aero derivative turbines are fitted with anti-ice heating on the leading surfaces of the engine air intake.

Area Classifications
The modules containing the gas turbine sets are typically classified 'non-hazardous' in accordance with API and IP Codes. Thus all hazardous equipment such as the turbine and the auxiliary fuel control facilities are housed within a pressurised and acoustically insulated enclosure. All electrical equipment must be suitable for the differing operational modes. During the purge cycle all electrical equipment is certified to Zone 1 standard. The air change in this enclosure during normal operation of the machines are in excess of 420 per hour. The majority of the set take the purge and cooling air from the plenum chamber and a negative differential pressure is maintained beneath the hood. For this purpose two booster fans before, and extraction fans after the enclosure are specified.

Later sets use an independent two stage filter before the acoustic enclosure which leads to a simple ventilation system using a single extract fan. A typical 2 generator module is shown in Fig 5.

Engine Cleaning
The compressor stages of aero derivative engines are cleaned by washing with water or solvent; only in exceptional circumstances, such as the fouling of the blades by diesel exhaust fumes, will abrasive materials be used. These reservations do not apply to the submain generators of the industrial type where abrasives are retained for the standard cleaning procedure.

Waste Heat Recovery
The exhaust ducting of the main generators is arranged to accommodate a heat exchanger in a bypass duct. The exchanger forms a part of a heat transfer circuit which is used to regenerate the triethylene glycol circulated in the gas dehydration process. Although the quantity of heat extracted from the exhaust is small, 1.5 MMHtu/h (440kW) safety and economic considerations made this scheme feasible.

Contamination
The exhaust of all turbines have been designed to discharge well above the level of the intake hood to avoid problems of exhaust ingestion.

Turbine Orientation
The main generators have been located at the opposite end of the platform from the Living Quarters. This is to reduce noise and to minimise the effect of the exhaust plumes on helicopters using the helipad on the roof. Wind tunnel tests have demonstrated that the exhausts of the smaller turbines nearer to the helipad do not cause serious disturbance to helicopter operations.
Turbine Assembly Techniques

The later machines, whilst being fundamentally unchanged, have all the principal components, i.e. has generator, power turbine and driven machine mounted on a single piece bedplate instead of the three separate bedplates originally supplied. This improved design has the effect of enabling such control wiring and piping to be installed under factory conditions, thereby reducing the workload in the module builder's yard. The set can be treated as a complete package, fully works tested, requiring service connections only. A 'three point' mounting system has been introduced which simplified structural steel work design and eliminated many of the problems associated with the erection of large machines on a number of resilient mountings. Fig 6 illustrates these design aspects.

It is believed these tests are beneficial in ensuring that the train is free of objectionable vibrations and proving the mechanical integrity of the design and erection. Faults discovered at this stage can be remedied more quickly and cheaply than on the platform turbine/pump trials, when oil production programmes may be put at risk.

As an example, each of the four crude oil export pumps for the Brent System was tested on its single skid with the gas turbine, pumping water through a closed loop including a pressure reducing valve. A portion of the water, after the flow measurement orifice plate was bled off, passed through a water cooling tower and subsequently returned to the loop before the pump suction branch. The test loop included the exact configuration of suction pipework in the module; this was considered necessary as space restrictions prevented a straight length of pipe preceding the pump suction flange. This test enabled the pump characteristic to be checked at full speed following the test at approximately 70% full load speed at the pump manufacturer's works.

POWER GENERATION TRIALS

Four of the main generators have been load-tested onshore in their power module, to check mechanical, control and electrical integrity. Compatibility with the main switch gear, synchronisation, speed and automatic voltage control mechanisms were demonstrated. Finally the ability to accept, reject and share electrical load was proved.

Some machines, where construction schedules prevented full onshore trials, have been statically checked, i.e. all pipework has been flushed and control

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Turbine Testing After Fabrication

In an endeavour to reduce the expense and inevitable delays encountered during offshore commissioning a policy has been adopted of maximising the degree of onshore testing. In addition to the normal performance and mechanical run test of individual items at the manufacturer's works, to ensure compliance with Shell and API specifications, string tests are carried out.

String tests are defined as mechanical run tests on all components of a train, coupled together in their final configuration, operating on no-load or reduced load. These are arranged, where practicable, on combinations of prime movers and driven machines which have not previously operated together.
loops, start circuitry and auxiliary lubrication systems have been proved. It was estimated that this stage accounts for some 70% of the work that is required to test a machine.

EXPERIENCES WHILST TESTING

Onshore tests carried out in the module include turbine driven water injection pumps and the Brent crude oil export pumps. Faults eliminated from the systems include:

1. Pipework resonance, associated with pump impeller vane passing frequency, giving rise to high vibration at the pump.
2. A high speed coupling balance problem produced by the coupling having an unacceptably high tolerance on the component parts.
3. A pipework configuration which would have produced maintenance problems offshore.

These difficulties were overcome in the (1) and (3) cases by devising on site, and subsequently checking with the specialist designers, revised pipework configurations and in the (2) case, by requesting the supplier to provide replacement couplings to a superior specification.

DOCUMENTATION

The provision of complete data books for the operating departments is regarded as an essential part of both the design and commissioning procedures. To cover the latter, docters listing in sequence the detailed method of checking each item of equipment, with a space for notes and the signature of the technician accepting the item as satisfactory, have been produced. These docters then become part of the information to be passed to the offshore commissioning teams and have been found to be of considerable value.

ELECTRICAL SYSTEM STUDIES

The performance of the electrical equipment on the platform depends on the constancy of the system voltage and frequency. The turbine generator units are provided with automatic speed and voltage control facilities which maintain a steady state condition for normal operations. These controls respond to any changes in the applied load. The capability of the generators to establish the new level of stability without undue disturbance to hydrocarbon production has been evaluated for each of the rotating plant combinations.

The object of the evaluation was to establish the acceptable normal and transient voltage and frequency limits and to confirm by calculation that the limits will not be exceeded in practice.

An on-line computer was used for these calculations to resolve the complex dynamic interrelations between the turbines and the various electric motor driven. The computer comprises a suite of programs incorporating models of various items of equipment that will be involved in the operational situations. Thus, there are models for all the generators with associated voltage regulators and speed governers and the different types of motors combined with their starting methods. Then, mathematical models accept the detailed design data obtained from the various manufacturers, hence it is theoretically possible to simulate the ideal and the worst operational conditions before the equipment is purchased.

In summary the transient stability programs provide facilities to calculate the performance of the electrical power system following any disturbance to the steady state condition. These disturbances include:

1. Fault occurrence due to insulation failure.
2. Power transfer within the network.
3. Starting of electric induction motors.
4. Loss of generation due to equipment failure.

ELECTRICAL SYSTEM CRITERIA

Early in the Brent system development, following a survey of international standards and practices, it was decided to adopt 60 Hertz as the generation frequency with a tolerance ± 1%. After estimating the power requirement the expected horse power range of electric motors and the availability of marine proven switchgear, it was decided to design on a two voltage level system. For power generation and for motors above 3000kW, the voltage level was to be 6,600 volts ± 5% and for the motors below 3000kW the voltage was to be 440 volts ± 5%.

It was agreed that during the starting or re-accelerating a motor or a group of motors a temporary voltage depression down to 70% of rated voltage would be acceptable and that these variations should not exceed the maximum time permitted for 100% system voltage to be re-established as not to adversely affect plant operations.

For example, when a motor is started the starting power suddenly imposed on the generator causes a drop in the generator voltage and speed. This drop will depend on the relative size and characteristics of the generator and the motor.

The existing standing load being supplied by the generator before the addition of the motor to be started will influence the extent of voltage fall. In all the case studies in the calculations load and the added motor load would equal the maximum output for the connected generators this being the most onerous operating requirement. The results of the motor starting studies are summarised in Table 3.

The electrical power system transient response is analysed for various conditions involving combinations on line, with a specified standing load and a given motor to be started.

The maximum system voltages and frequency deviations are examined. If the transient voltage is maintained within 7% of its initial value and the system frequency remains within its 2% tolerance, then the motor start is deemed to have been successful.

ELECTRICAL POWER APPLICATION

The effects of motor operation on the overall electrical power system performance has been considered above. The motors' constructional and design features have been specified to suit the physical & process environment. Many of the drivers are installed within process areas which are classified as being potentially hazardous in accordance with the Institute of Petroleum Safety Code.

Although generally installed within mechanically ventilated modules, the electric drives are of the totally enclosed, weather proof induction motor type for immersion & protected to minimize the corrosive effects of the damp salt laden atmosphere offshore.

The motor windings are air cooled. The excess heat being dissipated by surface radiation on units below 500kW and by means of water coolers on the larger machines.

Further the larger machines, in potentially hazardous areas, are automatically purged with air & then pressurised to comply with certification requirements.

Condition monitoring is achieved by recording the winding & bearing temperatures and the vibration.
<table>
<thead>
<tr>
<th>GENERATOR</th>
<th>ON LINE</th>
<th>MOTOR STATIONS</th>
<th>MOTOR STARTING CURRENT</th>
<th>STANDING LOAD</th>
<th>STUDY DATE</th>
<th>CONSULTANT PROGRAM</th>
<th>RESULTS AND CONCLUSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 GECS Avon (22000)</td>
<td>2.4 MW</td>
<td>4.5 P.L.C</td>
<td>18.9 kW</td>
<td>25.5 kW</td>
<td>E.ACS</td>
<td>26</td>
<td>Voltage drop to 85%. Voltage recovery to 100% in less than 3 seconds.</td>
</tr>
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<td>- 2.4 MW</td>
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</table>

Reference to study 23 indicates that with 2 GECS Avon generators on line, a standing load of 21 MW, then starting a 8.5MW compressor causes a voltage drop to 92% with recovery to 103% in less than 3 seconds.

The case studies illustrate the flexibility of a centralized electrical power system, and its ability to manage all the operating modes, reference figure 3 which are encountered on Shell-Iskand oil facilities.