Ormen Lange Phase 3: A ground-breaking subsea compression system

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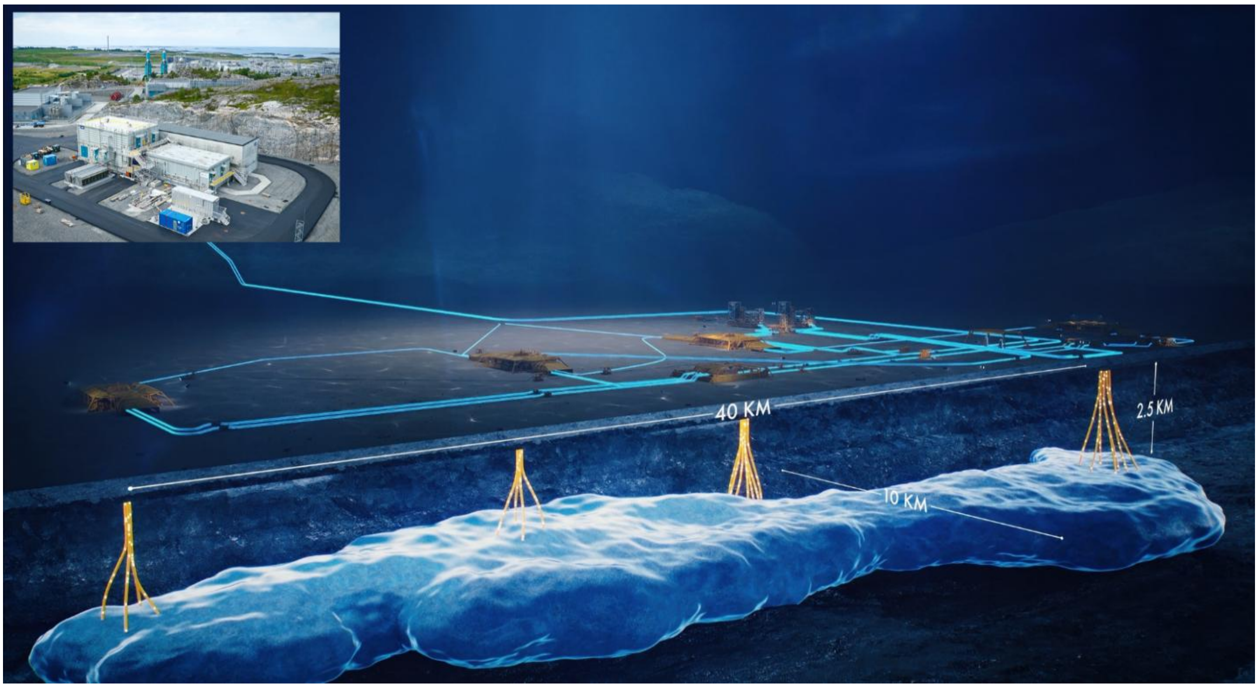

Figure 1: Ormen Lange gas field with OLP3

Abstract - One of Norway's most significant and advanced subsea gas projects is facilitating increased step-out distances and operational depths. The power system represents a break-through for large-scale subsea processing equipment, successfully addressing the engineering challenges associated with powering high-capacity gas compression at the industry's longest step-out distance.

The compression concept selected in 2019 relied on technology enhancements to be robust and cost-effective. The system vendor and its sub-suppliers handled equipment qualification in parallel with project execution, with Shell providing assurance, completing 20+ qualification activities. The qualification process was guided by industry standards issued by API and DNV. The compression system was started up in June 2025.

This paper presents the Ormen Lange Phase 3 (OLP3) project, the qualification process and start-up, with a special focus on the power system scope.

Index Terms — Power from Shore, Subsea, Cable, Variable Speed Drive.

I. ORMEN LANGE PHASE 3 PROJECT

The Ormen Lange gas field is located off the north-western coast of Norway. It is found 120km from shore and ties back to the onshore facility of Nyhamna. Figure 1 shows that the subsea production system consists of four templates with a total of 18 wells, which produces gas to Nyhamna via two 30" pipelines. From here the gas is exported via a 1200km pipeline to Easington in UK. The Ormen Lange gas field is operated by A/S Norske Shell with Petoro AS, Equinor, Orlen Upstream Norway AS and Vår Energi as license partners.

The field was discovered in 1997, and 10 years later produced its first gas [3]. Since the beginning of the Ormen Lange field development, there has been a commitment to develop offshore compression, either floating or subsea, and since then several technologies have been evaluated.

Maturation of subsea processing technology is a key enabler for unlocking remaining value on the Norwegian Continental Shelf, where future developments increasingly involve mature brownfield assets, long step outs, deep water, and challenging environments. OLP3 illustrates how disciplined technology maturation, collaboration, and reuse of proven solutions can make such developments technically feasible and commercially attractive.

In 2021 the final decision was made to start execution of the OLP3 subsea compression project, see also [6].

The OLP3 project consists of an onshore scope, two 120 km long umbilicals and a subsea compression scope.

The onshore scope includes the onshore parts of the compression system and civil works related to making a new dedicated substation area and integrating the compression system into the existing gas processing plant at Nyhamna.

The subsea compression scope consists of a manifold, two compression stations, subsea transformers, and foundations. Pipe spools and flowlines were also installed to connect the compression system to the existing subsea production system, all via the manifold.

The successful start-up in 2025 of the first of its kind subsea wet gas compression system represents a significant technological step change, setting industry record for subsea power step out and subsea to shore developments. The project demonstrates that advanced subsea processing systems can be industrialized and deployed reliably at scale.

II. THE SUBSEA COMPRESSION POWER SYSTEM

The main technology gap for the OLP3 power system was the increased step out distance between VSD and motor by almost 3 times compared to any existing system, to 120km. Also, to run four motors in parallel from one VSD.

Figure 2 shows a total of four 8MW wet gas compressors (WGCs), each containing two contra-rotating motors, located at 900m water depth, are supplied from two onshore Variable Speed Drives (VSDs) at a maximum frequency of 75 Hz; limiting the frequency is a key to enabling the 120 km step-out distance.

Onshore VSD output transformers increase the voltage to enable the long-distance transmission, while subsea step-down transformers reduce the voltage back to motor-voltage at the seabed.

Two alternative power supply concepts that were considered for selection: (A) an offshore power buoy with topside VSDs closer to the field; (B) a full electrical subsea distribution, including the variable speed drives. These alternatives were both de-selected due to cost and risk; the concept with onshore VSDs and 120km step out to the motors was the chosen concept. This is also the power topology that is used for the two other subsea compression systems installed to date; Gullfaks [4] and Åsgard [5], both on the Norwegian continental shelf.

The inclusion of the subsea transformers is a key enabler for the long step out, by allowing higher transmission voltage, leading to lower power losses. Another key enabler is the lower operating frequency of the wet gas compressors running at 75 Hz, compared to alternative dry gas compressors running at 120Hz. The lower frequency leads to lower charging current, and therefore lower losses.

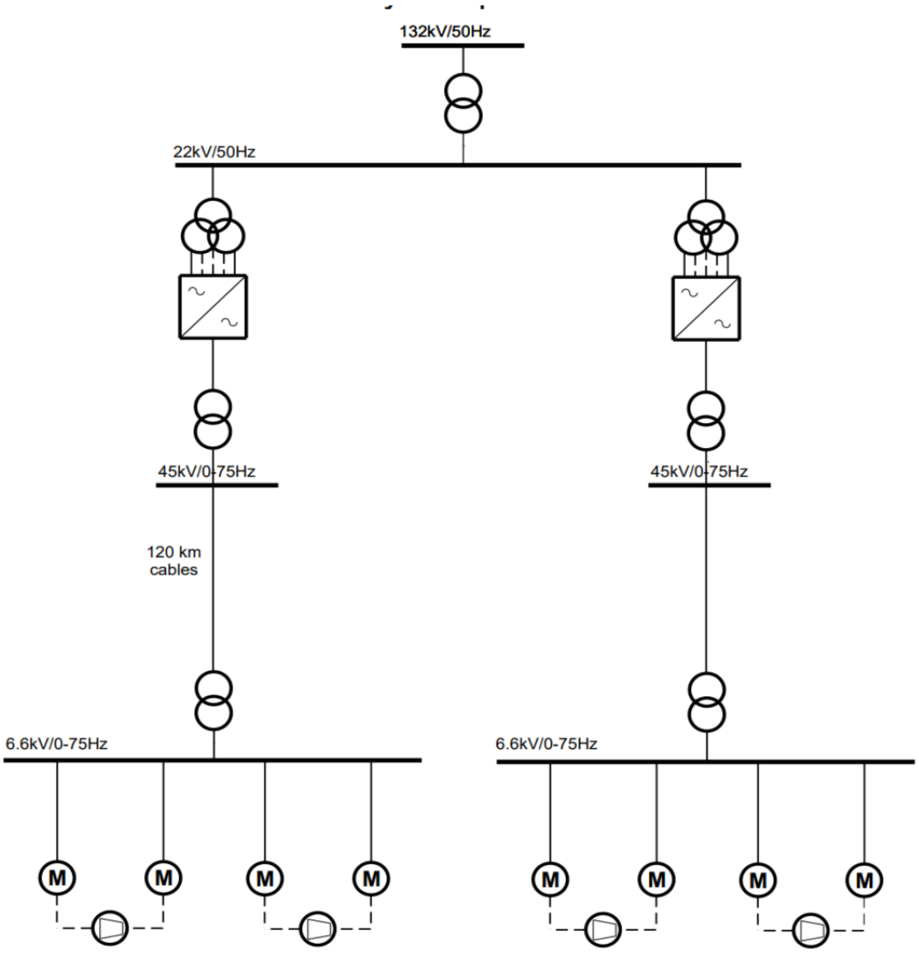

Figure 2: Simplified Single Line Diagram

III. FULL COMPRESSION QUALIFICATION SCOPE

The system vendor and its sub-suppliers carried out the qualification work, with Shell providing oversight all according to an extensive Technology Maturation Plan (TMP). A comprehensive qualification program addressed all technology gaps, completing 20+ TQP activities and following industry guidelines from API and DNV [1,2].

In the early stages of the project, the team chose to mature technology alongside engineering and construction to shorten the overall project timeline. This approach sped up technology deployment significantly, though it demanded thorough risk management and adaptable planning to prevent setbacks. The operator, system vendor, and sub-suppliers worked closely together, selecting key technology components and streamlining their qualification process, which led to a robust and cost-effective solution for the OLP3 project.

The entire qualification program was divided into five discipline-specific packages. Each package was completed successfully and achieved at least Technology Readiness Level (TRL) 4.

- TQ-1 Compressor Unit – capacity
- TQ-2 Power system – step-out
- TQ-3 Umbilicals – depth and power
- TQ-4 Control system equipment.
- TQ-5 Subsea process equipment.

After integration testing, the WGC system—including compressor units, power system, and auxiliary equipment—achieved TRL 5 and was ready for deployment. Following over six months of operation, it has advanced to TRL 6.

IV. POWER SYSTEM QUALIFICATION

The long-step out power system is based on utilizing industrial power products (transformers, switchgear, variable speed drives) located onshore at Nyhamna, using industrial of-the-shelf VSDs (9-level Integrated Gate Commutated Thyristor inverter with 36-pulse diode rectifier, 6,6kV, 2500A). Except for component qualifications, the main technology gap was the long step out power system with onshore VSDs. The table below shows a comparison with the two equivalent projects to date, Åsgard and Gullfaks subsea compression, see [4,5].

	Gullfaks	**Åsgard**	**OLP3**
VSD step out distance	16 km	45 km	120 km
Compressor rated frequency	75 Hz	120 Hz	75 Hz
Subsea Step-down Transformer	9MVA	22 MVA	25 MVA
Compressor size	5 MW	11,5 MW	8 MW
Motors per VSD	2	1	4
Compressor type	Wet gas	Dry gas	Wet gas

Figure 3 outlines the project steps taken to address technology gaps in the power system. Physical testing was necessary due to system novelty, as relying solely on analysis posed too much risk. Tests proceeded incrementally as equipment became available, with each qualification step increasing confidence and lowering project risk.

The qualification process began during the project's concept selection phase, with power system studies and physical tests using existing equipment. In 2018, a four-motor start-up test demonstrated that a single VSD could initiate and control two compressors, each powered by two motors. The following year, a scaled long step-out power test confirmed successful operation with a 120 km

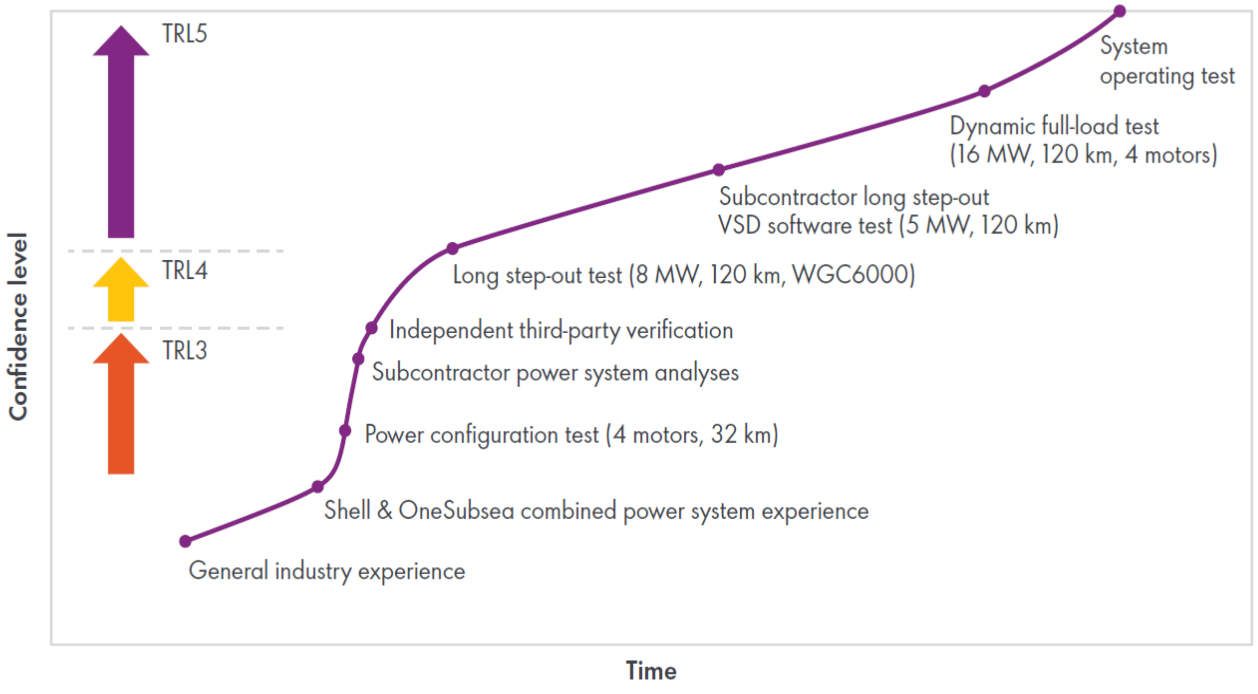

Figure 3 – Long step-out power drive system technology maturation (source [6])

power cable simulator at a 5MW load. These tests played a crucial role in choosing this concept for OLP3 in 2019.

In the FEED phase power system studies (load flow and electromagnetic transient) were executed, by both the main vendor and the main sub supplier for the power drive system, to conclude on system design and the ratings for the electrical components. This was further verified by independent 3rd party power system consultancy.

Also in the FEED phase, in Q2 2021, a VSD software verification test was performed with an industrial off-the-shelf a long step-out power system including step-up transformer, cable simulator and step-down transformer operating a back-to-back motor/generator test set up. The challenge for VSD control is due to the power losses and charging current, which vary significantly with load, frequency and voltage. Since there is not a closed loop control system with current/voltage measurements subsea, it becomes a challenge for the VSD to predict what is happening at the motor terminals. The motor terminal conditions are state estimated in the VSD control software.

The VSD software verification test gave confidence that it could accurately control the motors through various operational scenarios.

Finally, project execution with procurement and building of the system was started towards the end of 2021 after gaining sufficient confidence in the power system feasibility. Still, the main qualification test: the dynamic full-load test remained.

V. THE DYNAMIC FULL-LOAD TEST (16MW)

In Q1 2023 the dynamic full load test was successfully completed in a unique 16MW test arrangement. The test was done with as much of the delivery equipment as possible, at system vendor test facilty in Norway.

The full OLP3 project consists of two identical power trains of 16MW each, and the full-load test tested one complete power train, with test set-up shown in figure 4. The 16m long VSD cabinets, the VSD input- and output transformers, the subsea transformer, in a test pit filled with water, with subsea connectors and the subsea compressor, in a dedicated tank, were all delivery equipment.

The power cable was the only main piece of equipment that was not possible to include in the physical test due to its size (and timing of the test compared to its production). Therefore, a cable simulator was built for the project to represent the power transfer characteristics and transmission delay (for control) of the 120 km cable from the VSD to the motor.

The cable simulator (discrete inductors, capacitors and resistance) was designed on the “all models are wrong but some are useful” basis. Finite Element Modelling (FEM) software was used to evaluate whether a 2-section pi model was sufficient. Figure 4 below shows a 2-section pi cable model including skin effect. See [7].

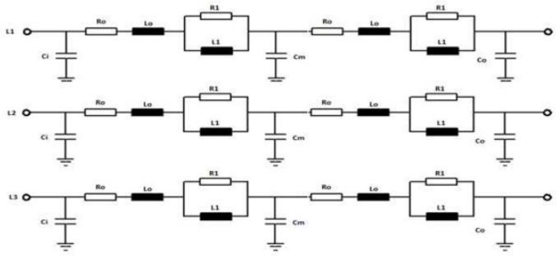

Figure 4 – 2-section pi cable model

The FEM software was used to check the system impedance over the frequency range of interest. At low value impedance points (serial resonance points) the voltage is amplified throughout the step-out system, appearing at the motor terminals.

While a 1-section pi model could be tuned to give the correct response at the nominal frequency, or the first parallel frequency of the step up transformer and cable, both cannot be achieved. Situations where the PWM output frequency is coincident with the resonant frequency of the step up transformer leakage inductance and the total cable susceptance must be avoided,

The disadvantage of the pi model simplification is that no information is available on the intermediate positions in the cable circuit; electromagnetic transient studies confirmed that damping of harmonic frequencies increases with step-out distance.

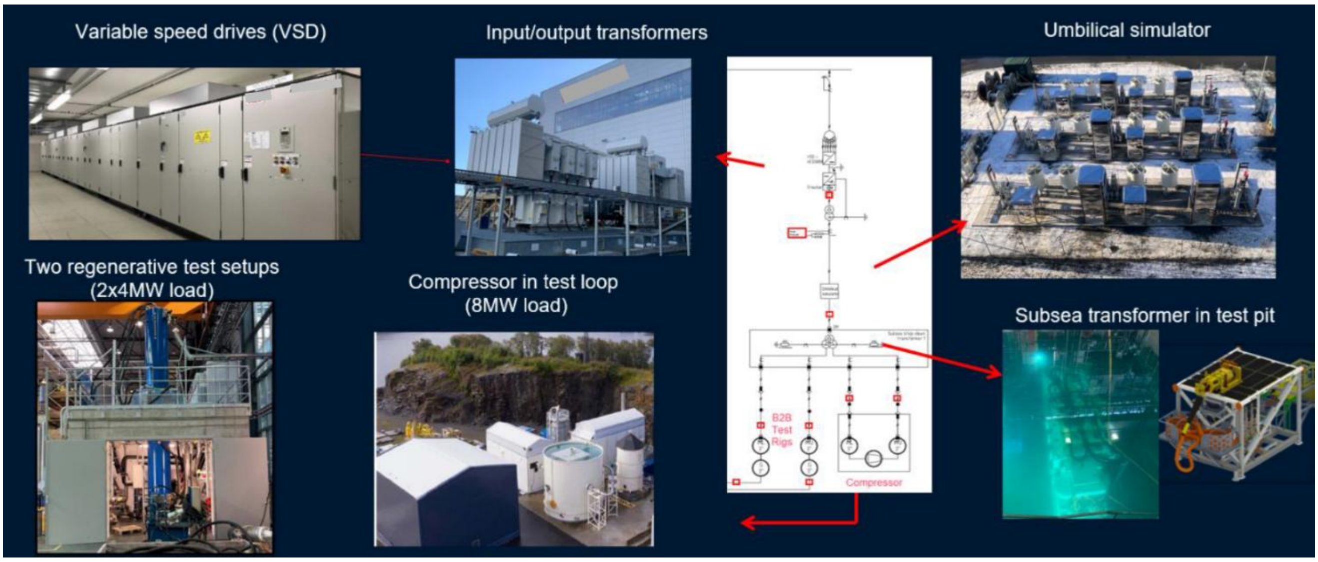

Figure 5: Dynamic Full Load Test Equipment

The test used a total load of 16MW. One 8MW compressor was installed in a hydrocarbon test loop, while two motor/generator/VSD setups simulated the second compressor. Using the regenerative VSD enabled more dynamic system testing than adding another compressor, which would be restricted by the process loop.

Figure 6 shows the long step out power supply on the right, with 2 motors driving the 2 contra-rotating compressors (and associated process loop) with the other 2 motors driving generators to feed power back to the local medium voltage grid.

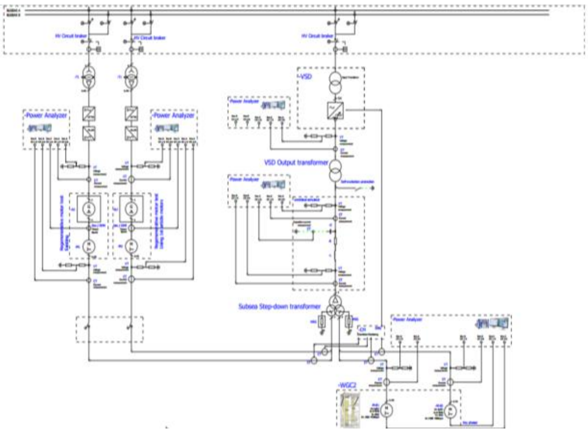

Figure 6 – Full load test key SLD

The main challenges below were addressed and confirmed to be covered during the dynamic full load test:

- Motor start-up (frequency and voltage boost for starting torque).
- VSD regulation and control for all steady state and dynamic loading scenarios including absorption of (cable) reactive power by the VSD (there is no separate reactive power compensation).
- Normal stop & trip scenarios verified, including VSD crowbar to reduce the energy in the step-out power system from the cable capacitance excitation of the motors.
- Harmonics are damped through the system, and within acceptance criteria.
- System resonances are avoided.
- Confirming accuracy of power system analysis.

The dynamic full-load test consistently demonstrated dependable performance across all load and transient scenarios. This evaluation facilitated the optimisation of VSD parameters to accelerate field start-up times and established a benchmark for subsea voltages, currents, and harmonics relative to onshore data. The resulting benchmark is instrumental in analysing subsea operations, particularly given the constraints posed by limited measurement availability.

A System Operation Test (SOT), including stack-up testing, was completed in the first quarter of 2024. According to API 17Q guidelines, this allowed the power system and its components to be classified as TRL 5.

VI. COMMISSIONING & START-UP

Once onshore and subsea installations are finished and all relevant certificates—mechanical completion, subsea installation completion, and ready for commissioning—were signed, commissioning could begin.

The cold commissioning was broken down into sub system levels, which for electrical consisted of:

a) Power Drive System
b) Subsea Control Power System
c) Low Voltage System
d) Uninterruptable Power Supply System

When all subsystems were commissioned, the “Ready for Start-Up” certificate could be signed, and hot commissioning could start. From an electrical point of view the first spin and direction of rotation check was a very exciting milestone. All 8 subsea motors, 2 in each compressor, started without problems and were spinning in the right direction, which was verified by the correct pressure build-up in the system.

This was an industry first, proving that the system with a VSD onshore starting up 4 motors at 120km distance and 900m water depth was working.

After first spin and start-ups, stops and trips were tested. Thereafter, the full speed range and load matrix were covered. The static torque limiter was tested, which is a current limit, depending on the speed, to protect the subsea compressors.

The testing started with single station testing and continued with parallel and series operation. When moving from single to parallel operation it was verified that the running VSD did not trip when energizing the second power drive system. This was another important test to verify the robustness of the electrical system.

The final very exciting test was a trip from maximum production in parallel operation. This test proved that the system could handle an emergency stop on both systems at the same time, without negatively impacting the rest of the Nyhamna gas processing facility. The crowbar in the VSD output activates during an emergency stop and prevents overvoltage in the transmission system.

Due to proper preparation with detailed procedures, a one team approach at site, a “hot commissioning playbook” with carefully thought-through “what-if” scenarios, and a thorough test program throughout the project, the OLP3 subsea compression system was successfully commissioned and started up in June 2025, with no significant issues, and earlier than scheduled.

VII. CONCLUSION

The OLP3 project is an example where technology maturation performed in parallel with project engineering and construction to reduce the total execution time, has been a real success. The total project was executed within schedule and budget.

This project has established subsea compression for use in remote and deep fields. It is anticipated that the technological advancements achieved here creates opportunities for similar gas fields elsewhere.

Some final points to summarize the business value delivered by OLP3 project:

1. The subsea compression system is expected to increase the recovery factor by 10% to an notable 85% and a total production increase of between 30-50 billion cubic meters of gas to the market. The system allows life-time extension of the Ormen Lange field, thus, being a sustainable way of adding gas to the market.

2. Reducing CO2 emissions is achieved by enabling replacement of coal for gas in Europe's energy mix, as well as a substantial benefit of placing the compression system at the seabed: Compressing the gas subsea before transporting it to shore reduces losses and hence the power consumption and emissions associated with the gas production.

VIII. REFERENCES

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IX. AUTHORS

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