Project Result Report
"Feasible power electronics for demanding subsea applications"- project no: 176025/S30

Acknowledgements
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Background
Subsea oil exploitation requires complex electric power systems adapted to high pressure environment. On a short term there is a need for local supply systems around wellheads with gas boosters, oil pumps, separators and other equipment. At a later stage one expects to develop energy supply systems for long step-outs where high voltage DC is a viable solution. This all requires local large power converters at the seabed at various depths, even exceeding 3000 meters.

Presently, designs offered by the industry aimed for subsea converter operation are based on concepts where the power circuits are completely assembled in steel vessels at atmospheric pressure. As the sea depth and the converter power rating increase, the pressure vessels gradually become heavy and unwieldy devices due to need for increasing the increasing wall thickness. Consequently, the heat conduction from the power electronics components to seawater also becomes problematic. Therefore the oil companies are looking for more feasible solutions for subsea power electronics. Enabling pressure tolerant power circuits is a significant step in that direction, giving the possibility for obtaining reduced weight and volume, while still keeping costs and reliability within acceptable limits.

The most important sub-goal for the project was to clarify the operability of pressurized power components and power circuits through cooperation with manufacturers and by own research including laboratory experiments on components and live power circuits. The complete converter power circuit should operate with satisfactory reliability up to the target ambient pressure of 300 bar.

The project has demonstrated that even critical components such as power semiconductors and capacitors are able to operate at high voltage under high hyperbaric pressure when made with proper pressure balanced encapsulations. The project has also exposed some important remaining challenges, mainly related to materials and methodologies for component packaging.

Main results and achievements
In a self-financed project at SINTEF Energy Research previous to the present project a literature survey was done. Only a limited number of studies on PTPE (Pressure Tolerant Power Electronics) technologies were found and many of these were even outdated due to recent technology development of encapsulation and material development. Furthermore, most of the papers are referring to applications aiming at short time or temporary subsea operations (e.g. ROVs). Therefore the research carried out in the present research project probably represents the best picture of the PTPE frontier of knowledge and technology, at least when it comes to open accessible information. The project has demonstrated that even critical components such as power semiconductors and capacitors are able to operate at high voltage (1 kV+) under high hyperbaric pressure when made with proper pressure
balanced encapsulations. Maybe the most important achievement from the project is demonstrating pressure independent performance (conduction, blocking, switching) of semiconductor chips and their terminations (bondings, press contacts) in the range 1-300 bar.

The project has substantiated that the semiconductor chips like IGBTs (Insulated Gate Bipolar Transistor) and their terminations (bondings, press contacts) have unaffected electrical performance (conduction, blocking, switching) in the pressure range 1-300 bar.

The project has substantiated that metallized film capacitors for converter DC-links can be adapted for pressurized operation and have unaffected electrical performance in the pressure range 1-300 bar.

The project has demonstrated that IGBT gate drivers including auxiliary power supplies can be designed for reliable operation under pressurized condition up to 300 bar.

The different test programs have unveiled that there are still several insulating material and packaging related challenges to be addressed. Two incidents with failures during long term testing of planar IGBT modules has demonstrated that direct liquid insulation of the power semiconductor chips is critical regarding possible impurities in the liquid. Live testing has also triggered failures of a power capacitor that were expected to cope with operation in pressurized liquid.

It is concluded that close to 100% filling of voids in the components is necessary. Sufficient filling of complex components like press-pack IGBTs is challenging, but the project has demonstrated that such filling is possible if adequate procedures are opted.

Some gate driver components are critical regarding packaging and material compatibility. Insufficiencies have been demonstrated for opto-couplers related to long term reliability in pressurized environment. Some optical fiber transmitters have proved to have insufficient encapsulations, and also the optical performance is affected by ambient liquid.

The physical experiments on live pressurized power circuits were limited by voltage and current limitations for the pressure vessels penetrators. DC-link voltage for the converter test objects was limited to 1000 V, while the test currents had limits in the range of 50 A. Also the cooling capacity for the pressure vessel limited the power levels for the tests. Regarding the voltage limitations they in fact correspond closely to the voltage limitations for the selected IGBT and capacitor test objects.

Transferring the test limitations for the phase-legs used in the experiments to ratings for a complete three-phase PWM converter (three phase-legs), the rating for that converter would be in the range 400 V/20 kW (giving also an operating safety margin on the vessel penetrators ratings). This may seem to be very small compared to required power levels for compressor drives for gas boosting (e.g. 6.6 kV/10 MW+). However, one should bear in mind that high-power high-voltage converters are composed of individual components with strict voltage and current limitations far below the converter output ratings. Therefore, regarding perspectives for high-voltage, high-power PT converters, the focus should be on adapting PT for the individual components. It is argued that provided the same internal component insulating properties are obtained for pressurized solutions as for standard commercial devices, medium-voltage and high-voltage PTPE converters can be realized by applying the same topologies as for other converters, and with the same pros and cons. Main challenges are related to long-term effects regarding material compatibility and components performances.

During the project there has been an increasing interest for the possibilities that are opened by enabling pressure tolerant power electronics. Now there is an increased conviction that PTPE is feasible. Several oil companies are saying that they consider projects applying PTPE. Also several converter manufacturers have announced that they will develop PTPE product. There is also an increasing interest among component manufacturers (IGBTs, capacitors etc.).
Anyhow, the PTPE technology is still very immature and long-term reliable converter designs are challenging with this new technology. SINTEF recommends taking one step at a time by starting with modest converter power and in any case not the most critical applications. SINTEF has also recommended non-critical low-power demonstration projects as the first step.

SINTEF is prepared to utilize the achieved competence and experience from the project by contributing to the realization of PTPE:
- By continuing generic research – e.g. on materials and packaging of components.
- By support for qualifying materials, PT components and PTPE power circuits.
- By validation of component and converter designs.
- By third-party verification and qualification of production prototypes.

Tasks not achieved as originally planned
For different reasons some reorganization and reductions of activities have been necessary. The most significant are:
- Only two dielectric liquid candidates have been used as test liquids; Midel®7131 and Silicon oil 200R 50cSt. Midel®7131 has been used for most of the experiments due to its easy handling and equipment cleaning procedures (silicon oils are hard to remove from contaminated equipment).
- The scope for investigating alternative methods for insulation of IGBT has been less than the ambitions at project start-up.
- Voltage and current test levels have been less than the ambitions at project start-up.
- The investigations of cooling conditions for liquid filled power circuits have been less extensive than planned. Cooling calculation tools and cooling methodologies are very important since the component temperature conditions are closely related to reliability; not only by the temperature as such, but also regarding possibilities for avoiding pumps for forced cooling.
- High pressure testing of phase-legs has been limited to two phase-legs representative of the two main IGBT technologies (planar and press-pack).

Remaining problems
Despite uplifting results from the present project it is also recognized that to achieve PTPE products with sufficient long-term reliability, some remaining fundamental problems need to be solved. The problems and uncertainties are mainly related to materials for electric insulation, and how to apply the materials for appropriate packaging of the most vulnerable components.

In 2012 SINTEF is starting a new research project supported by the Research Council PETROMAKS program and industry partners where the following very important remaining PTPE challenges will be addressed:
- Criticality for long-term operation of semiconductor chips towards impurities and contamination in insulation materials (e.g. liquid).
- Need for PTPE application-specific tests on liquid insulation performance.
- Standard encapsulations are not pressure tolerant, but adaptation is possible.
- Material incompatibility issues.
- Cooling issues.
- Sealing and filling of voids, depending on encapsulation technology.
- Risk for deteriorating performance of communication links (optical fibers and optocouplers).
- Special insulation requirements for high-voltage converters (6.6kV+).
- Need for diagnostic monitoring to verify insulation integrity of components and converters.

The name of the new research project is:
“Pressure Tolerant Power Electronics for Subsea Oil and Gas Exploitation “ PRESSPACK
Summary of documentations

Conference papers:

Journal Papers:

SINTEF report:

Documentation reserved for the Project Consortium:
- Confidential project summary report:
  TR F7137 " Feasible power electronics for demanding subsea applications".
- Total about 50 Project Memos and Technical Notes.
- Total about 24 workshop presentations have been prepared and presented on project workshops.