

Project description (extract)

Title: Feasible power electronics for demanding subsea applications

This project proposal is one out of three related KMB-project applications on subsea power components and systems submitted within Petromaks. The others are titled "Electric power systems for subsea processing and transportation of oil and gas" and "Electrical insulation materials and insulation systems for subsea high voltage power equipment"

PART 1: The KMB Project

1. Objectives

Principal objective

Establish fundamental competence on new and pioneering concepts for realizing power electronics converters for subsea applications. The developed know-how will give Norwegian vendors and oil companies new possibilities for realizing future challenging oil and gas projects

Sub-goals

1. Provide a review of the major weaknesses and uncertainties of the today's concepts for high power converters for subsea applications.
2. Clarify the operability of pressurized (300 bar) power circuit and driver circuit components through cooperation with manufacturers and by testing components in laboratory.
3. Demonstrate possible new design solutions by use of pressurized power circuits and transistor driver circuits.
4. Provide methodologies and guidelines for qualified pressurized converter designs, including support for upgrading of specifications
5. Accomplish a PhD degree within dielectrics for pressurized power electronics

2. Frontiers of knowledge and technology

Future Needs

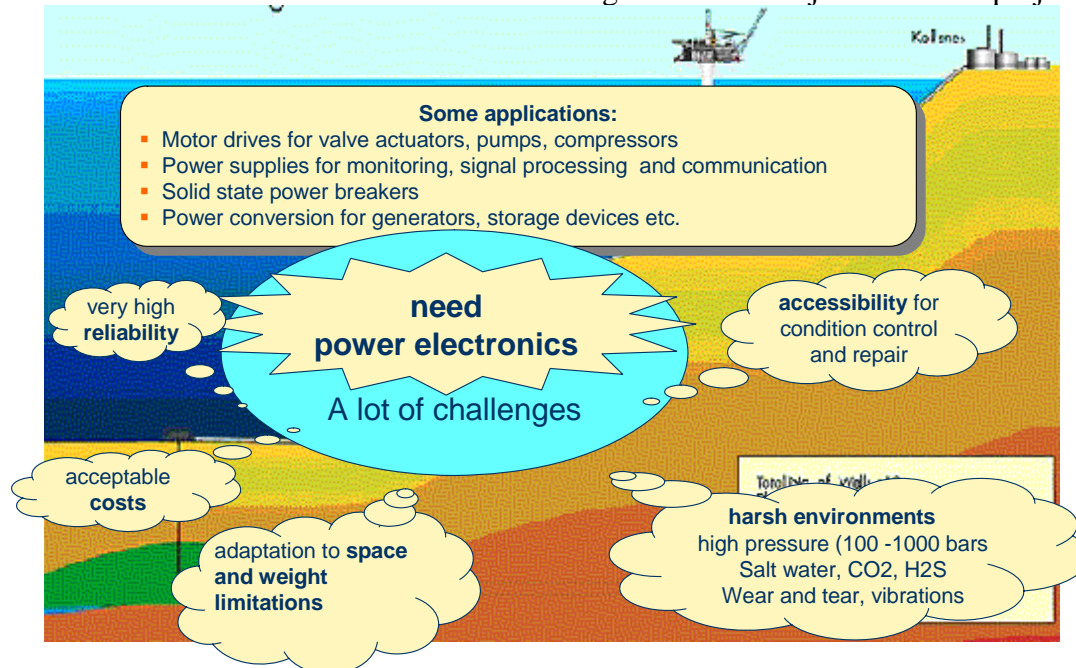
Reference is made to OG₂₁ (www.og21.org), which is a task force established by the Ministry of Petroleum and Energy (MPE) of Norway in 2001 to assist the petroleum industry formulating a national technology strategy for added value and competitive advantage in the oil and gas industry.

Processing on the seabed is especially relevant for the development and operation fields with high water production and for subsea fields. Especially will possible future exploitation in the Barents Sea bring about tremendous challenges concerning transmission and conversion of electric power. Especially are the oil companies visualizing the need for high power variable speed drives for oil pumping and gas recompression.

Status

Ongoing subsea oil and gas projects, like the Ormen Lange Subsea Compression Project, have shown that the frequency converter is the Achilles' heel when it comes to obtaining feasible solutions. The challenges are related to obtaining satisfactory reliability figures and obtaining manageable size, weight and costs. The today's converter concepts for subsea operation are based on standard components installed in one bar gas filled pressure vessels. As the sea depth and the converter power rating increase, the pressure vessels gradually becomes huge unwieldy modules. The reliability of proposed high power converter concept for subsea applications is also questionable.

The field development projects (e.g. Ormen Lange) have normally too short perspective for enabling the necessary technology push that is necessary to obtain new technology with documented reliability on individual components and materials. SINTEF Energy Research therefore recommends a joint long term research project involving the Research Council, oil company and supplier industry, with the intention to establish new know-how according to the main objective of this project proposal.



In an ongoing self-financed project at SINTEF Energy Research pilot investigations on pressurized IGBT-modules is showing promising results. An IGBT module, switching at 300V and 150A, has been tested in silicone oil pressurized to 200 bar for four months. No change in operational performance or negative effects from high pressure has been observed. The self-financed project will continue with similar testing of other vital power components and electronics.

A literature survey from the above mentioned self-financed project indicates that not much have been done world wide on developing pressure tolerant power electronic devices. There are however some statements from manufacturers, e.g. of oil filled power capacitors, that components are adaptable for pressurization. Products with pressurized power electronics for seismic application (temporary subsea operations) have been realized. No products for permanent subsea applications, applying pressurized power electronics, have been found.

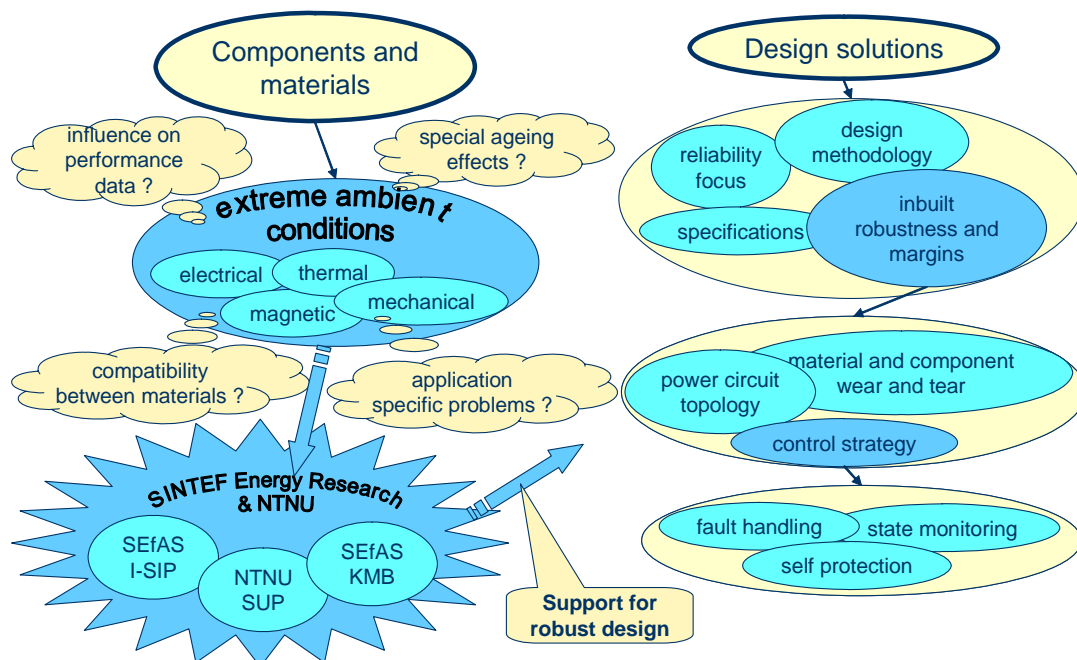
SINTEF Information and Communication Technology (SINTEF ICT) has been working with directly pressurized electronic systems for the last two years within the KMB project *Reliable microelectronics for harsh environment*. The main motivation for this activity has been the possibility to greatly reduce the electronic encapsulation size when the electronics is exposed to the high external pressure. In addition the elimination of high pressure feed-throughs is an advantage, since these are often a weak link in the design. The research has so far shown that integrated circuits can operate reliable for long time periods (8000 hours) at pressures up to 1000 bars. Material compatibility and the behaviour of passive components have been identified as main challenges. Currently the behaviour of ceramic chip capacitors under static and dynamic pressure is investigated. SINTEF ICT has employed a PhD student focusing on failure mechanisms for electronics exposed to high temperature and high pressure.

Reference is also made to the NTNU SUP-project "Enabling technology for Subsea production of oil and gas using electricity for power Supply and control" with the planned PhD on "Power Electronics Pressurization". The power electronics team at SINTEF Energy Research has a long tradition for high quality guidance of PhD students working on subjects matching a priority area at SINTEF Energy

Research. This proposed KMB will be of vital importance for establishing such a prioritized area within subsea power electronics. The power electronics team also highly benefits results from the students work. A substantial synergetic effect from the proposed KMB-project and the SUP at NTNU is therefore to be expected.

3. Research tasks

Designing power electronic converters is a complex matter involving both the converter designer, the user (customer) and the manufacturers of individual converter components. The designer need to know the worst case operating conditions for the converter, both in normal operation and under fault conditions. This call for information from the user and from the load (e.g. motor) manufacturer. The designer also needs intimate correspondence with the manufacturers of critical converter components (e.g. power semiconductors). Especially regarding questions related to special application of components, e.g. derating and special protection requirements in order to obtain very high reliability, restrictions and possibilities for harsh environmental (e.g. pressure) applications etc. The figure below tries to illustrate that reliable converter design mainly depends on the quality of individual components and building materials, and on the skill of the converter designer. I.e. selection of power circuit topology, cooling, control electronics etc. for obtaining satisfactory reliability, volume, weight, cost etc.



Although this project proposal does not involve application specific designs, the above mentioned considerations are important for the accomplishment of the project, especially considering the sub-goal providing methodology and guidelines. The research activities aim to provide new know-how for designing more reliable and feasible converters for technologies and competence for subsea applications.

The main problems to be addressed

The main challenge of the project is to prove that a complete power circuit of a power electronics converter, also including gate-drivers with power supply, can operate with satisfactory reliability in high pressure environment. Then it is only the electronics for the main converter control that needs one bar container. Control pods have normally relatively small volume and weight, and a tidy interface of low power penetrators and interface to the surroundings. The assumed main challenges related to pressurization of power circuit components are as follows:

- Power semiconductors like IGBTs and power diodes: Discussions with component manufacturers and reports from previous international research indicates that the major problems concerning pressurization of power semiconductors are related to the encapsulations. In this project the promising results from the above mentioned project, e.g. with encapsulations removed or modified and dielectric liquid directly exposed to the silicon chips, will be continued
- Gate drivers, including power supply: The switching power valves (e.g. IGBTs) together with its drivers are regarded as the most vulnerable components of the power converter. The common design challenges are reinforced by pressurization. SINTEF Energy Research has long term build-up of competence on robust and customised drivers for IGBTs. The previous research activities on drivers have also resulted in commercial products, among other things drivers delivered to CERN. Drivers are also a mixture of power electronics and electronics. Scientists at SINTEF ICT, working with pressurization of electronics, are planned to be involved in this project.
- Capacitors: Capacitors are required as dc-link storage capacitors, power filter capacitors, snubber capacitors and driver circuit capacitors. While electrolytic capacitors are regarded as questionable for pressurization, liquid filled film capacitors are reported to be feasible for pressurization. SINTEF ICT also reports interesting results from pressure testing of ceramic capacitors
- Sensors/ transducers: Sensors are needed for measurement of voltage, current and temperature, for the purpose of control, protection and state monitoring and surveillance. The challenge in this project will be to provide simple and robust methods for sensors suitable for pressurization. Special designs may become necessary.
- Materials for DC-insulation and high dv/dt-stress. The internal voltage condition for a power electronic converter is an awful mixture of DC and very high rate of change of voltage (high dv/dt). Dielectric stress to materials exposed to a mixture of DC and high dv/dt, compatibility between solid and liquid materials etc. bring about a lot of challenges. Concerning these subjects it is assumed that this project will benefit from proposed KMB-project on "Insulation materials" from SINTEF Energy Research
- Cooling of power devices. The today's concepts for high power subsea converters based on installation in one bar containers experience significant cooling problems due to poor internal heat conduction and high wall thickness of the steel container. The main challenge considering cooling is to utilize the advantage from pressurized power circuit to obtain significantly more efficient and cheaper cooling systems.

Even though the already mentioned pilot investigations at SINTEF Energy Research are promising, there is a long way to go before qualified solutions are achieved.

As mentioned above, pressurization of electronics for main converter control is not covered by this project. This could be carried out as a separate project in parallel or subsequent to this project, and probably in charge of another institute than SINTEF Energy research.

The results from the Petromaks KMB will be predominant generic, i.e. it will be independent of application, power range etc.

Task descriptions

Task 1: Review of the today's concepts

The objective of this activity is to clarify the major weaknesses and uncertainties of existing and proposed converter concepts for subsea applications. To the extent information can be released, the

project team at SINTEF Energy Research will utilize information and experience from projects on evaluation of concepts proposed for subsea projects like Ormen Lange and others. A review report summarizing major weaknesses and prospective improvements will be issued. The report will also contain base guidelines for the focus in the subsequent activities.

Task 2: Identify critical components

A review of actual power circuit topologies will form the basis for identifying components needed for realizing a pressure tolerant power circuit. The candidates are the components normally constituting converter power circuits such as power semiconductors and capacitors, essential additional components such as gate drivers including power supply, sensors and cooling circuits. The review will not highlight special topologies or compare topologies, but aim to focus on components required to form building blocks for several types of topologies in a broad power range, but especially medium and high-power converters. This task also assumes a good dialog with participating converter manufacturers. A summary report with candidates subject to investigations will be worked out.

Task 3: Feasible technologies for pressurizing

A thorough feasibility study of power circuit components will be accomplished one by one. For each component there might be several alternative technologies. (E.g. the DC capacitors could either be film type or electrolytic type.) Dialogue with the manufacturer's own expertise as well as involvement from SINTEF's own material experts will be important in this phase of the project. Components constituting driver electronics will mainly be managed by SINTEF ICT. A literature study, also including open results from related international research programs will be included. A report will be worked out, containing identified components, feasibility for pressurization and plans for required special tests. The results from the report will be input for task 5. The plan for special tests will also contain needs for special laboratory equipment. Results from study of gate driver component study will be input to task 4

Task 4: Pressurized gate drivers

Results from the feasibility investigations of gate driver component in task 3 will be input to idea-shaping for simple and robust gate driver systems including power supplies. Here SINTEF's own experience from gate driver development is expected to become very useful. The most promising concepts will be realized as prototypes and prepared for pressure testing in task 5. A report will be worked out including circuit diagrams for the proposed designs, results from one bar testing, and plans for pressure testing.

Task 5: Laboratory pressure testing of components

This is undoubtedly the most extensive activity of the project. The most promising components will be tested under specified pressure (e.g. 300 bar) in the laboratories at SINTEF Research. The test bench will be designed for enabling electrical tests on pressurized objects. Under the tests electrical parameters will be measured to monitor any changes due to long time effects. Accelerated aging tests, e.g. by increasing the ambient temperature and/or pressure cycling, will be considered. After finished test period the test object will be investigated by electrical measurements and visual inspections to uncover any effects of long time exposure to high pressure. Test reports will be worked out on individual components..

Task 6: Demonstration of pressurized power circuit

This task aims to realize and pressure test a converter power circuit under pressure. This circuit will represent a building block of a converter including all components investigated in the preceding tasks. An obvious circuit candidate is a bridge arm of a two-level converter, constituting upper and lower IGBT, DC-link capacitor bank, possible snubber circuits, gate drivers, output power filter and essential parts of the cooling circuit. Power rating for the demo circuit will be 10-100kW

Task 7: Evaluate prospectives for pressurized medium and high-power converters

The building blocks described in task 6 will be representative for almost all types of AC and DC converters that is relevant for subsea power conversion. Although the practical subjects on pressurization in this project mainly will concentrate on relatively low power, valuable information will

be achieved for evaluating prospectives for pressurized medium (1-10 MW) and high-power (10-100MW) converters.

Task 8: Methodologies and guidelines

Findings and conclusions from the preceding activities will form the basis for preparation of methodologies and guidelines for qualified pressurized converter designs. It is also the intention that this activity will give valuable support for upgrading of existing component and converter designs.

Task 9: PhD scholarship

The PhD student will focus on dielectrics for pressurized power electronics. He will enter the project team and be fully integrated in the project.

4. Research approach, methods

The methods for achieving the goals of the project are more or less indicated in the task description in chapter 3. The research will comprise theoretical and experimental studies within power electronics, electronics, material science and heat transfer (cooling). A major challenge of the project is to prove satisfactory operability of components and materials under ambient conditions far beyond normal operation conditions for commercial available components. This calls for close cooperation between experts in the project and experts with the component manufacturers in connection with theoretical analysis during the experimental phases, and in connection with preparation of methodologies and guidelines. It is also to be expected that special specimens are needed from the manufacturers. Here the institute will extend the cooperation with manufacturers established in the above mentioned self-financed project on pressure testing of IGBTs. Results from the experimental studies will also be made available to the cooperating component manufacturers, as an element of contributing to new components adaptable for high ambient pressure. Most of the experimental work will be accomplished in the laboratories at SINTEF Energy Research and NTNU. A combination of dedicated material tests, component tests and tests on live power circuits constituting power circuit modules will be necessary. Most of the gate drive component tests will be accomplished at SINTEF ICT in Oslo.

As the KMB-project proceeds and results emerge, it is assumed that industry partners in the project may find commercial interesting results. Then it will be reasonable to peel off such activities, e.g. for a continuation in a BIP-project. Such possible discussions will be taken by the steering committee of the project.

The following elements are assumed to play an important role for successful accomplishment of the project:

- Application of long experience and existing competence within power electronics
 - Physical understanding of power semiconductors, including knowledge of correlations between operating conditions and operating reliability and lifetime
 - Experience from R&D on gate drivers and snubber circuits.
 - Experience from previous development projects on special converter designs like hyperbaric welding converters and compact converters for electric vehicles.
 - Experience from evaluations of the today's high power subsea converter concepts
- Existing contacts and new alliances with component manufacturers
- Exploitation existing competence within adjacent R&D projects in SINTEF and NTNU
 - "Electrical Insulation Materials and Insulation Systems for Subsea High Voltage Power Equipment" - Applied KMB- project to Petromaks March 2006
 - " Electric power systems for subsea processing and transportation of oil and gas " - Applied KMB- project to Petromaks March 2006
 - "Reliable microelectronics for harsh environment" Ongoing KMB-project at SINTEF ICT
 - "Enabling technology for Subsea production of oil and gas using electricity for power Supply and control" - Ongoing SUP-project at NTNU

- "Power electronics for extreme subsea and downhole ambient conditions" - Self-financed SINTEF project.
- Experimental work. The project will utilize existing and new (under acquisition at SINTEF Energy Research) pressure chambers for dedicated tests
- Theoretical analysis and calculations. It is assumed that special problems call for advanced calculation tools and methods. E.g. finite element calculations for investigation of stress on insulation due to high DC electric fields and high dv/dt, and for investigation of cooling problems and methods.
- Publishing. Project results will be published in international recognized periodicals and conferences. It is assumed that this will give important feedback on the project. Subjects and milestones for publications are outlined in chapter 7. However, if patentable ideas emerge during the project, the publication plan may be altered.