Under pressure

As demands on subsea oil and gas exploitation grow evermore extreme, **Magnar Hernes** describes how advances in materials and components can help to ease the pressure

Could you outline the aim of your recently completed project on 'Feasible power electronics for demanding subsea applications' (2006-12)?

The most important goal was to clarify the operability of pressurised components that represent the most common power circuits of power electronic converters. The complete converter power circuit should operate with satisfactory reliability up to the target ambient pressure of 300 bar.

Your new project, 'Pressure Tolerant Power Electronics for Subsea Oil and Gas Exploitation', is scheduled to finish in 2015. What has this research revealed to date?

The main aim is to provide the required material and packaging knowledge in order to understand the fault mechanisms that affect the operation lifetime of subsea Pressure Tolerant Power Electronics (PTPE) converters, with particular emphasis on insulating material issues. The knowledge acquired will be used to support manufacturers making products with the satisfactory reliability (MTTF 10+ years). Target pressure has been increased to 500 bar (5,000 m sea depth) and targets regarding voltage levels have also been increased (to 6.6 kV AC/15 kV DC).

How are these two projects linked and how have their findings influenced each other?

The first project focused on what we could call 'party killers' for PTPE: whether, for example, pressure and insulating liquid could be destructive for the basic operation of the critical components. It addressed pressing questions such as whether the very high pressure could be destructive for the operability of the silicon chips; if the insulating liquid would lead to unacceptable deterioration of the operability of optic fibres; and whether it is possible to achieve sufficient component mechanical stress relief by close to 100 per cent vacuum-filling of the components.

This initiative concluded that such problems could be avoided. However, possible issues related to long-term effects were also demonstrated, especially for electrical insulation and material compatibility. The new project is a direct continuation of our previous work, highlighting possible long-term material problems.

What challenges or gaps in knowledge is your current research seeking to address?

The project seeks to address a variety of problems. One challenge is the critical need for long-term operation of semiconductor chips, protecting them from impurities and contamination in insulation materials. We also seek to understand the need for PTPE application-specific tests on liquid insulation performance.

Standard component encapsulations are not pressure tolerant, but adaptation is possible, so we are looking to address material incompatibility issues and cooling deficiency issues. We hope to improve sealing and filling of voids and alleviate the risk for deteriorating performance of communication links (such as optical fibres and optocouplers). There are also special insulation requirements for high-voltage converters (6.6 kV+) and there is a need for diagnostic monitoring to verify insulation integrity of components and converters.

How have you been testing the operability of pressurised power components and power circuits?

Various tests have been performed on materials, circuits and individual components. For components and circuits, one can distinguish between passive tests and live tests: live tests apply voltage; passive tests do not. For live tests, the test criteria have been that the individual components should endure the same electrical voltage, current and thermal stress as for standard components.

Multiple laboratory experiments have been executed. We have conducted 'destructive' pressure tests (passive) in nitrogen atmosphere with high pressure slew rates to exclude weak components that could not be used or needed to be modified. We have carried out long-term compatibility tests of insulation materials, eg. between silicone gel and insulation liquids. Operability tests of gate drivers and auxiliary supply have been completed – including operability of optic fibres and transmitters in a liquid environment. The most extensive part has been long-term tests of components and circuits representing modules of complete converters in liquid environment at 1 bar and in the pressure range 1-300 bar.

What does the future hold for your research?

The new project is still in the start-up phase and the first results for publication are expected in mid-2013. While no specific events have been decided, we plan to disseminate our work at special conferences on power electronics and materials (such as via the IEEE, as well as dedicated oil and gas conferences like the Offshore Technology Conference (OTC).

Reaching new heights at new depths

SINTEF, the largest independent research organisation in Scandinavia, has been researching how complex electrical power systems can be adapted to high-pressure environments, allowing energy production to reach new extremes

AS THE NEED to further explore the deepest sea oilfields and create new sources of offshore energy such as wind farms increases, so does the need for electric components that can withstand the extremities of the environment. While the basics of components in power electronics are the same, where the extreme environment of the deep is concerned, there are some crucial differences, as Magnar Hernes, a project leader at SINTEF, outlines: "The basic differences are related to the insulation medium (air needs to be replaced by incompressible isolation material, like liquid, gel or solids), new packaging of components (due to new insulation material), cooling methodologies and mechanical design".

With that in mind, the team at SINTEF has been studying current local supply systems for critical subsea equipment such as gas boosters, oil pumps, separators and other equipment, but also looking to a future of remote supply systems where high-voltage direct current (DC) might be required. This work is complex even on land, and the challenges only increase when working at depths of over 3,000 m. SINTEF is leading the way in developing better solutions for subsea power electronics: circuits which can take the pressure and which keep costs at a reasonable level without sacrificing performance or dependability.

A PRIORITY AREA

At present, such electronics are not pressure tolerant, meaning the vessels that house them require thick steel walls to counter the large pressure exertions from outside (eg. 300 bar/3,000 m depth). A key sub-goal in the project has been to elucidate the operability of pressure-tolerant power components and power circuits in alliance with manufacturers. The target is the development of circuits which operate up to a pressure of 500 bar without such construction. So far, Hernes believes they have demonstrated that even critical components like power semiconductors and capacitors can operate at high voltage while under high hyperbaric pressure, but only when made with proper pressure-balanced encapsulations.

With oil exploitation an increasingly controversial activity due to sustainability issues, it is important that SINTEF and the Research Council of Norway have a strong regard for ethical and environmental issues. All new R&D projects are checked to ensure that they are in line with SINTEF ethical standards as part of the application process. Indeed, Hernes believes the Pressure Tolerant Power Electronics for Subsea Oil and Gas Exploitation project meets the ethical standards and goes a step further: "Subsea oil gas processing is not only within ethical limits but is a prioritised R&D area for both the Research Council of Norway and SINTEF Energy Research. The subsea electric power R&D projects is also assumed to have relevance for the offshore renewable energy business, e.g. enabling subsea substations for offshore wind power plants".

THE BEST PICTURE

Up to this point, a limited number of studies had been carried out regarding Pressure Tolerant Power Electronics (PTPE), and many are now technologically outdated. Advances in encapsulation and material development have led to a fresh look at PTPE and Hernes believes his group's work is offering a more comprehensive view of longer-lasting tools: "The research carried out in the present research project represents the best picture of the PTPE frontier of knowledge and technology when it comes to open access information".

Amongst the most important achievements so far has been the demonstration of pressure-independent performance in conducting, blocking and switching semiconductor chips and their terminations in the range of one to 300 bar. Furthermore, the project has substantiated that metallised film capacitors for converter DC-links can be adapted for pressurised operation and have unaffected electrical performance in the pressure range of one to 300 bar.

Other technical advances include demonstrating that insulated-gate bipolar transistors (IGBT) gate drivers, including auxiliary power supplies, can be designed for reliable operation under pressurised conditions of up to 300 bar. Regarding some of the most vulnerable components in terms of pressure-tolerance, Hernes summarises their main conclusion: "Close to 100 per cent filling of voids in these 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 followed".

CLOSE COOPERATION

SINTEF Energy Research has covered most of the competencies required for PTPE research – the work sits parallel to other research activities – particularly with regard to power electronics

INTELLIGENCE

PRESSURE TOLERANT POWER ELECTRONICS FOR SUBSEA OIL AND GAS

OBJECTIVES

To take a further step towards the realisation of pressure tolerant power electronics (PTPE) for real applications. This will involve addressing some important remaining challenges related to materials for electric insulation, and how to apply the materials for appropriate packaging of the most vulnerable components.

PARTNERS

SINTEF Energy Research

Norwegian University of Science and Technology (NTNU)

INDUSTRY PARTNERS

Statoil
Total E&P Norge
ABB
GE Oil & Gas
FMC Technologies
Siemens
Framo Engineering
Aker Solutions
M&I Materials

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The Research Council of Norway

All industry partners

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MAGNAR HERNES graduated as an electrical engineer at the Norwegian University of Science and Technology in 1977 and is currently a senior research scientist at SINTEF Energy Research. He has broad experience in the development of power electronics for the industry, including UPS, motor drives and for subsea applications, as well as analysis of complex power systems containing power electronics, such as oil and gas process plants.

and material expertise. It has been crucial for the project members to work alongside other organisations: "Particularly worthy of mention is a research project on energy-efficient and reliable power electronics for offshore wind power. In this project, we have a close cooperation with Chemnitz University of Technology on lifetime testing of power semiconductors," Hernes notes.

> SINTEF are leading the way in developing better solutions for subsea power electronics

The study has had a strong set of collaborators and has attracted more interest in the field of PTPEs, with several oil companies considering applied projects. Not only that, there is an increasing interest among component manufacturers, and several converter manufacturers have announced they will develop a PTPE product. Among the key supporters of this work are the Research Council of Norway's PETROMAKS Program, as well as industry partners Petrobras, Statoil, Total, Siemens, Aker Solutions, EXPRO, Wärtsilä and the Norwegian University of Science and Technology. SINTEF has worked closely with component manufacturers such as IXYS, Tyco, Westcode, ICW and EPCOS who have contributed significantly by providing test samples and expertise.

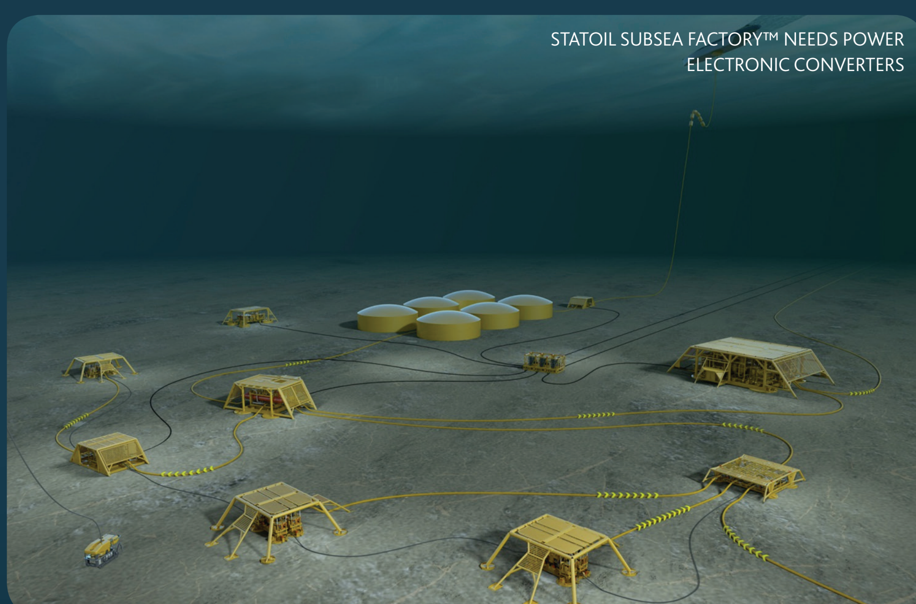
ADDRESSING NEW CHALLENGES

While the group has had many successes in developing PTPEs that could shape the energy sector in the future, Hernes acknowledges there is still work to be done: "To achieve PTPE products with sufficiently long-term reliability, some fundamental problems need to be solved. These uncertainties are mainly related to materials for electric insulation and how to apply the materials for appropriate packaging of the most vulnerable components". As with every project, success is coupled with learning experiences; two incidents during long-term testing of planar IGBT modules have highlighted the vital importance of cleanness when power semiconductor chips are in direct contact with the insulation liquid. During the next phase of the project, some responsive reorganisation and a reduction in activity will take place.

With these revisions in place, the group hopes to address some challenges during the next phase of the project, including the criticality in long-term operation of semiconductor chips towards impurities and contamination in insulation materials such as liquids. There is also a need for application-specific PTPE tests on liquid insulation performance, as well as material incompatibility and cooling deficiency issues. The sealing and filling of voids needs to be enhanced, depending on encapsulation technology, and the risk for deteriorating performance of communication links (optical fibres and optocouplers) must also be addressed. Finally, there is the need for special insulation for high-voltage converters (6.6 kV+) and diagnostic monitoring in order to verify the insulation integrity of components and converters.

MORE SPONSORS

Looking towards the next phase of the project, Hernes is optimistic regarding collaboration across the oil sector: "The first project had seven sponsors, while the new one has 10. Results are continuously communicated to an electronic project room where partners can express their opinion about the results and suggest preferences for research topics. The response from the first project was excellent, and is the main reason for pursuing the new one".



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