

# Impact of Subsea Processing Power Distribution: Subsea Switchgear Module A Key Enabling Component in Subsea Installations

Terence Hazel - Senior Member IEEE

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# Abstract

Subsea high and low voltage switchgear is a key enabling component for subsea process units. Locating the switchgear module at the heart of the subsea load center avoids having to provide any top-side facilities, greatly reduces the operation expenditures and reduces the cost of the power lines. The subsea environment has a very strong influence on the design, fabrication, assembly and testing of the module, both the enclosure itself and the switchgear equipment inside of the enclosure.

After the introduction and some general information regarding the subsea switchgear module, the feasibility study and various conceptual design calculations performed during the development of the switchgear portion will be described. Since this is the first time that such a large electrical distribution system has been installed in a subsea environment, the main purpose of these studies was to ensure a very high availability of the switchgear to provide power to the process loads. Reliability studies combined with mechanical and thermal analyses were performed to ensure correct installation and operation in a subsea environment at about 1000 m below sea level. Electromagnetic compatibility studies were also performed to avoid any nuisance operations of the switchgear and controlgear which could result in loss of production.

After the information about the switchgear portion, the design, fabrication and testing of the enclosure itself will be described. There are two main criteria for the enclosure. The first is the high pressure due to installation on the seabed. The second is the requirement for the installation of the switchgear within the enclosure prior to its submersion, and also access to the switchgear during maintenance operations at the surface. This criterion requires removable enclosure parts that must have adequate sealing to prevent any leakage when submerged. Also very important are the constraints due to the handling of the complete module when installing it and also when it requires servicing.

Finally the integration of the switchgear portion within the enclosure will be described.



# Feasibility Study and Conceptual Design Phase

The purpose of this phase of the project is similar to a Front End Engineering Design (FEED). Due to the severe constraints and also the fact that this is the first project where a subsea electrical distribution system will be used, it was necessary

## Reliability Study

One of the most challenging tasks in any reliability study is first determining exactly what is meant by acceptable operation. After this basic design requirement has been defined and accepted by all parties, the reliability study can begin. For this project, the acceptable operation was supplying power at 22 kV, including the premagnetization, to at least one of the VFD process units and supplying LV power to at least one of the UPS modules. The power must be supplied for a minimum of 5 years without any intervention. The depth of installation precludes any intervention of any form. Failure to supply power to the VFD or UPS will result in a production shutdown and the lifting of the subsea electrical distribution module for repair. The loss in revenue as well as the expenses related to the repair of the electrical equipment make this 5-year period an absolute minimum design requirement.

In addition to the classical requirements for reliability calculations, there were several other constraints that had to be respected. One of the highest level priority constraints was avoiding the increase in the size of the switchgear equipment that could lead to an increase in the diameter of the enclosure or its overall height. An increase in the enclosure diameter will result in a large increase in the total weight which would require redesigning much of the subsea structure. The other high level priority constraint was elimination of risks of malfunctions. Controls must be executed correctly without any nuisance tripping or undesired operation of any switching devices. This requires the integration of concepts of electromagnetic compatibility (EMC) right from the start and has important consequences on the layout of equipment and cabling. There were also some lower priority criteria such as ease of access

to define all electrical equipment and systems prior to actual material ordering and manufacturing of the switchgear portion. The main design activities of this phase for this equipment are described below.

for maintenance, and limiting the length of the module.

One of the best ways of enhancing reliability is the use of standard equipment that has been in service for many years. Not only has this equipment proven itself over the years, but the reliability data  $\lambda$  associated with it is well known. All electrical equipment used in this project is standard, off-the-shelf. The only adaptations made were to accessories such as fixing plates. After a careful selection of the equipment required to meet the electrical system design, the electrical distribution system as a whole was examined from a reliability standpoint. Standard techniques such as Markov graphs were used and comparative analyses of different possible solutions were carried out. One of the main results of the study was the redundancy of each device in the distribution system except for the incoming circuit since only 1 incoming cable is foreseen.

Due to the constraints mentioned above concerning enclosure diameter, it was necessary to include the physical aspects of the design in the reliability study, not just the electrical aspects. The physical location of the penetrators for 22 kV subsea cable connection were modeled in order to be sure that any possible insulation failures due to their location would be taken into account. The results of EMC considerations were also incorporated in the physical layout to determine if there were any detrimental consequences to the overall reliability of the system.

## Project Execution

that an electrical distribution system has been located at the heart of the process facility on the sea bed. The switchgear portion of the project was therefore split into two phases. The first phase consisted of a feasibility study and conceptual design for the subsea switchgear. After finalization of this phase, the contract to actually construct and test the subsea electrical distribution system equipment was placed and executed.

## Equipment Sizing Report

One of the main design principles used throughout the whole project was leave nothing to chance. The Equipment Sizing Report was one of the first documents prepared and consists of a list of all the design data for all devices used in the project. Electrical, mechanical and reliability data for each device is compiled in this document. In addition it was often necessary to select a particular device or material. The reasons why the device or material was selected is documented and included as an annex to the Equipment Sizing Report. One example is the selection of low-voltage fuses rather

than miniature circuit-breakers. The reason a fuse was selected is that the miniature circuit-breaker can accidentally open if subjected to a mechanical shock fixed mounted fuses do not have this failure mode. Another engineering note produced was the HV busbar calculation. The conductor cross-section was determined based on the rated design current, and also on the mechanical stresses that had to be withstood due to the maximum short-circuit current. The busbar support insulators were also defined at this time.

## Electromagnetic Compatibility Considerations

Defining the constraints to be incorporated into the electrical and installation designs due to the integration of electromagnetic compatibility considerations is fundamental to the subsea switchgear module design. It will determine the relative positioning of the equipment operating at different voltage levels, and the requirements for physical separation of HV and LV power cables, control and instrumentation cables. Failure to correctly define and meet these constraints could result in unreliable operation which is not acceptable for this particular application. Another

important aspect of this study was determining the type of materials to be used for the support structure of the switchgear devices. Standard steel was selected rather than stainless steel due to its much better properties for reducing the coupling between the equipment that emits electromagnetic radiation and the victims such as electronic equipment. The proper choice of materials and their correct earthing and bonding are key to a robust design which eliminates nuisance tripping that could result in loss of production in a subsea environment.

## Mechanical Calculations of the Switchgear and Support Structure

The complete subsea switchgear module is assembled on shore and then lowered to its final resting place several hundred meters below sea level. During the handling the electrical equipment and supporting structures will be subject to vibrations, pitch and roll. These requirements were the input to the mechanical design which was executed for the complete electrical distribution system. The maximum roll was given as 30 °, the maximum pitch as 15 °. The complete structure was modeled in Pro Engineer and the 3D model loading into ANSYS for calculations. Finite element modeling was used with a 5 mm mesh size. The finite-element model contained 169,412 nodes and 159,423 elements. All data regarding the

materials used was available in the Equipment Sizing Report. The displacement of the complete electrical substation structure was calculated for all conditions of roll and pitch. The modeling and the results of the displacement calculations are shown in Fig. 3. The maximum displacement was found to be 4,5 mm. The electrical distribution equipment is fixed only to the floor of the enclosure in order to minimize the interface and to avoid the transmission of any dimensional changes in the enclosure to the distribution system. The 4,5 mm displacement under worst conditions was well within the acceptable limits to ensure that the distribution equipment would never be close to coming into contact with the enclosure.

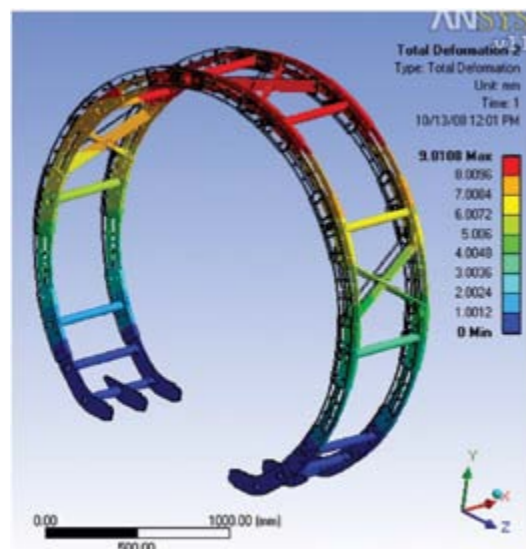


Fig. 3 - Displacement Calculations of 22 kV Busbar Support Structure

It was also necessary to verify that under no conditions would the switchgear devices or materials used be subject to unacceptable stresses. Stress calculations were done under all roll and pitch conditions. The maximum stress was found to be 100 MPa which is well below the yield limit of 355 MPa for the steel that was used.

The displacement and stress at each location of the supporting structures was shown in the models. The even distribution of both showed that there were no potential weak points in the mechanical design of the switchgear support structure.

## Thermal Studies

The subsea electrical distribution system has 4 each 22 kV to low-voltage transformers. These transformers are the main source of heat within the enclosure. The transformers generate heat through the iron losses which are independent of the load through the transformer, and copper losses which increase as the load increases. Some heat is generated in the switching devices and some low-voltage devices but this is minimal. The purpose of the thermal studies was to check that the heat generated by the transformers and other devices would be correctly dissipated through the enclosure wall to the surrounding water. As shown in Fig. 4, the heat is dissipated first by convection within the enclosure, and

then by conduction through the enclosure walls. There are different operating modes and each has an important influence on the losses in the transformers. The several combinations of iron losses and copper losses resulting from these different operating modes were used in the calculations in order to check that there were no operating conditions which could lead to unsatisfactory heat dissipation. The operating mode applied for the calculations shown in Fig. 4 was both trains in operation, and both step-down transformers energized and equally loaded. This is the reason for the very symmetrical flow of nitrogen within the subsea enclosure.

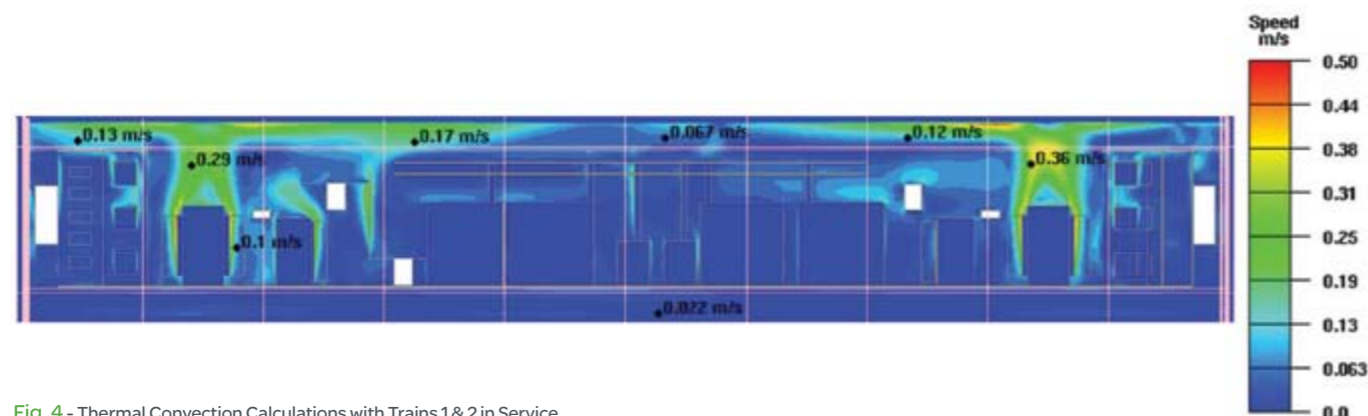


Fig. 4 - Thermal Convection Calculations with Trains 1 & 2 in Service

The initial studies showed that there was a hot spot due to the unsymmetrical heat dissipation of the transformer closest to the low-voltage panels. The design of the radiators of the transformer was modified in order to eliminate this hot spot. The thermal studies also included the internal arrangement of devices within the low-voltage panels. One result of this study was

## Assembly Procedure

The complete electrical distribution system is installed within the cylindrical enclosure having an exterior diameter of 2.8 m. It is necessary that the electrical equipment be easily installed within the enclosure in order to avoid any possible damage during the final assembly phase. The assembly procedure therefore was a very important design criterion which was incorporated right from the start. The result of the assembly design study was the split of the electrical distribution system into 11 separate racks. There are basically 4 types of racks – low-voltage cubicle racks (2 each), transformer racks (4 each), 36 kV circuit-breaker racks (4 each), and voltage transformer rack (1 each). Fig. 5 shows the final assembly of the 11 racks and the individual low-voltage cubicle, transformer, and circuit-breaker racks. The assembly procedure was integrated into the reliability analysis to be sure that there were no

adding a ventilation opening in the top of the low-voltage panels to avoid any accumulation of heat in the upper compartment of the panels. The thermal studies showed correct dissipation of heat by convection within the complete subsea enclosure and the absence of any unacceptable temperatures under all possible operating conditions.

detrimental effects due to this design. Each rack was prewired and equipped with withdrawable wheels. Since access was provided at both ends of the enclosure, it was possible to install the racks in a symmetrical manner starting with the voltage transformer rack located in the middle of the enclosure. After installation & fixing of this rack, the circuit-breaker racks could be rolled in (2 on each side) and fastened. Similarly for the transformer racks and finally the low-voltage cubicle racks.

Access to each rack is possible from either end of the enclosure after all switchgear equipment has been installed. This makes the assembly easier and also greatly facilitates maintenance when the module is lifted from the seabed. This access requirement was also a very important design criterion.

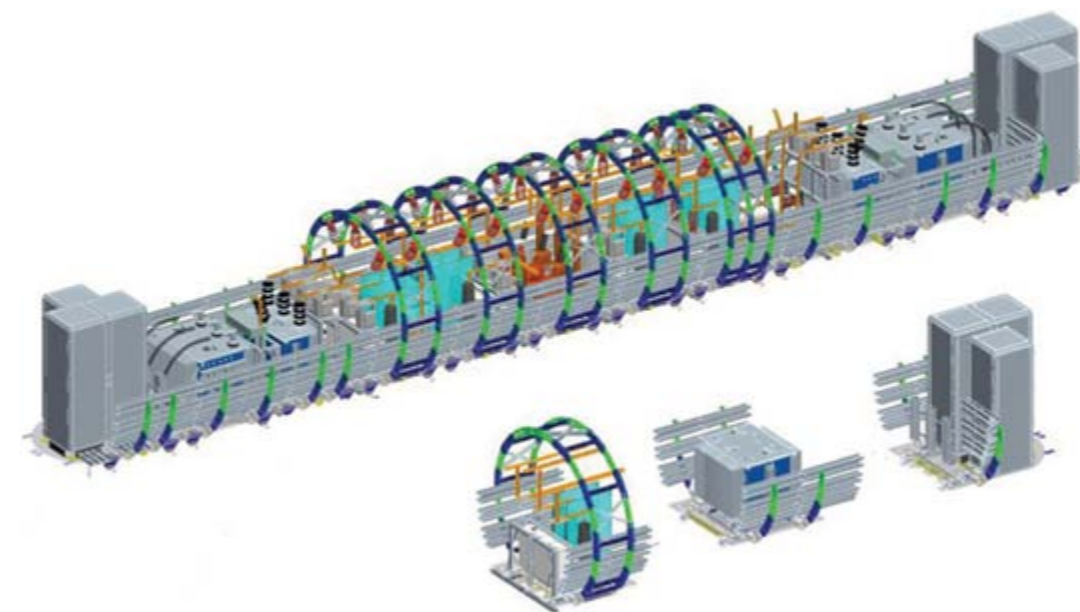


Fig. 5 - Final Assembly of 11 Racks for Complete Subsea Power Distribution System

The use of retractable wheels greatly facilitates the installation and reduces the risk of damage to the racks during installation. No excessive force is needed while introducing the racks into the enclosure. Once the rack is in its final position within the enclosure, the wheels can be retracted and the rack fixed to the bottom of the enclosure.

Complete prewiring was also a result of the assembly procedure study. Extensive use of bayonet-type connectors for low-voltage control and instrument cables reduces the possibility of wiring mistakes during final assembly, and

## Interface Engineering

Every project has interfaces. Some are internal and are handled by the supplier. Others are with third-party suppliers and handled via the purchaser. In all cases, interface engineering is required and the results must be correctly documented in order to understand the reasons behind each decision. Fiber optic cables were used for communication purposes. Their use required interfacing with third-party suppliers to ensure that all connectors were correctly chosen, as well as the interface with the submarine cables. Some of the third-party interfaces for the electrical distribution system were the high-voltage and low-voltage penetrators for connection to

loosening during transportation. The correct earthing of the cable trays is essential for EMC considerations. This was also in integral part of the assembly procedure since there are power and control cable links to each of the 11 racks. One way of ensuring that there would be no conditions of unacceptable stress was to use flexible connections between the racks. Not only did this allow for fabrication and assembly tolerances, but prevented any stress from adjacent equipment to be applied to the rack. The flexible connections also prevent the transmission of vibrations, the main source of which is the transformers.

submarine power cables, and the VFD supplier. The enclosure itself, described in the paper is also from a different supplier than the switchgear portion. One reason for deciding to fix the electrical distribution system support structure only to the bottom of the subsea enclosure was to reduce the interface with the enclosure. The mechanical studies described above justified this decision which was further confirmed when analyzing the assembly procedure. The smallest interface is the easiest to design and often the most reliable. Changes to equipment often will not result in changes to equipment from the other supplier if the interface is designed correctly.

# Detailed Design and Manufacturing of the Switchgear

The feasibility study and conceptual design phase of the switchgear portion ended after a complete project review with the client. The next phase

## Shop Drawings

Although standard electrical components such as HV circuit-breakers and HV instrument transformers were used, the support structures had to be designed for purpose. The calculations performed during the feasibility study had validated the conceptual design and the choice of materials, but now it was necessary to execute the individual shop drawings for fabrication. Shop drawings were made for each item and completely specified

## Assembly Drawings

The assembly process began with the fabrication of the individual racks. Assembly drawings were prepared for each type of rack and included the complete list of parts for each. Assembly instructions and test procedures were also written to ensure correct assembly at each step. This is just part of the "leave nothing to chance" philosophy that had been adopted for the switchgear design right from the start. Parts control was used to ensure that all components were mounted and that nothing extra was used. After the complete support structure of each rack had been fabricated, the electrical components

was the detailed design based on the documents produced during the conceptual design.

the piece to fabricate. Painting specifications had been made during the conceptual design and were applied to all items. Predefined earthing system connection areas where no painting was allowed were included in the specifications. Test specifications were produced together with each shop drawing in order to verify correct fabrication immediately after the piece had been made.

such as HV circuit-breakers, transformers and low-voltage cubicles were installed and tested. The retractable wheels were added to the rack after installation of the components to allow easy handling of the completed racks.

Special attention was paid to the assembly of the transformer racks. The transformers are the heaviest pieces of equipment within the subsea distribution system and it was important that they be securely fastened. The fastenings were designed such as not to loosen due to vibrations.

## Electrical Drawings

A complete set of electrical drawings were produced in a similar manner to the shop drawings and mechanical assembly drawings. All devices to be installed and all connections are shown on the drawings. Test procedures were defined to allow verification during the fabrication. As mentioned in the Reliability Study section above, redundancy was required in order to meet the project requirements. This meant two sets of identical low-voltage distribution cubicles, two sets of protection cubicles, and two sets of control cubicles. Each set could be powered from either of the transformers, and could supply low-voltage AC power to either of the UPS modules. Each set of low-voltage cubicles was installed at either end

## Interconnections

There are many interconnections required among the racks. Some interconnections are HV and LV power cables, while most are control and measurement cables. In accordance with the requirements resulting from the EMC conceptual design, the routing selected for all HV and LV power cables was below the rack steel base, in cable trays fixed to the bottom of the enclosure. This provides the best shielding with respect to the control and measurement cables which were installed along the sides of the busbar support structure. All control and measurement cables were installed in cable trays with covers. As described in the Equipment Sizing Report section above, standard steel was used as this provides the best shielding from power cables and other sources of electromagnetic disturbances. The cables were connected to the rack and rolled up to facilitate reconnection once the racks had

of the enclosure. This provided enhanced reliability but resulted in more interconnection cables. Microprocessor-based protection relays were used for the 22 kV circuits and their sole function was to trip the circuit-breaker should an electrical fault occur. On-off switching of the circuit-breakers was via hard-wired signals connected to PLC outputs. All status contacts were wired to the PLC input cards. Each circuit was protected by two relays. The use of two relays decreases the risk of not tripping should a fault occur, but increases the risk of a nuisance trip. The reliability study showed that the risk of a nuisance trip was much lower than the risk associated with not tripping and thus the use of redundant protection relays was confirmed.

been installed within the cylindrical enclosure. The location of terminals for power cables, and plugs for control and measurement cables was carefully chosen to facilitate erection and testing. Each cable was assigned to a particular tray to ensure that no trays were overloaded, and that the cable would be close to its termination points. The interface to the submarine cables is through third-party penetrators. The mounting angle had to be within specific limits to ensure the correct oil level within the bushing. A specific interface made of flexible braided copper was designed. The interface with the penetrator was provided with an extra set of holes to allow last minute adjustments during final assembly. The braided copper and flanges were subjected to several tests including ageing to ensure that they met all of the requirements.

# Full Assembly and Factory Acceptance Testing

Prior to shipment to the shipyard for assembly within the subsea enclosure, the complete electrical distribution system consisting of 11 racks was assembled and connected together as shown in Fig. 6 for Factory Acceptance Testing. A complete set of tests were carried out with the customer. After the initial visual inspection and mechanical validation testing, electrical tests were carried out. These included primary and secondary

injection, voltage levels, protection relay operation and interface testing with the PLCs. Functional tests were then performed to verify all switching combinations. The resulting punch-list items were quickly eliminated and the racks were then disconnected, packed separately and shipped to the shipyard for assembly within the subsea enclosure.

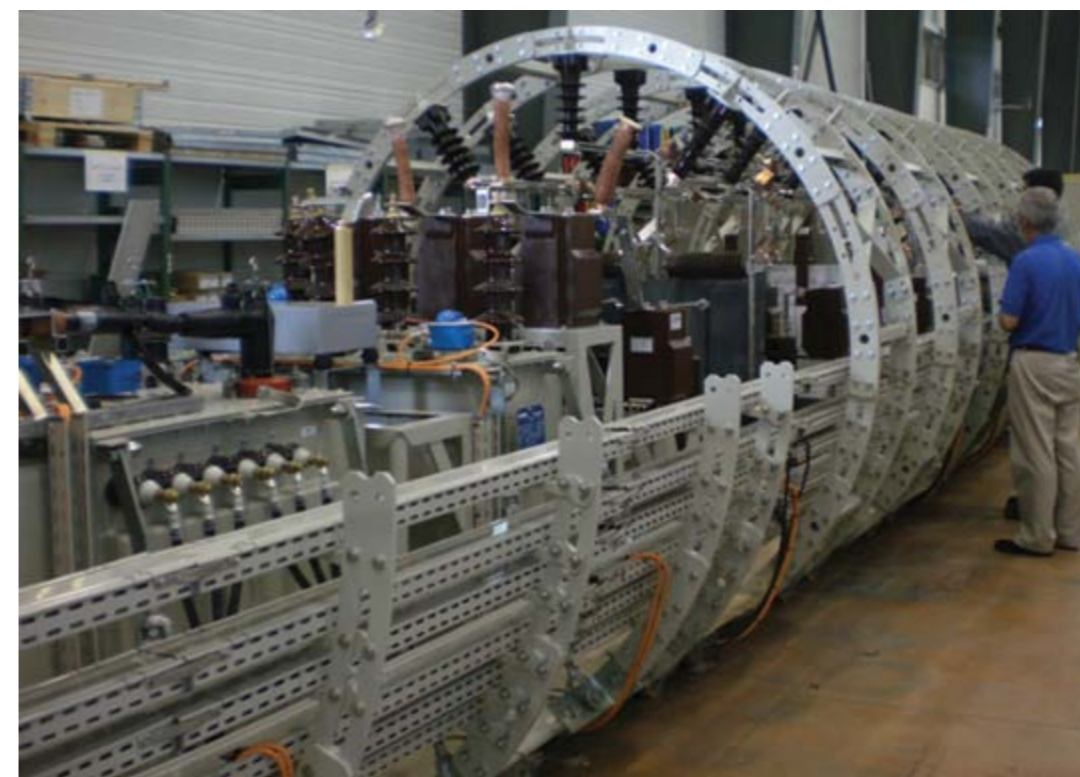


Fig. 6 - Pre-Assembly of Complete Subsea Switchgear System for Factory Acceptance Testing

# Enclosure Design

The subsea switchgear module enclosure is mechanically designed according to EN 13445 code (using Design by Formula method) and DNV-RP-F301 having external pressure as the main load during the operation condition on the seabed.

Interfaces with electrical switchgear rack and module structure were very important. Fabrication tolerances (especially ovalisation) and material/welding inspection were closely monitored considering that there will be no visual inspection during operation condition on the seabed.

## Key design requirements:

- Design life 30 years.
- Design pressure about 100 barg.
- Number of nozzles/penetrations through the enclosure was kept as low as possible in order to minimize the areas for potential leaks.
- Hemi-spherical shaped dished heads were selected in order to give a smooth area between the shell and heads and also to reduce possibility for buckling in any transition areas due the external pressure. Elliptical and torispherical heads are not suitable for deep water enclosures.
- The design for the body flanges needs special considerations due to the external pressure and the fact that they will be periodically opened for inspection and resealed.
- During operation, inspection will be impossible (or at least very limited) in very deep water.
- Minimizing of welding to the enclosure body shell.
- Reduction the number of enclosure flanges, allowing correct accessibility during assembly and inspections. The subsea switchgear module is designed as a single mechanical item, provided with all supporting pieces that will allow integration into the subsea structure through one fixed and one sliding saddle. The design takes into account all handling during manufacturing, testing, installation and maintenance. The position of the saddles was determined based on the subsea installation support modules supplied by the client.

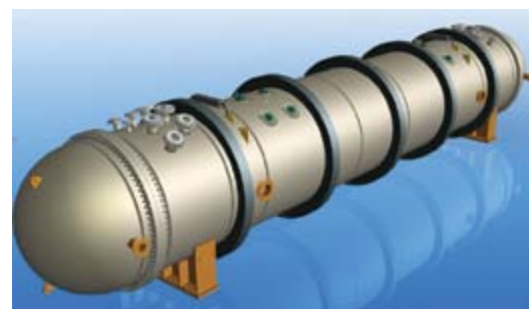


Fig. 7 - Subsea Switchgear Module Enclosure

Taking into account the expected interventions on the subsea switchgear module unit, the number of full external pressure cycles is very low (no fatigue considerations need to be taken into account). Cathodic protection with anodes and coating paint are provided to prevent corrosion of the enclosure. Special attention is given to sealing against water ingress that is accomplished by two metal separate barriers to seawater. Each sealing barrier is testable during assembly process. The selected seal provides an exceptional tightness proved by a helium leak test.

Fig. 7 shows the conceptual design of the enclosure. The flanges and saddles at both ends are visible as well as the penetrations. Stiffening rings are provided to enhance the rigidity of the enclosure and allow the reduction of the wall thickness. Their location was carefully coordinated with the position of the penetrators and weld seams.

## Enclosure Design Criteria

For the design of the CB enclosure (according to EN 13445-3) the following loads/actions has been considered/evaluated:

- Internal and/or external pressure: about 100 bar external pressure, cca 10 bar internal proof-test pressure Weight of the enclosure and all internal switchgear components.
- Maximum weight of content under operating conditions. This includes both internal equipment and simulated water-filled enclosure.
- Weight of water under proof-test pressure test conditions.
- Wind, snow and ice loading. Wind load is applied during transport and storage onshore (worst case scenario for skirt support is when the enclosure is empty).
- Earthquake loading.
- Other loads supported by or reacting on the enclosure, including loads/acceleration during transportation and installation. For example horizontal and vertical acceleration impact, and tilting during accidental offshore recovery, or during installation. Fig. 8 shows an example of some of the calculations that were performed to validate the design.

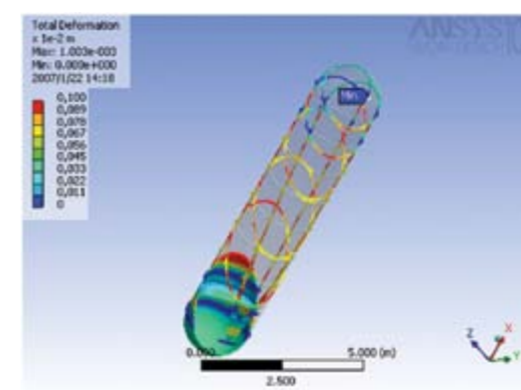


Fig. 8 - Enclosure Stress Calculations

The total deformation of the complete enclosure was determined and is shown in Fig. 9 (no ovalization or local defects are considered). The influence of the strengthening rings on the deformation of the enclosure is clearly visible in Fig. 9. The number, location and type of strengthening rings can be optimized such that the total weight of the enclosure is reduced to a minimum. During subsea installation, the enclosure will be subjected to about 100 bar differential external pressure when lowered from 0 m to about 1000 m water depth. It is important to consider these deformations when engineering the interface to electrical switchgear installed within the enclosure. As described above, the electrical switchgear equipment is fixed only to the bottom of the enclosure thus decoupling the enclosure deformation from the switchgear design.

Roark's formulas for membrane stresses and deformations in thin-walled pressure vessels, were used in order to evaluate the total deformation (no ovalisation or local defects are considered). The total enclosure length deformation including both domes is cca. -10.00 mm.

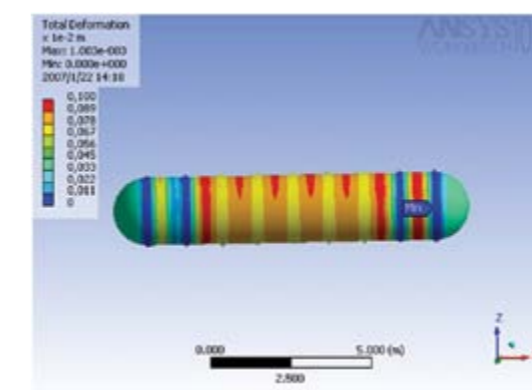


Fig. 9 - Deformation Calculations of Complete Enclosure

## Enclosure Flange Design

Water tightness is a key aspect and it is accomplished by two separate barriers to seawater. Each sealing barrier is testable during assembly. Inconell overlay welding was performed on the body flange faces in order to prevent corrosion at the contact area between the seal and body flange.

Detailed calculation of the body flange has been made according to EN 13445-3 section 11. The maximum utilization factor for the designed body flange occurs when the flange is bolted-up during assembly. A detailed FEM analysis was performed to check maximum stress and deformation along the cross section of the body flange. Furthermore a detailed FEM analysis was also performed to determine the contact area status between the flange faces in bolting-up condition and operation (see Fig. 10).

The flange design and selection of the bolts and tightening method take into consideration the exceptional case of loading which is installation and retrieval with tilting, and considering the internal volume filled with water as well as the switchgear and other electrical equipment. The contact status between the flange faces was studied using Ansys workbench. Special attention was given to the mesh generation and element size.

## Vortex-Induced Vibration (VIV) Considerations

The natural period of the subsea switchgear module during operational scenarios has been determined by using Ansys software. A VIV susceptibility assessment was performed in accordance with DNV Note 30.5. It is assumed that there is no additional axial load applied to the enclosure. The enclosure is a horizontal vessel supported on two saddles. Hence there is no need to perform a VIV susceptibility analysis considering a wind speed of from 20 to 40 m/s during onshore/offshore transport. Conservatively the instantaneous flow velocity

The flange bolts are dimensioned to withstand:

- $T_a$  = seal requirement pretension and spring force back from the seal after assembly.
- $T_v$  = weight of the enclosure/unit considering conservatively the unit filled with water and the switchgear and other electrical equipment. The vertical impact acceleration during offshore recovery and tilting is also considered. The vertical and horizontal acceleration will not act simultaneously, so the calculations performed are very conservative since both are considered to be acting at the same time. In this case the calculation is over conservative as the switchgear subsea module enclosure will only be handled horizontally. This consideration is also covering the tilting of the unit during offshore recovery and installation.
- $T_h$  = horizontal impact acceleration and operational sea bottom current.

Based on the above considerations the required pretension for the body flange bolts is calculated and all flange bolts are prestressed during the installation of the flange. Maximum utilization factor for the designed body flange is occurring in the bolting up condition. As mentioned in EN 13445, sect 5.5.2, the strength of the cladding is not taken into consideration. Conservatively, the flange thickness is reduced to account for cladding.

normal to the enclosure was considered from 0.1m/s to 2.0m/s and there is no induced excitation in-line or cross flow for the enclosure. The reduced velocity  $V_r$  is well out of the range that can induce in-line or cross-flow VIV. With the actual incident current velocity and the corresponding subsea switchgear module dimensions and mass, both in-line VIV lock-on and cross flow-flow VIV excitation can be neglected for enclosure. Therefore it was concluded that there is no need for further fatigue damage analysis during the design life of the subsea switchgear module.

## Summary of mechanical design of the CB enclosure:

The following is a summary of the results of the calculations and engineering performed during the design and fabrication of the enclosure.

- Mechanical detail design performed according to EN 13445 for 30 years design life.
- Minimized weights and dimensions (only 2 saddles, number of stiffening rings, body flange dimensions).
- Custom flange design - (low deformation and small dimensions) using EN 13445 and FEM

Workbench Ansys.

- Designed for assembly and handling.
- Custom design with respect to interfaces with internal and external components and equipment.
- Material selected considering market availability and project schedule.
- Empty enclosure weight: cca 100 T Internal.
- Diameter: 2600 mm.
- Overall Length: cca 17 m.

## Proposed actions to reduce enclosure wall thickness in future deep water

- Introducing a different design approach as recommended in DNV-RP-F301, when external pressure is the governing criteria for required wall thickness. EN 13445 code may be use with a relaxation of the safety factor when determining the wall thickness.
- Using non linear analysis and strain criteria instead of stress criteria.
- "Design by formula" method to be replaced with "Design by analysis" method - benefit is minimum 10 % -15 % reduction of weight. Design by analysis is based on FEM with the powerful ANSYS Workbench - ver.12.
- Introducing of high strength material (special welding procedures, chemical composition) - i.e. Weldom 700.
- Aim for low wall thickness corrosion allowance (benefit 3-5 mm wt reduction) Aim for reduced

ovality during fabrication. Ovality and out of straightness are the main causes for inducing and propagating buckling - also inside EN 13445 with better ovality - no buckling.

- Optimized body flange design for external pressure only - dramatically reduction of flange size and weight.
- Seal selection (no water leakage up to 400-500 bar) this kind of seal is already used for 1000 bar in nuclear application.
- Double barrier seal system selected - no leakage - the actual flange is suitable for 3000 m with minor changes.
- Re-use of the body seals - from proof test to operation, and after recovery - important cost reduction.
- Using of the stiffeners ring inside the enclosure.

## Assembly of Switchgear within Enclosure

The 11 prewired switchgear racks and the enclosure were shipped to the assembly area. After a series of preliminary inspections and tests, the insertion of the racks within the enclosure could begin. As designed, the racks are rolled into the enclosure; the wheels are retracted and the rack is securely fastened to the mounting rails which form part of the enclosure.

Fig 10 shows a transformer rack installed within the enclosure. The connections to the penetrators leading to one of the VFDs are on this rack.

The hole for one of the penetrators can be seen above the transformer rack.

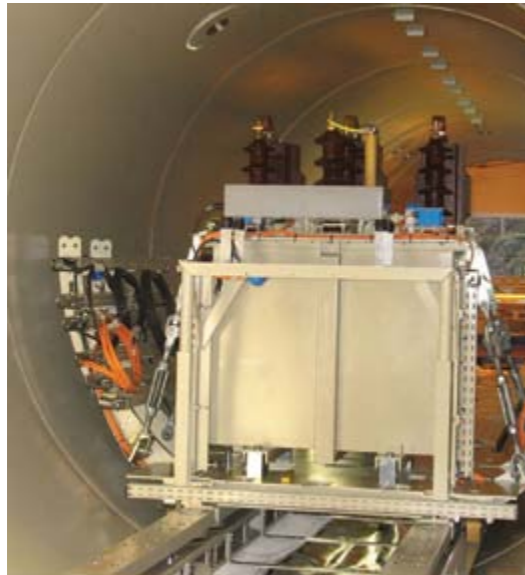


Fig. 10 - Transformer Rack inside Enclosure

After the installation of each rack, the cabling for that rack is installed. The HV cables are kept as far as possible from all other cables as can be seen in Fig. 11. The cable trays for the HV cables are fastened to the support structure of the enclosure and the HV cables installed. As previously described, the correct separation of HV cables from all other cables as well as good bonding and earthing are the keys to electromagnetic compatibility. These criteria have an important influence on the design of the subsea switchgear module as a whole.



Fig. 11 - HV Cable Installation

## Conclusions

Rethinking the traditional design process is required for the design, manufacturing and assembly of a subsea electrical distribution system.

The most significant design criteria are the impossibility of human access for maintenance or operation at the equipment, and the requirement of the provision of power to the process loads for a minimum duration of 5 years before accessing the equipment. Keeping in mind the general philosophy of "leave nothing to chance", extensive calculations were made to validate the conceptual design of this first subsea distribution system prior to beginning with any fabrication. Since there are many actors involved in this innovative project, interface coordination was of paramount importance. The paper has described the main design and manufacturing efforts that were used to define this subsea switchgear module. The real validation will begin in 2011 with final installation of the complete subsea process unit including the subsea switchgear module under the surface.

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**Schneider Electric Canada Inc.**

Head Office  
5985 McLaughlin Road  
Mississauga, Ontario  
L5R 1B8  
Tel: 1-800-565-6699  
[www.schneider-electric.com.ca](http://www.schneider-electric.com.ca)

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