A comparison of AC and DC power feeding systems based on the NEMO experiences

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Abstract

The NEMO Collaboration is involved in an intense activity to develop, apply and test technical solutions for an underwater laboratory with two prototypes called NEMO Phase 1 and NEMO Phase 2. In this framework both options of AC and DC power feeding systems have been explored. The design, realization, test and operation of NEMO Phase 1 AC electrical power and control system was carried out and concluded. The operational experience with this system will be reported. Presently the design and realization of the DC power system of NEMO Phase 2 is under way. Both these systems are described and compared, with a special focus on the results of NEMO Phase 1, on the tower power subsystem, and on the long term high pressure tests that have been carried out on the electric and electronics devices.

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1. Introduction

In the last years the NEMO collaboration has studied some technological solutions for the realization and installation of an underwater km^3 scale neutrino detector [1]. In this framework both options of AC and DC power feeding systems have been explored and tested in the two deep sea sites in which the collaboration is testing prototypes. The NEMO Phase 1 apparatus located 20 km East of Catania at 2000 m depth, and connected with 28 km long electro-optical cable (EOC) to the shore station uses a three-phase AC system. The NEMO Phase 2 is presently under construction on the site of Capo Passero in South-East Sicily. There a 100 km long electro-optical cable, already deployed, connects the 3500 m deep sea site to the shore station. A DC power system is under development.

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2. The NEMO Phase 1 AC power system

The main NEMO Phase 1 components are:

- a *Shore Station* in which the power feeding station, the on shore power control system, the data transmission, acquisition and storage systems are installed;
- the *main electro-optical cable*, 28 km long, that brings power and communication to the underwater laboratory;
- the underwater installation comprising a *Junction Box* (JB) that contains the electric and electronics devices for communication and power distribution, and a prototype tower with four floors where scientific instruments are mounted.

2.1. The NEMO Phase 1 power system

The electrical power system [2] consists of a three-phase feeding and distribution system able to supply all the electrical loads located in the Junction Box and in the minitower floors.

The NEMO Phase 1 total amount of power consumption on-shore, including the power losses, is less than 800 VA.

In Figure 1 a simplified diagram of the system is shown. The line-to-line nominal voltage levels in each node and the power delivered to each floor are indicated.

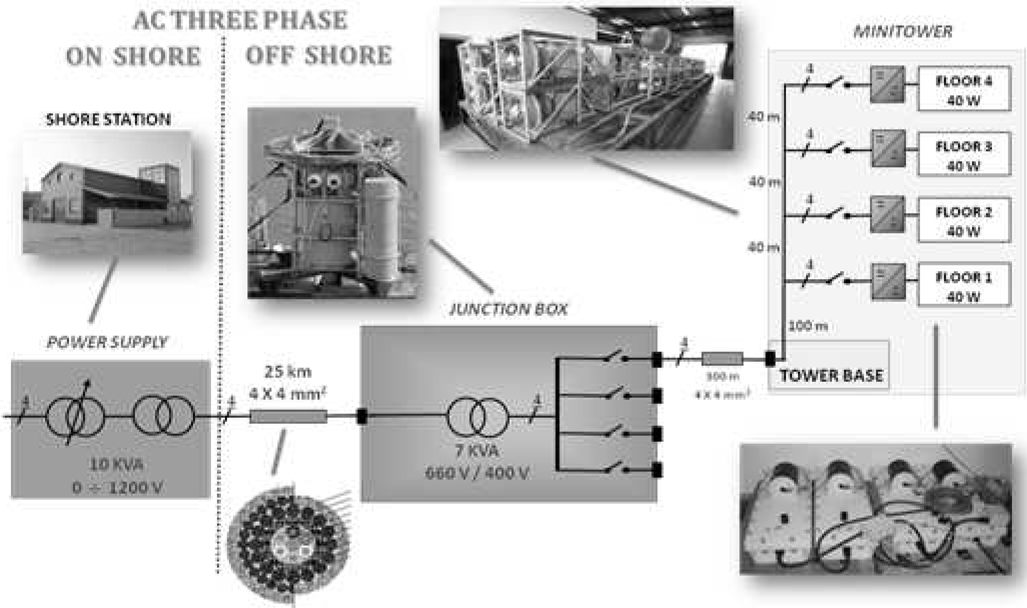

Figure 1. Scheme of the NEMO Phase 1 Power Distribution System.

The *on-shore power supply* is composed of a variable transformer and a three-phase step-up transformer. It allows to regulate the voltage during the start-up and shut-down phases of the system.

The *main electro-optical cable* includes four conductors with a copper section of 4 mm^2 and a maximum allowable voltage of 1200 V.

The *JB* is equipped with a three-phase step-down transformer of 7 kVA, characterized by an input voltage of 660 V (line-to-line) and an output one of 400 V (line-to-line). The JB has one input line and four output lines. At the input line are connected two redundant linear power supplies to feed the local power control system, suitably protected against short circuit. All the lines are equipped with voltage and current transducers and each output line is equipped with a breaker that can be switched on and off from the on-shore control panel. One of the output lines has been used to feed the tower, the remaining three are available for other users.

In each tower *floor* a floor power module hosts two AC/DC linear converters, one to feed the floor control system and the other one to supply the floor loads. The latter is characterized by the presence of a six-pulse rectifier. Its input voltage is 400 V AC (line-to-line) and the output voltages are: 12 V,3.5V, 5.5V DC. In the floor module a solid state relay piloted by the floor control system and current and voltage transducers are also present.

2.2. The NEMO Phase 1 power control system

The NEMO Phase-1 power control system is able to:

- acquire environmental parameters such as temperature, humidity and pressure inside the containers;
- acquire electric parameters such as currents and voltages of all the feeding lines;
- switch the power on and off to each feeding line;
- detect an electric fault and remotely control the breakers in order to isolate the portion interested by the fault;
- set the breaker thresholds remotely;
- monitor and store all the parameters acquired during the start up, shut-down, fault and normal operation of the system;
- give an on-line readout of the line voltages and current values during the on-shore voltage regulation.

A controller is present in each container. Communication between the field control system and the shore is provided through optical fibers while communication among the field control levels uses a conveyed wave system transmitted over the electrical wires. This choice allows a complete independence of the power control system from the data transmission system and from the optical fibers. A schematic diagram is shown in Figure 2.

All the components of the power control system, power supplies included, are redundant.

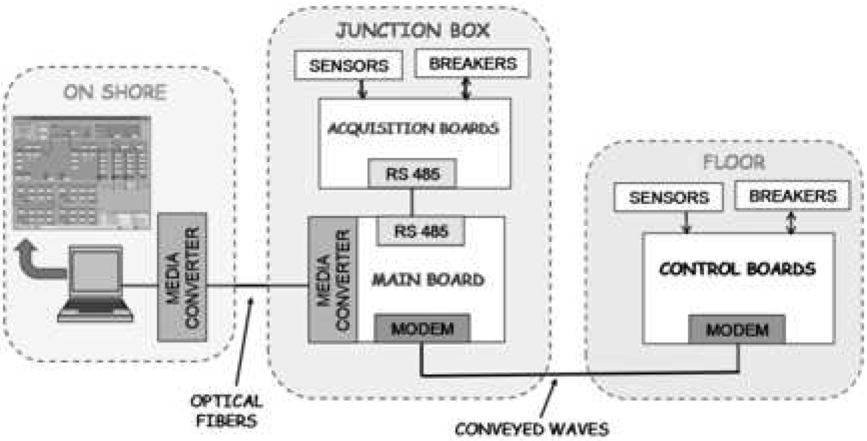

Figure 2. Scheme of the NEMO Phase 1 Power Control System.

3. The NEMO Phase 2 DC power system.

The NEMO Phase 2 components are conceptually similar to those of the Phase 1 and include, as shown in Figure 3: a *Shore Station* ; a 100 km long *main electro-optical cable* (EOC); an underwater installation comprising a Medium Voltage Converter (MVC) and a *tower*, with a sequence of sixteen floors where scientific instruments are mounted.

In this case, due to the larger distance from the shore a DC solution was preferred, since this optimizes the power feeding and minimizes the cost of the EOC.

The NEMO Phase 2 electrical power system consists of a DC feeding and distribution system.

The *on-shore power supply* is a 50 kW AC/DC converter with an output voltage of 10 KV. It allows to regulate the voltage during the start-up and shut-down phases of the system and is equipped with dummy loads for operational testing.

The *main electro-optical cable* is a standard Alcatel telecommunication cable with one central conductor with a copper resistance of 1,5 Ω/km and 20 optical fibers. It is characterized by a nominal voltage of 10 kV. Two sea electrodes, located on-shore and off-shore allow the sea current return.

The *MVC* is a 10 kW Alcatel DC/DC converter with a 0,9 estimated efficiency at full load. It is characterized by an input voltage of 10 kV and an output voltage of 400 V [3]. Three outputs are available, one to feed the tower and two for other users.

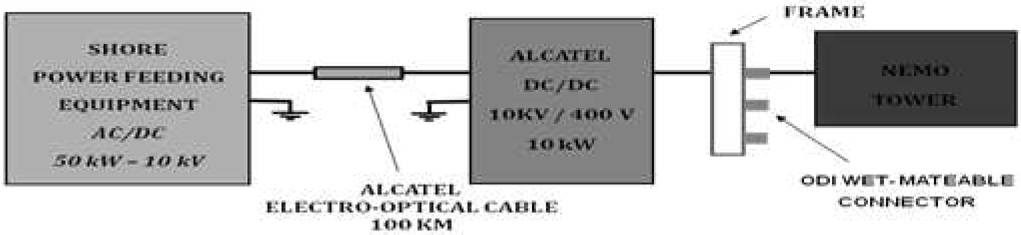

Figure 3. Scheme of the NEMO Phase 2 DC Power Transmission System.

3.1. Tower power and control system

The NEMO Phase 2 tower power and control system has been designed following the criteria and experience acquired from the Phase 1 project with the changes due to the choice of using DC instead of AC, and some improvements to reduce power consumption and containers dimensions. Some improvements of the control system have also been implemented.

The total power consumption estimated for a tower is 600 W. The tower power and control systems are located in power modules, one on each floor and one on the tower base, as shown in Figure 4. In each power module a power supply board called PMS (Power Module System) and two (for redundancy) power control boards called PCS (Power Control System) are present [5].

Each *PMS* board hosts a Vicor DC/DC converter to feed both the power control system and the local loads. It is characterized by an input voltage of 400V, an output voltage of 5,5 V, a power of 50 W and a full load efficiency equal to 0,81. In this board is also installed a breaker (B0,B1….B16) to switch on and off the low voltages (5,5V, 12V, 4,2V) required by the base and floor loads. Moreover the PSM is equipped with a soft start system, an input and an output filter, an opto-isolated high voltage sensor, low voltage and current sensors.

The tower base PSM contains a second breaker (BT) which allows the switching on and off of the full tower backbone, and consequently, of the sixteen floors.

The *tower backbone* is a Nexans electro-optical cable with five twisted pairs with a copper section of 0,35mm^2. Two are used to feed the floors, two are used for communication by the power control system (for redundancy), one is used by the time calibration system. Fiber optics are used for the data transmission system [4].

To optimize the voltage drop along the tower backbone one twisted pair is used to feed the odd floors and one is used for the even floors.

Each *PCS* board hosts all the components of the power control system. The power control system, as in the Phase 1 is able to: monitor voltages, currents, temperatures and pressure; switch on and off the breakers located in the module; set the breakers threshold from the on-shore control panel. The communication between the field control system and the shore is provided by optical fibers while communication among the field control levels uses twisted pairs. This improves the data transmission rate with respect to the conveyed wave system used in Phase 1 Another improvement consists of the introduction of sensors to monitor the tower kinematic and mechanical behavior both during the unfurling operation and in steady state. For this purpose tri-axial magnetometers and accelerometers are present to give the exact position of the floor [5].

As in Phase 1 all the components of the power control system are multiply-redundant.

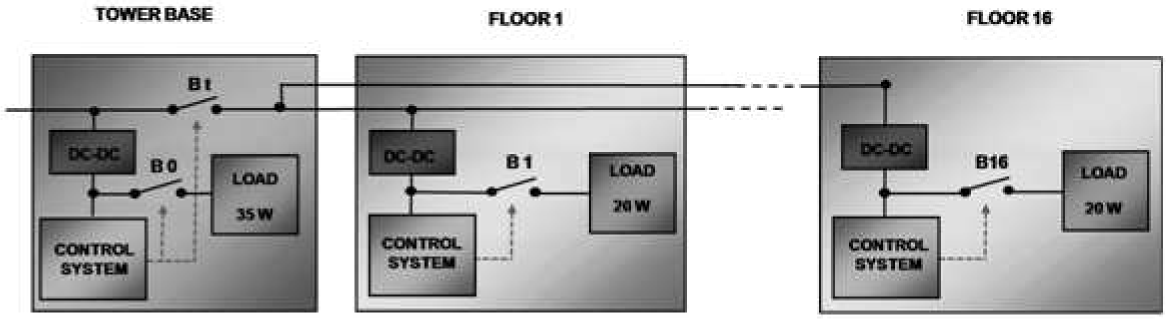

Figure 4. Scheme of the NEMO Phase-2 Tower Power and Control System.

4. High pressure tests on electric and electronics devices

The placement of as many devices as possible under pressure in an oil environment has a significant impact on the container design. This solution will improve reliability - due to the reduced number of sealed connections that represent possible failure points - and on cost, due to the reduced dimensions and the use of low cost materials, rather than expensive titanium alloys. Our goal has been to test and characterize, for over three years, the maximum number of electric and electronic devices under pressure in an oil environment [2] As a result all the components of the NEMO Phase 1 power and control system worked under pressure. Now we are working to have the same results for the Phase 2.

Conclusions

The power feeding and power control system of NEMO Phase 1 and of NEMO Phase 2 are presented. The construction of a three-phase AC and sea-return DC underwater feeding systems will allow for an in-field comparison of the two options. NEMO Phase 1 was realized and operated after the deployment in December 2006 [1]. NEMO Phase 2 is presently under realization. The main electro-optical cable have been deployed, the on-shore power supply has been installed and tested. Concerning the tower the goals of reducing the power consumption, of improving the control system and of reaching a space saving have been successfully achieved. Presently all the components of the power feeding and control system are ready for the final test in preparation for the integration.

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