KM3NeT deep-sea cabled network: the star-like layout

Rosanna Cocimano, on behalf of KM3Net Consortium[a]

[a] Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud, Via S. Sofia 62, 95123 Catania, Italy

Abstract

KM3NeT is a future deep-sea research infrastructure hosting a neutrino telescope with a volume of more than one cubic kilometer to be constructed in the Mediterranean Sea. In the context of the Preparatory Phase of KM3NeT, funded by the EU FP7 framework, the engineering design of the deep-sea telescope has been carried out and optimized to prepare rapid and efficient construction. This paper presents the technical solutions that have been developed for the construction of the deep sea floor network. Special focus will be on the star-like subsea network with emphasis on the electrical power system, the deep-sea electro-optical cables, the connection systems and the junction boxes.

Keywords: Underwater DC power system, Medium Voltage Converter

1. Introduction

KM3NeT is a future deep-sea multidisciplinary observatory in the Mediterranean Sea that will provide innovative science opportunities spanning Astroparticle Physics and Earth and Sea Science. This is possible through the synergy created by the use of a common infrastructure allowing for long term continuous operation of a neutrino telescope and marine instrumentation [1] [2].

The design has been built on the extensive experience gained in the Mediterranean pilot projects ANTARES, NEMO and NESTOR, as well as on deep-sea know-how from other fields of science and industry.

The construction of a deep-sea telescope is technically highly challenging: the components must withstand the enormous pressure and chemically aggressive sea water whilst being reliable enough to minimize complex maintenance operations. The deployment operations must be safe, robust and precise, since all these impose severe constraints on the telescope design. The design for a km^3 electrical power system conforms to all the above-mentioned requirements [3]. An outline of the star-like layout electrical power distribution for a building block (1/3 of full detector) is described in this paper. It is the result of evaluation based both on physics objectives, technical issues and costs.

2. System description and design requirements

The detector will require the installation of thousands of photon detectors with their related electronics and calibration systems several kilometers below sea level. The light sensors are photomultiplier tubes contained in instrumented spheres called optical modules, distributed in clusters (storeys) along a vertical structure called a detection unit (DU). The horizontal distance between detection units is 180 m and vertical distance between storeys is 40 m, leading to an instrumented volume of one cubic kilometer for every 50 detection units.

The full detector will host 320 DUs. Detectors of such a size will require a certain amount of modularization, consequently the full detector has been divided in 3 building blocks.

For the design of the electrical power system of a building block (Figure 1) the following requirements have been taken into account:

- 104 DU;
- DUs to be distributed on the sea-floor in a matrix layout covering an area of ~ 2.6 km^2 ;
- incorporation of one associated science node (EMSO - European Multidisciplinary Sea floor Observatory), the node to be located 1-2 kilometers away from the DU matrix;
- submarine infrastructure distance from the shore: 100 km (max);
- submarine infrastructure depth: 2500 - 4000 m;
- power consumption per DU ~ 350 W;
- power consumption per associated science node ~10 kW;
- total offshore power requirements ~ 45 kW.

The star-like layout is schematically shown in Figure 1. The power required by the detector is fed from shore by an AC/DC Converter (400V AC 3 phase / 10 kV DC), the Power Feeding Equipment (PFE). Power and communication pass via a Main Electro Optical Cable (MEOC) to the submarine apparatus. At the end of the MEOC is located a Primary Junction Box (PJB). From there power is distributed via a seafloor cable network that branches via Secondary Junction Boxes (SJB) to the DUs.

The PJB steps down the voltage from 10 kV DC to 400 V DC and distributes power and communication to the SJB. The

Horizontal Electro-optical Cables (HEOC) connect the PJB to the SJBs.

Each SJB distributes power and communication to 8 DUs. Interlink (IL) Cables electro-optically connect the SJBs to the DUs.

Inside the DU the power is further distributed to the optical modules (DOM) via two vertical backbone cables: the Vertical Electro Optical Cable (VEOC).

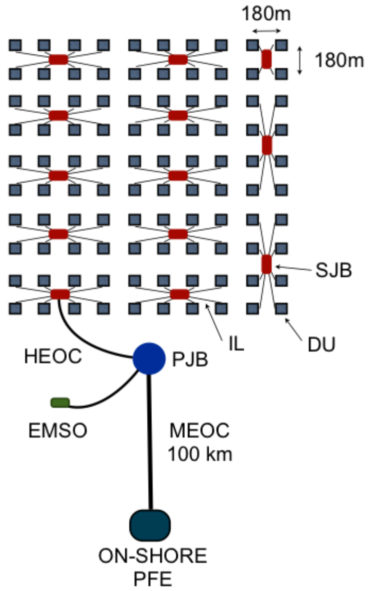

Figure 1: Layout of a Building Block

3. Primary Junction Box

The PJB is located at the end of the MEOC. It is a key element of the detector. Its main function is to step down the transmission voltage and to distribute power to the SJBs via the HEOC. A block diagram of the PJB is shown in Figure 2. The PJB is composed of:

- the MEOC termination called the Cable Termination Assembly (CTA) that splits the electrical conductors and the optical fiber paths;
- the Medium Voltage Converter (MVC) system, that steps down the voltage from 10 kV DC to 400 V DC;
- the Optical System Box and the Power System Box that manage respectively the optical communication from/to shore and the power distribution to the SJBs;
- the input and output electro-optical connectors operable by Remote Operated Vehicle (ROV), including spares.

Underwater connection technologies, available to the telecommunications, oil and gas industries - including the deep-sea wet-mateable optical, electric and hybrid electro-optic connectors, marketed by SeaCon Inc. and ODI Inc. - will fulfill the project requirements. We will of course take advantage of any promising new development in this domain.

The MVC transforms 10 kV DC input to an output of 400 V DC. An example of such a converter is the 10 kV to 375 V DC, 10 kW medium-voltage converter built by Alcatel for the NEMO project [4] and the NEPTUNE project. These converters are both operational. The power converter is housed in a pressure vessel filled with a dielectric fluid for cooling and insulation. The main characteristics of this medium-voltage converter are: 5.7 ÷10 kV input voltage, 375 V output voltage, and 85.4 % power conversion efficiency at 10 kV and full load. A market survey is under way to find a supplier for a future 60 kW unit. Contacts with companies including PBF, Ocean-Works, Bruker have been established.

The Power System Box, as shown in Figure 3, hosts the power distribution system, the power monitoring and control system.

The distribution system foresees an input line coming from the MVC and 13 output lines for the SJBs plus spares. All the output lines are equipped with remote operated relays.

The monitoring and control system allows a bi-directional communication of control and data between the shore station and the submarine apparatus. The system communicates with:

- the shore station via an optical fiber connection;
- the SJBs via an optical fiber connection and, for redundancy, a conveyed wave system with a modulation over the power lines;

This system will monitor all the parameters important for the correct functionality of the submarine apparatus, including: voltage and current in all the lines, temperature, humidity, pressure and vessel water ingress. Moreover the system will allow the switching on and off of all the output lines during normal operation and to automatically isolate a faulty line. Trip current threshold will be remotely-settable.

The PJB is an element where a single point failure can have severe consequences for detector operation. It must be highly reliable in operation and must facilitate recovery for maintenance or replacement. Both the ANTARES and NEMO projects have deployed and operated junction boxes in the deep sea with all the required functionalities.

4. Secondary Junction Box

Each Secondary Junction Box serves a group of 8 DUs via the IL cables. The SJB is a simplified version of the PJB. It hosts input and output ROV wet-mateable connectors, a power system box and a optical system box. The power system box foresees redundant input and output lines. All the output lines are equipped with remote operated relays. The system communicates with the DU via optical fiber and a conveyed wave system.

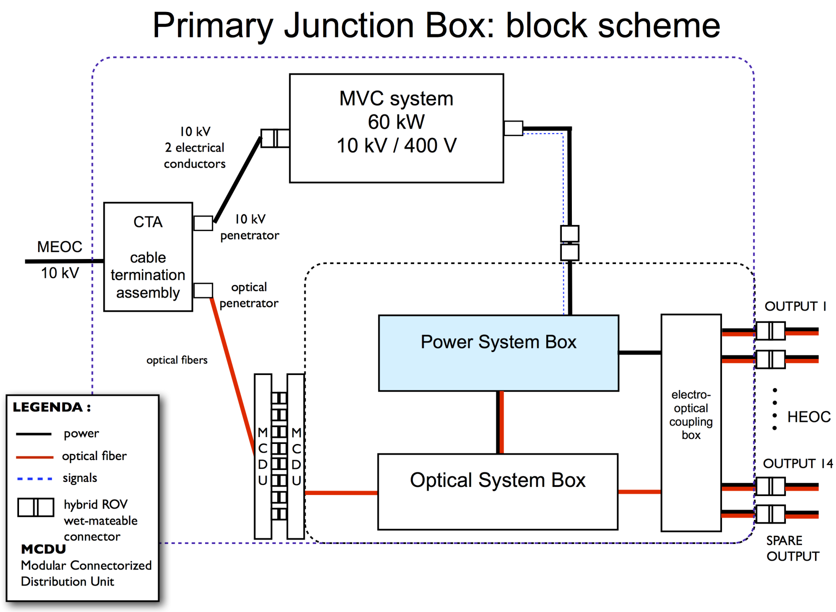

Figure 2: Primary Junction Box block diagram

5. Electrical Power system power requirements and calculation results

The power requirements for a building block are determined mostly by the detection units. Each DOM has a consumption of 8.7 W leading to 350 W power consumption per DU (40 DOMs) plus an additional 10 W for the local control. The PJB and SJB require respectively 300 W and 100W for their internal electronics. In addition the associated science node consumption is ∼ 10 kW. Consequently the total power requirement off shore is ∼ 48.6 kW.

The electrical power system has been subdivided into transmission and distribution subsystems.

The transmission system goes from the shore station to the PJB. It is a 10 kV DC monopolar system with the MEOC copper conductor energized at 10 KV. The positive electrode is located on shore while the negative electrode is offshore. The singe copper conductor of the MEOC is up 100 km in length, with a resistance of ∼ 1.5 Ohm per kilometer, guarantee reasonably low voltage drop and Joule losses.

The distribution system goes from the PJB output to the electrical loads located along the DU backbone. It is a 400 V DC bipolar system. It has been designed taking into account both deployment issue, related to cable cross-section and weight, and system efficiency. To keep each cables Joule losses and voltage drops below 6% the cables should have the following characteristics:

- the HEOC and IL each composed of two 16 mm2 cross section Cu conductors with a maximum length respectively of 2000 m and 350 m;
- the VEOC composed of two 18 AWG cross section Cu conductors with a length of 880 m;

A market survey has been launched with the submarine electro-optical cable industry with the aim of procuring the different types of deep-sea cables whose conductor specifications are reported in Table 1.The contacted companies include Alcatel-Lucent, Nexans, Draka and JDR. The power flow from on-shore to off-shore apparatus for a building block of 104 DU with a star-like power distribution is summarized in Figure 4. It shows that the major losses are concentrated in the MVC (10 kW with a 85% efficiency). These are comparable to the Joule losses in all the deep sea local network cables (3kW), and the MEOC (6.2 kW) combined. The total on-shore power requirement is approximately 70 kW and the total power loss is around 27%.

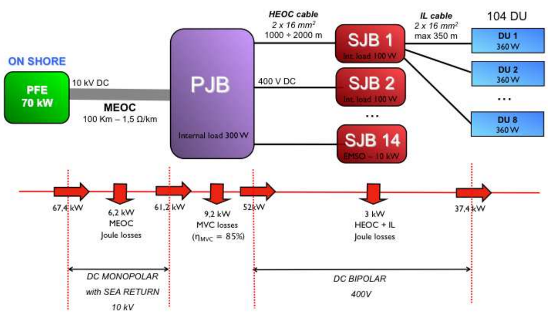

Figure 4: Building Block Power flow scheme

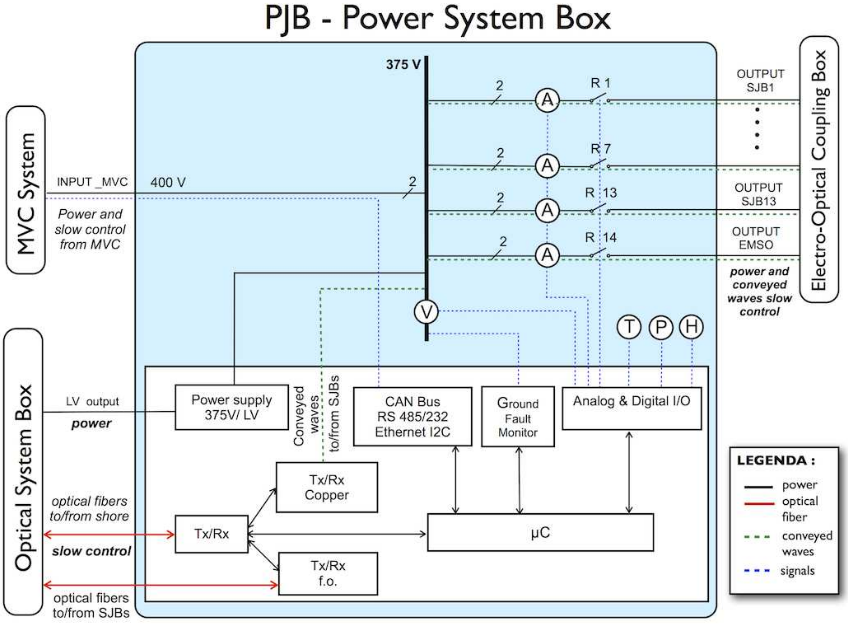

Figure 3: PJB Power System Box block diagram

Cable Name	Length	Copper Wires	Qty	Qty/km
MEOC	100 km	1X 1,5 Ω/km	1	100km
HEOC	1-2 km	1X 16 mm^2	14	20km
IL	100-350m	1X 16 mm^2	104	25km
VEOC	880m	1X 18AWG	208	200km

Table 1: Electro-optical cable specification for a Building Block

6. Conclusions

This paper presents the results reached by the Working Package H of KM3NeT Preparatory Phase, funded by the EU FP7, on the design of a star-like deep sea floor network for a building block (1/3 of the full detector).

7. References

[1] http://www.km3net.org.

[2] KM3NeT Technical Design Report (ISBN 978-90-6488-033-9), April 2010

[3] M. Sedita, R. Cocimano, G. Hallewell, Power and Submarine Cable Systems for the KM3NeT kilometre Cube Neutrino Telescope, Proceedings of the Topical Workshop on Electronics for Particle Physics, CERN - 2009-006, 286-290

[4] R. Cocimano, NEMO medium voltage converter factory acceptance, operational and final integration tests Nuclear Instruments and Methods in Physics Research A 626-627 (2011) S130S1