10869 **Session 2022**
Insulated Cables – B1
PS1 – Learning from Experiences

Lessons learned in the maintenance of REE's submarine lines

Daniel BLANCO*[(1)], Gonzalo DONOSO[(1)], Elena NOGUEROLES[(1)]
(1) REE
Spain
daniel.blanco@ree.es. gdonoso@ree.es, enogueroles@ree.es

SUMMARY

The Spanish TSO owns several submarine interconnectors: the links between the Spanish mainland and the Balearic, and the interconnectors between the Spanish and Moroccan electrical systems and the interconnectors between different islands of the Balearic and Canary Islands. These submarine installations are made up of single or three-pole cables of different technologies and voltage ranges. As the owner of these installations, the TSO carries out different maintenance tasks in order to guarantee their availability at all times.

Taking into account the accumulated experience during the last years, the TSO has implemented improvements, based on lessons learned, in its submarine cables' maintenance strategy. The aim has been to minimise maintenance costs by maximising the availability of these facilities. This strategy is essential mainly due to three factors: the importance of the existing submarine links for the transmission grid, the high cost of the maintenance operations involved in them and the need of anticipation to the growing number of submarine electrical installations projected for the coming years, in both national and international interconnectors.

The improvements obtained by the experience are related to the following aspects:

- Preparation of contingency plans for failures, in coordination with the regional area of the company in which the interconnectors are located.

- Work and equipment for faults pre-location, that includes technical training of the personnel.

- Fault location by means of submarine ROVs (Remotely Operated Vehicles) with own personnel supervision.

- Development of compatible accessories for different submarine cables, looking for the technical viability and cost reduction of the repairs.

- Standardization of spare parts from the engineering phase in future submarine interconnectors, in order to increase the contracting possibilities, trying to reduce the repair schedules, the costs and the logistic problems.

Repair of faults in deep waters by making three or more joints, in which may appear, as a consequence, complicated and expensive activities.

- Tools and actions carried out by the TSO to prevent external aggressions: AIS (Automatic Identification System) and surface patrolling that tries to control, by different means, unwanted behaviour of ships sailing the waters above the submarine lines (anchoring near the line path or use of forbidden fishing gears).

- Crossings management with other power or telecommunication submarine cables, to avoid interferences and to improve the knowledge near our assets' surroundings.

- Importance of monitoring systems to obtain information about the state of the cables, to track the changes of the environment and to adequate the maintenance strategy. Gradual introduction of different systems like distributed temperature sensing (DTS) or distributed acoustic sensing (DAS) is considered.

- Collaboration and communication management with other assets' colleagues from different Transmission System Operators (TSOs). In some international power interconnectors, the asset belongs to different TSOs, located in other countries, with specific laws, procedures and languages. All these characteristics have to be taken into account and must be managed properly.

Through this series of lessons learned, the TSO manages optimising both response times and efficiency in the use of resources. Thanks to this learning, reduction of costs and enhance of the benefits (in the control and quality of maintenance work) are obtained, as well as greater availability of the assets.

KEYWORDS

Submarine power cables, Interconnectors, Lessons learned, Maintenance

1. INTRODUCTION

The TSO's mission is to guarantee that the assets of the transmission grid are always in optimum condition in terms of availability and reliability. Submarine power cables are essential to improve security and guarantee supply, increasing the efficiency of the electrical systems and allowing a greater integration of renewable energies.

The TSO owns more than 1.200 kilometres of submarine power cables:
The Spain-Morocco double-interconnector is located in the south of the Iberian Peninsula. This 400 kV interconnector goes through the Strait of Gibraltar in a single core configuration with a maximum water depth of 635 metres.

In the east side of the Iberian Peninsula, we can find several submarine cables. The Peninsula – Balearic Islands link is the first submarine high-voltage direct current (HVDC) transmission link in Spain, and it ranked second in the world in terms of maximum depth at which the cables was laid (1.485 metres) by then.

The Mallorca-Ibiza submarine double-interconnector run along the seabed at depths of up to 800 metres.

The Ibiza – Formentera double-interconnector is the oldest submarine power cables owns by the TSO and it has been in service for more than 40 years.

Recently, the Mallorca – Menorca interconnector has been commissioned to contribute to the stability and quality of Menorca's electrical system.

Finally, in the Canary Islands we can found the submarine power cables that connect the Lanzarote island to the Fuerteventura and La Graciosa islands.

Interconnector	Year	Tec	Voltage (kV)	Cable Insulation	Cable Lenght (km)	Total Lenght (km)	Max. Depth (m)	Type of cable
España-Marruecos 1	1999	AC	400	OF	29	116	610	4xSingle-core
España-Marruecos 2	2006	AC	400	OF	31,1	93,3	635	3xSingle-core
Península-Baleares 1	2011	DC	±250	MI	243,6	730,8	1485	3xSingle-core
Mallorca-Ibiza 1	2015	AC	132	XLPE	125,9	125,9	797	1xThree-core
Mallorca-Ibiza 2	2015	AC	132	XLPE	125,5	125,5	800	1xThree-core
Mallorca-Menorca 2	2020	AC	132	XLPE	53,2	53,2	80	1xThree-core
Ibiza-Formentera 1	1974	AC	30	EPR	14,6	14,6	34,36	1xThree-core
Ibiza-Formentera 2	1982	AC	30	EPR	11,9	11,9	33	1xThree-core
Lanzarote-Fuerteventura 1	2005	AC	66	EPR	14,3	14,3	59,5	1xThree-core
Lanzarote-Fuerteventura 2	2022	AC	132	XLPE	14,5	14,5	80	1xThree-core
Lanzarote-La Graciosa 1	1982	AC	20	EPR	1,1	1,1	12,4	1xThree-core

Table 1. Principal characteristics of the Submarine power cables owned by the TSO

As shown in table 1, those submarine power cables are different in type of technologies, insulation, voltage, length or depth, which makes maintenance of these assets a challenge.

Taking into account the location of these submarine power cables as shown in figure 1, it is important to highlight that the Strait of Gibraltar supports a very large density of maritime traffic. Furthermore, the assets located in Balearic Islands see increased the number of boats specially in the summer months.

These high densities of maritime traffic elevate the risk of having a fault due to anchoring, fishing, etc.

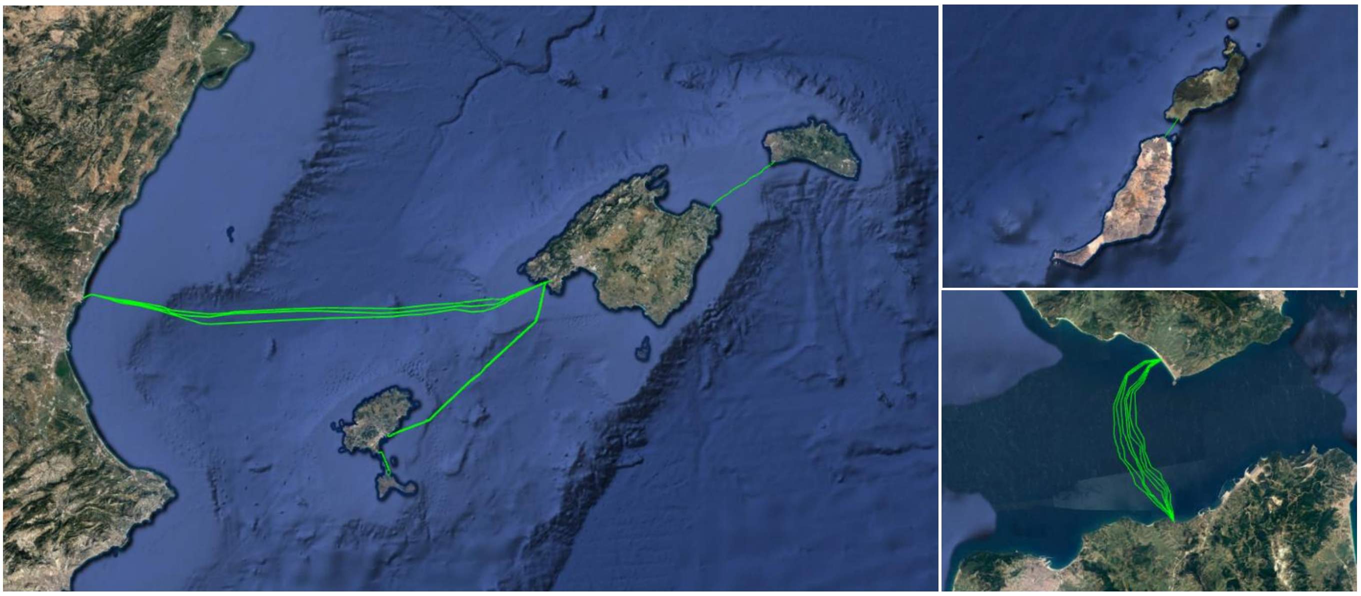

Figure 1. Location of the submarine power cables in the Spanish's grid

During the past years the TSO has accumulated experiences from the maintenance activities as well as the fault repairs which have allowed us to establish a maintenance strategy based on experience and lessons learned.

2. MAINTENANCE STRATEGY

The maintenance strategy design has to begin from the Engineering, Procurement and Construction (EPC) phase. It is important to take under considerations some aspects that will affect the assets in the maintenance operations.

- **Spare materials** play a key role in the maintenance strategy. The TSO has defined a minimum spare materials stock based on the following fault hypothesis: Faults in two phases of a single core submarine cable or in two areas of a three-core submarine cable at the same time as shown in figure 2.

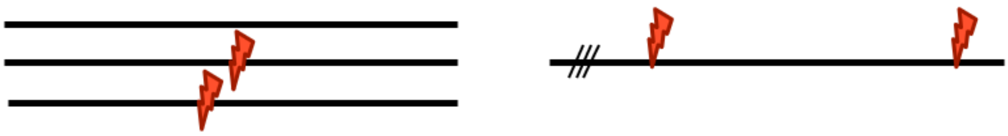

Figure 2. Fault hypothesis considered for spare material designed.

As the submarine power cable spare materials represent a high cost as well as the warehouses to store it is important to standardize these materials in order to maximize its use in as many installations as possible.

- **Protection** of the submarine power cables is important to ensure the integrity of the assets during its whole life operation. The objective of this is to protect the cable from fatigue, overbending or external damage. Many years from experience have demonstrated that faults occur more likely in a cable that has not been properly protected. For that reason, and especially in the nearshore areas where the fishing activity is higher, submarine power cables need to be designed and built with additional protection in order to avoid future damage and the high cost of the maintenance operations for repairing.

The TSO's experience has proven that burying the cable in seabed is the most effective protection system to prevent any external damage. Other protection methods such as concrete mattress, rock dumping, sandbags or cast-iron shells have shown effectiveness in areas where the jetting or trenching is not possible.

Figure 3. Cable Protection Systems (CPS)

- Another relevant aspect is the **As-built documentation**. It is important to ensure the correct transfer of the installation to the maintenance team. The documentation must include all the information related to the project such as cable and accessories design, tests and quality records; manufacturer method statements to install and repair; implemented protection systems, bathymetry, detailed route position list (RPL) with precise details of all the necessary cable route events, coordinates, depths, etc.

All this documentation must be stored following a similar structure for all projects so that all information is easily found and can be used in a unique way and without discrepancies, saving time and misunderstandings when a fault occurs, and action is required in a fast and agile way.

2.1. PREVENTIVE AND PREDICTIVE MAINTENANCE

The TSO's experience in the asset's maintenance has allowed us to evolve from the traditional periodic maintenance model to a risk-based asset maintenance model. It is important to analyse the situation of each submarine installation to determine the concrete actions to implement in order to minimize the risk of failure in the submarine assets. During the last decades the TSO has detected some actions and activities based on its experiences and lessons learnt to establish a correct preventive and predictive maintenance.

- Elaboration of **contingency plans** for failures which contains all the actions to perform in case a fault occurs. These contingency plans are prepared in coordination with the field operations' teams of the company in which the assets are located. The objective of these contingency plans is to optimize repair times since an optimized planning will save a high cost in the submarine power cable repair. Contingency plans should include:

    - Descriptions of the installation: it describes all the characteristics of the installations such as location, manufacturer, characteristics of the assets, bathymetry, route position list, etc.

    - Maintenance history record: it describes all the relevant maintenance works carried out in the assets as a consequence of a fault o predictive and preventive maintenance.

    - Risk analysis. It analyses the weak points that represent a greater risk in the installation.

    - Material and human resources: It contains how all the material and human resources available are organised in case of a fault such as spare materials, pre-localisation and localisation equipment, maintenance crews or vessels.

    - Emergency action plan: it describes all activities to perform when a fault occurs from pre-localisation to commissioning indicating for each activity both the material and human resources needed, time schedule and estimated cost.

- **Submarine survey** along the cable route in order to be aware of the actual state of the submarine cable. These submarine surveys will be carried out according to the data obtained from different factors or systems such as risk and health of the submarine assets, number of alarms from AIS, surveillance/patrolling systems, monitoring systems, etc.

    The aim of these surveys is to detect areas where the cable is exposed, freespans, evidence of fishing activities, new crossings not notified, cable damages or any relevant event that can affect the submarine assets operation under rated conditions.

- As a result of the submarine survey, all the detected events have to be analysed in order to propose and schedule **maintenance activities** to amend those anomalies and avoid future failures.
- The TSO's experience has demonstrated that a high percentage of the faults happen due to an external aggression. In order to mitigate this fact, the TSO has implemented tools and actions to prevent external aggressions in its submarine assets.
    - **Automatic Identification System (AIS):** this system allows to identify vessels sailing above the submarine lines (anchoring near the cable corridor or use of forbidden fishing gears in the vicinities of our assets). The TSO has established surveillance zones and, through a system of rules, allows sending warnings to ships through SRM via AIS to warn about the presence of power submarine cables in the area. the TSO has established the following rules to send automatically a Safety Related Message (onwards SRM) for warning all potential risk vessels when they are inside a protected zone

        - 1st SRM to the potential risk vessel detected sailing below 2 knots in the protection zone. No warning to the TSO.
        - 2nd SRM to the vessel if after 30 minutes there is no answer, and it is still inside the protected zone. Warning to the TSO.
        - 3rd SRM to the vessel if after 30 minutes there is no answer. Warning to the TSO.

        All these data are stored and analysed allowing the detection of possible areas of high maritime density as well as non-compliance with the established anchoring or fishing forbidden zones.

    - **Surface Surveillance Patrol**: As a complement to the AIS system, the TSO has established a surface surveillance patrol, especially in those installations that represent a high risk due to the elevated maritime traffic density of the area. The aim of this patrol is to warn on-site those vessels that are ignoring the restricted areas established in the nautical charts and AIS SRMs.

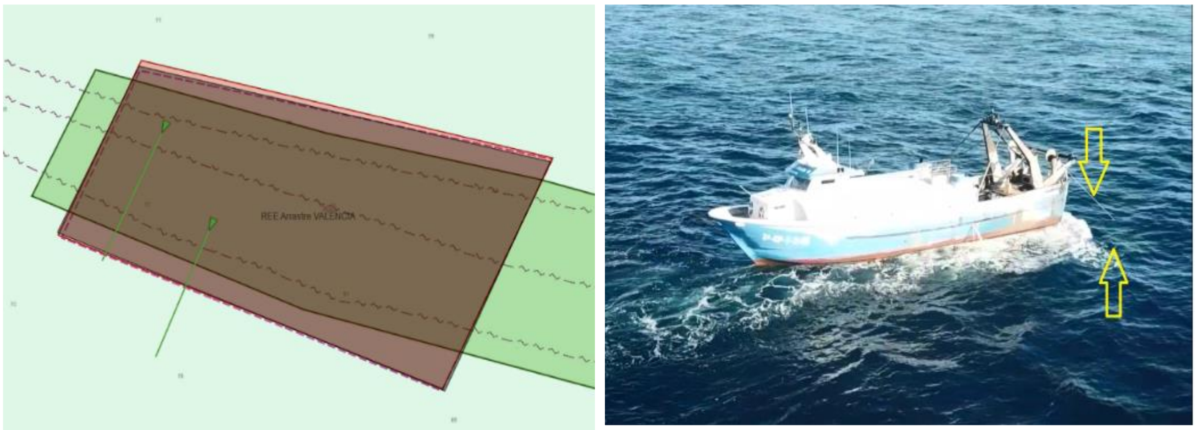

Figure 4. AIS and surface surveillance

the TSO has experienced a drop in the number of alerts from the AIS system as a result of the implementation of the surface surveillance system. In the area of the Gibraltar Strait the number of AIS alerts has decrease by 50% compared to the average of the last four years, as shown in figure 5. During the last year it has been shown that surface surveillance has had a dissuasive effect on vessels.

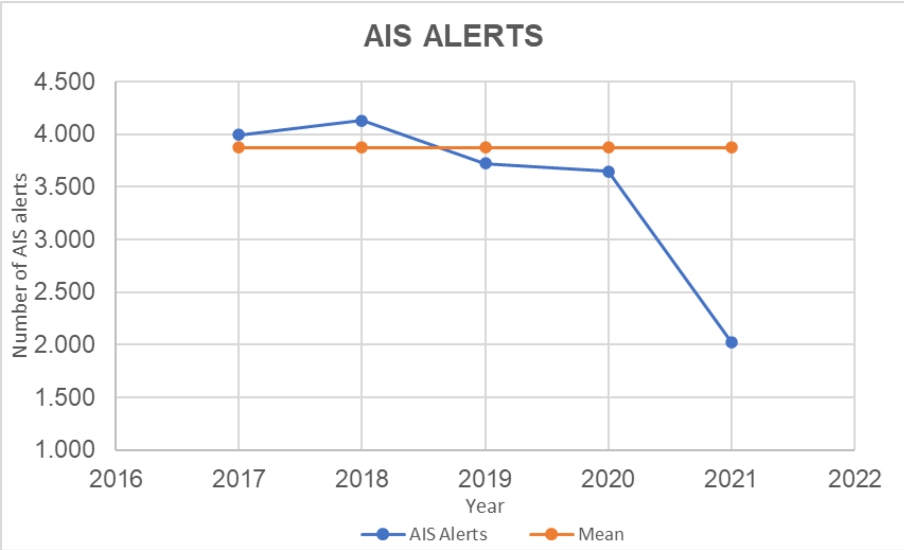

Figure 5. AIS Alerts in Gibraltar Strait

- **Monitoring systems** can help us to obtain information and data about the power cable and its surroundings. These systems take advantage of the fibre optic cable installed inside the power cable or bundled to it to track the changes of the environment and to adequate the maintenance strategy. Over the years the TSO has implemented and tested different systems in order to monitor its submarine assets.

    - **Distributed Temperature Sensing (DTS)** uses fibre optic cables as linear temperature sensors. The result is a continuous temperature profile along the cable that can be used to detect, locate and track events or for Dynamic Cable Rating purposes.

    - **Distributed Acoustic Sensing (DAS)** uses fibre optic cables as acoustic sensor to detect vibrations that can be identified with events such as cable movements, external threat, waves, vessels moving near the cables, etc.

- Identification of the **crossings** with other power or telecommunication submarine cables in other to establish agreements and protocols between both companies, and method statements about how to proceed in case of a fault or maintenance works. There are more than 1.3 million km of submarine cables across the globe, so a crossing management is vital to avoid interferences and to improve the knowledge of the power cables' surroundings.

One of the lessons learnt about this matter has been to adhere the TSO to organizations which helps to deal with the crossing management. These organizations promote awareness of submarine cables as critical infrastructure and establish internationally agreed recommendations for cable installation, protection and maintenance.

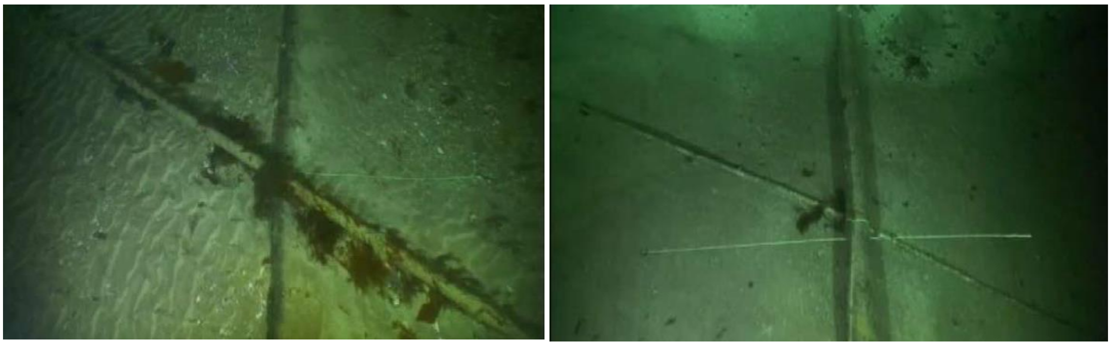

Figure 6. Power submarine cable crossing with a FO cable

- Development of **compatible accessories** for different submarine cables and accessories in order to minimize the spare material stock and to have less dependence on external agents.

- As many transmission lines run parallel among them, analysis of the **induced voltages** on the cables is essential to optimize unavailability of the circuits and guarantee the safety of personnel working on repairs.

- Collaboration and **communication management** with colleagues from different TSOs. Some of the submarine power interconnectors are shared between TSOs, located in other countries, with specific laws, procedures and languages. All these characteristics have to be taken into account and must be managed properly.

- Proactivity to inform third parties about the works to be performed in our assets in order to demonstrate transparency and avoid misunderstandings that may impact the company reputation.

2.2. CORRECTIVE MAINTENANCE

Submarine power cables are critical assets to improve security and guarantee the energy supply in all the electrical system. When a fault occurs, it is essential to be prepared in order to minimize the unavailability of the installation. Over the last years, the TSO has implemented some actions based on the experience to improve the management of faults, in order to reduce the impact and cost of these activities.

- It is very important to be able to pre-locate and locate the fault in the less possible time in order to not only repair faster the breakdown but to fix any kind of environmental impact that might happen. For this reason, the TSO has acquired its own **testing equipment and technically trained its personnel** to be able to pre-locate the fault and avoid external dependency.

For the pre-localisation phase it is also important to have all the information of the cable such as length of each section, coordinates and depth. This information will allow to reduce the margin of error of the pre-localisation and determine the correct means and equipment for the localisation phase. Appropriated vessels and ROVs must be chosen taking into account weather forecast, sea characteristics and depth of the fault.

- **Communication of the fault** to the owners of the surrounding infrastructures in order to evaluate the impact of the repair campaign and to agree on the operations to be carried out.

- **Permits** of the Maritime Authorities are normally managed by the vessel consignee. As these permits can delay repair operations, it is important that, as owners of the installation, provide support by contacting the Maritime Authorities to explain the situation and to obtain the permits in the shortest possible time.

- **To supervise the activities** carried out by the contractor is essential to guarantee the proper performance of work and to ensure that the operations are being performed following the agreed procedures. The TSO has trained and qualified its own personnel to be able to supervise on board the activities in the repair campaigns.

Figure 7. The TSOs submarine power cable team

- Having a proper **spare parts management** strategy will limit the time to repair. Besides this, experience has shown the necessity to have extra joints on board the vessel in case of unexpected events.

According to depth in which the fault is located a scenario of two joints (d<200m) or three joints (d>200m) is required. The typical schedule for a submarine cable repair for U ≥ 132kV is shown in table 2. This schedule does not consider transit, mobilisation, and demobilisation time.

Phase	Days
Pre-localisation	1
Localisation	2
Offshore activities: unprotect cable	10
Offshore repair activities: 2/3 joints scenario	45/60
HV Test	1
Total	**58/74**

Table 2. Typical submarine cable repair duration for U ≥ 132kV

3. CONCLUSION

The maintenance of submarine power cables has to start from the Engineering, Procurement and Construction (EPC) phase where some important decisions are made, and that will affect the maintenance operations during all the life cycle of the asset.

To establish a correct maintenance strategy some aspects based on experience have to be considered in order to optimize the response times and improve the availability of assets. This optimization will allow to reduce the high cost of the submarine repair campaigns and maintenance activities. The TSO has implemented the following actions to improve the quality of its maintenance strategy:

- Evolve the periodic maintenance survey model to a risk-based asset maintenance model.
- Development of repair preparedness plans to improve the response times.
- Implement a surface surveillance patrol in areas of high maritime density to reduce the external damage risk.
- Identification of crossing and agreement management.
- Adhere external organizations to promote awareness of submarine cables as critical infrastructure.
- Develop a spare parts management to reduce spare material cost.
- Acquire testing equipment and technically trained its personnel to pre-locate the fault and avoid external dependency.
- Train in-house personnel to supervise the activities carried out by third parties.

These analysis and activities based on the lesson learnt will improve the quality and control of the works obtaining more control in the decision making.

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