15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPS85

AN UPDATE ON IRIS DEMONSTRATORS*

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Abstract

Superconducting energy savings devices by IRIS Abstract IRIS (Innovative Research Infrastructure on applied Superconductivity) is a major project to build a research infrastructure in applied superconductivity, recently approved in Italy and led by INFN Milano. In this framework, we are developing two superconducting energy savings devices, both working at 20 K either in helium gas flow or by cold-heads: An HTS dipole (Energy Saving Superconducting Magnet) and a 1 GW rated superconducting line (Green SuperConducting Line). ESMA is an HTS ReBCO metal insulated racetrack dipole, this magnet will be 1 m long with a medium-sized round bore of 70 mm diameter and a maximum central field of 10 T. The paper reports the design updates, presenting and discussing the main technological choices (coil layout, ramping time, etc.). An R&D plan is supporting the technology choices and the construction that will be carried out in Industry will also be included.

We are also developing a 130 m long MgB2 Superconducting Line (GSCL), capable of carrying 40 kA at 25 kV, an almost zero-dissipation DC transmission line. The paper will present the up-to-date status of the IRIS energy-saving devices, ESMA and GSCL: design, tests, and production.

INTRODUCTION

Figure 1: Italian cities involved in the IRIS project.

* This work is part of the project IR0000003 - IRIS supported by the NextGeneration EU-funded Italian National Recovery and Resilience Plan with the Decree of the Ministry of University and Research number 124 (21/06/2022) for the Mission 4 - Component 2 - Investment 3.1.

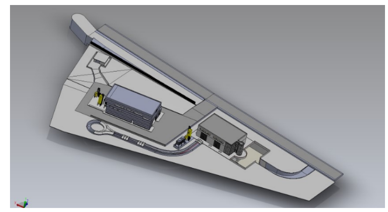

Figure 2: Rendering of the exterior of the new Salerno plant, showing the trench for the line.

Table 1: Summary of GSL Main Characteristics

Superconductor	MgB_2
Voltage	25 kV
Operating temperature	20 K
Line length	130 m
Expected losses	1.5 W/m @ 20 K
Bending radius	2.2 m
Inner pressure	10 bar

The Italian Minister for University and Research has recently allocated funding to support an Innovative Research Infrastructure on applied Superconductivity (IRIS) in Italy [1]. This initiative involves a partnership among existing laboratories from various institutes, including INFN (leading the project with 4 labs: Frascati, Genoa, Milan, Salerno), CNR (SPIN institute in Genoa, Naples, and Salerno), and five universities: Genoa, Milan, Naples, Salento, and Salerno 1. IRIS aims to enhance Italy's capabilities in superconductivity for accelerator applications by upgrading existing infrastructures with state-of-the-art instruments.

In the frame of the project IRIS two innovative demonstrators for the use of superconductors as energy saving materials, both in civilian and scientific application, are under study and will be produced by the end of 2025 by the company ASG of Genova. The two demonstrators are the Green Superconducting Line (GSL), a 1 GW power transmission line, and the HTS dipole magnet ESMA (Energy Saving Magnet for Accelerators). The line will be tested in the new cable facility in Salerno that will have a 140 m long out-door trench and will be open access for companies and research institutes for at least 10 years. In this article we present some updates on this two demonstrators.

GREEN SUPERCONDUCTING LINE

The Green Superconducting Line (GSL) is a 130 m DC power transmission line designed to carry 1 GW of power at

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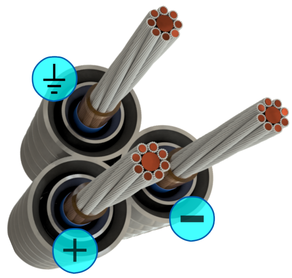

Figure 3: An operating line will be composed by 2 phases (+ and -) and a grounded spare for full redundancy.

a medium voltage of 25 kV and a high current of 40 kA. The line will be based on MgB_2 superconductor with operating temperature of 20 K (helium gas will be used) (Table 1).

Preliminary analyses were conducted on a conceptual design for the line, considering it to be composed of four cables embedded within a single cryostat [2]. However, knew knowledge from our partner ASG made us to move to a different configuration.

Updated Line Configuration

The new line configuration foreseen three different cables, each within its own cryostat. Two of them will curry current and the third is kept as grounded spare. The aim of this configuration is to keep the full redundancy, that is one of the main required for an operating line, keeping the cables far enough to prevent voltage breakdown between them in case of breakage of one cable (in case of a big failure the heart will used as return, as commonly done for existing HVDC power lines) (Fig. 3).

Cable Configuration

Each cable is made up of 8 petals spiralling around a copper core. Each petal contains a copper core around which are twisted 14 strands of MgB_2 with a diameter of 1.33 mm. Petals will have a twist pitch of tp_p = 800 mm and strands of tp_s = 250 mm.

Following the previous configuration, magnetic analyses were performed to determine the peak field on the strands. Additionally, a mechanical analysis was conducted to assess the stress and strain induced on the strands by bending the entire cable. These analyses are crucial for evaluating potential reductions in the strands' critical current. Furthermore, an ongoing study on quench behaviour incorporates these analyses, along with a thermal analysis.

Other Line Components

In addition to studying the cables and the cryostat, we are also investigating some important ancillary components. These components are critical to the proper functioning of the system and provide significant benefits for diagnostic purposes. The aim of the research is to ensure that every necessary and useful part is fully understood and integrated

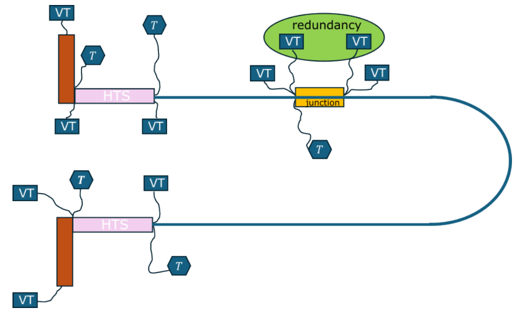

Figure 4: Scheme of voltage taps and thermometers for GSL.

to optimise the overall performance and reliability of the system.

A critical component to be included in the demonstrator and tested at the new IRIS facility in Salerno is an in-line junction between two sections of the same cable. This junction will be identical to the one used to repair an active line in situ in the event of damage.

In addition, studies are underway on sensors to keep the line under control during operation. The main type of sensors are voltage taps and thermometers and the criticality is related to how they are brought from inside the line at 50 kV to the outside at ground level. A very preliminary scheme of the sensors and the junction is reported in Fig. 4.

Cost and Advantages

With a COP^{-1} (coefficient of performance) of 50, the cryogenic power consumption for a 1 km superconducting line is 75 W per megawatt (MW). This level of power consumption is comparable to existing high-voltage DC (HVDC) power lines, which makes it a viable option for energy efficiency.

The medium voltage and smaller cross-section of the superconducting line reduces the required safety buffer zone, making it an optimal choice for densely populated urban areas. This advantage allows for infrastructure improvements without extensive land use or significant safety concerns.

ESMA

ESMA (Energy Saving Magnet for Accelerators) is a high temperature superconducting (HTS) metal-insulted dipole magnet (Fig. 5, Table 2). The primary objective is to provide a robust background magnetic field for the Genoa facility, facilitating the characterisation of new materials and superconducting cables. In addition, this project will contribute

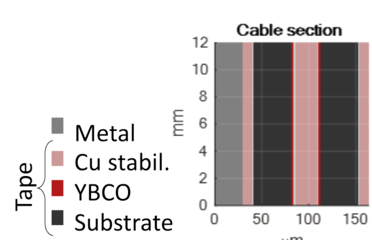

Figure 5: Section of the section of the cable for ESMA.

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Table 2: Summary of ESMA Main Characteristics

Number of pancakes	12 (6 x 2)
Cable turns / racetrack	350
Magnetic Energy	3.5 MJ
Current from PS @ 10 T	1150 A
Operating temperature	20 K
Curvature radius	128 mm
Good field region	H50xV30xL350
Aperture radius	70 mm
Total tape consumption	12 km

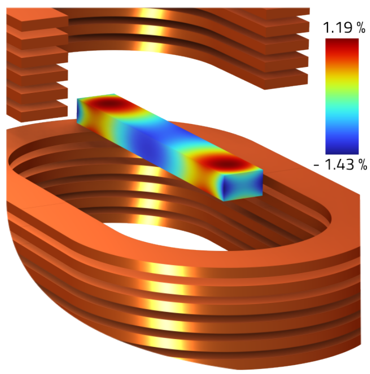

Figure 6: ESMA field quality region.

to the development of high field magnets for next generation high energy colliders such as the Future Circular Collider (FCC) and the Muon Collider [3].

Goals

The primary objectives of this study are twofold:

1. **Provision of a background field**: To provide a background magnetic field for the Genoa facility, allowing the characterisation of new materials and superconducting cables.
2. **Supporting high field magnet research**: Contribute to the development of high temperature superconducting (HTS) high field magnets for next generation high energy colliders such as the Future Circular Collider (FCC) or the Muon Collider.

Magnetic Design

ESMA is designed to generate a dipolar magnetic flux density in the range of 2 to 10 Tesla (T). It aims to maintain a field quality within 1.5% at all field levels (Fig. 6). The design targets a critical current margin of at least 20% or a thermal margin of 10 Kelvin (K). Discussions are ongoing on stray field shielding to ensure optimum performance.

Mechanical Design

The mechanical design employs a modular structure concept, wherein each pancake coil is mounted on a steel tray in conjunction with the mechanical containment structure and winding mandrel. The aforementioned modules are then stacked to form the complete assembly. Conduction cooling is achieved through the insertion of copper plates into each module.

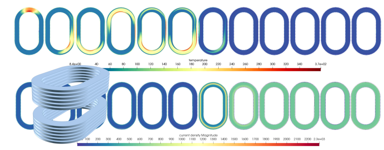

Figure 7: ESMA quench simulation.

Quench Protection

Quench protection represents a crucial aspect of the design of magnets. A series of studies have been conducted to simulate magnet discharge events triggered at a 10 millivolt (mV) threshold (Fig. 7). This was achieved by inducing a quench with a 40 watt (W) heater for 0.1 second. The simulations indicate that the maximum hotspot temperature is approximately 350 K, with current densities reaching up to 3000 A/mm^2. Further research is being conducted with the objective of optimising the protection design by adjusting the contact resistance and exploring different protection schemes with the aim of improving the reliability and performance of the system.

CONCLUSION

The IRIS project, led by INFN Milano, focuses on the development of two superconducting energy-saving devices: the 1 GW superconducting line (GSL) and the HTS dipole magnet (ESMA). GSL, a 130 m long MgB2 superconducting line, is designed for highly efficient DC power transmission, capable of carrying 40 kA at 25 kV with minimal losses and suitable for urban environments due to its reduced safety zone requirements. A new test facility in Salerno will carry out the tests for the line and will be open access for companies and research institutes. ESMA, a ReBCO metal-insulated racetrack dipole magnet, is designed to generate a central field of up to 10 T with high field quality, contributing to high-field magnet research for future colliders such as the FCC and the Muon Collider..

Overall, the IRIS project aims to improve superconducting capabilities for high energy physics applications, with continued research and optimisation essential for the successful deployment of these innovative technologies.

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