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SUPRAPOWER:

Superconducting, reliable, lightweight, and more powerful offshore wind turbine

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suprapower

Superconducting light generator
for large offshore wind turbines

Final Report

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1. PUBLISHABLE SUMMARY

1.1 EXECUTIVE SUMMARY

Offshore wind market demands higher power rating and more reliable turbines in order to optimize capital and operational costs. The state of the art shows that conventional generators are difficult to scale up to 10 MW and beyond due to their huge size and weight. Superconducting direct drive wind generators are considered a promising solution to achieve lighter weight machines.

SUPRAPOWER (www.suprapowe-fp7.eu) was a research project funded by the EU FP7 programme. It started in December 2012 and finished in May 2017. The project was conceived to design an innovative, lightweight, robust and reliable 10 MW class offshore wind turbine based on an MgB_2 superconducting generator (SCG).

Tecnalia Research and Innovation lead a project consortium of eight outstanding European companies and research institutions: Columbus Superconductors SpA, IEE-Slovak Academy of Science, University of Southampton, Karlsruher Institut fuer Technologie, D2M Engineering SAS, Solute Ingenieros and Ingeteam Services SA.

As result of SUPRAPOWER a 10 MW 8.1 rpm direct drive 48 salient poles synchronous generator has been developed and patented (EP 2521252). It is a partially superconducting generator (SCG), MgB_2 superconducting wires at cryogenic temperature (20 K) are used in the field coils, but copper wires at ambient temperature in the armature coils. The cooling system is a cryogen-free topology. It has a warm iron rotor configuration which consists of one modular cryostat per pole that encloses only the superconducting coil, while the iron of the pole remains at room temperature. Heat is extracted by conduction through a thermal collector inside a cryostat which links all the modules. This is cooled by conduction by two-stage Gifford-McMahon cryocoolers which rotate jointly with the rotor. A helium rotary joint connects the stationary helium compressors to the rotating cryocoolers.

The 10 MW SCG active parts show a 25.6% weight reduction with respect to a 10 MW permanent magnets generator (PMG) ones and the total reduction of the tower head mass (including nacelle and blades) is of 7.2%. The achieved head mass reduction permits an 11% reduction of the tower weight and 9% of the fixed foundations (monopile). Thus 0.5-1 M€ of cost reduction can be achieve just due to material savings. Installation, O&M, decommissioning and all other marine operations do not complicate due to the SCG and 0.9 M€ savings could be achieved in this field.

A scaled magnetic rotating machine has been designed and constructed for the validation the concept of the 10 MW SCG. Main innovative elements and features as superconducting and cryogenic implementation, modularity and quench detection system are equal to those of the 10 MW SCG ones. Several new solutions have had to be developed for this first-ever manufacturing of this scaled machine, which was successfully completed by project end. The superconducting coils and the cryogen free cooling concepts have been successfully tested and validated. However, the test results of the scaled machine have not permitted its complete validation and have revealed new requirements for proper functioning.

The project has demonstrated the SCG is cost-competitive with, and provides several technical advantages over direct drive PMGs. Test results and experimental activities have enhanced the value of the patent of the SCG. But the development of the SCG still requires further R&D, validation and demonstration activities.

1.2 Summary of SUPRAPOWER project context and objectives

1.2.1 Context

Offshore wind energy is rapidly developing motivated by stronger and more regular winds at sea, and increasing site restrictions on land. At the end of 2016 the European cumulative installed capacity was 12.6 GW offshore and 141.1 GW onshore. With almost 300 TWh generated in 2016, wind power covered 10.4 % of the EU's electricity demand. [1]

In 2010, according to the International Energy Agency, global offshore wind cumulative capacity could reach 100 GW in 2020 of which 40 GW in Europe [2]. Recent regulatory and economic developments in the EU have changed the offshore wind energy perspective for the next 15 years. In light of uncertain governance towards achieving EU climate and energy binding targets, EWEA updated the European wind energy industry's vision to 2030. EWEA's new Central Scenario expects 66 GW of offshore wind capacity and it estimates that wind could produce 245 TWh, covering 7.7%.

However, severe cost reductions are demanded in order to be able to reach these market perspectives. In this sense, higher power rate wind turbines are pointed out as the innovation with higher Levelized Cost of Energy (LCoE) reduction potential [3] [4].Indeed, there is already a trend towards more powerful turbines: the average capacity rating of the 361 offshore wind turbines (WT) under construction in 2016 has been 4.8 MW**,** 15.4% larger than in 2015 and more than the double respect to 10 years before [5]**.** The average rated power of new installed WTs is expected to reach 6 MW in 2016 and 8 MW in 2020, and it is already remarkable that in 2016 the first 8 MW turbine has been grid-connected at sea. Main WT manufactures are developing new turbines of 5 to 8 MW, mainly based on medium speed (60-600 rpm) and low speed (8-20 rpm) drive trains with permanent magnets generators (PMG).

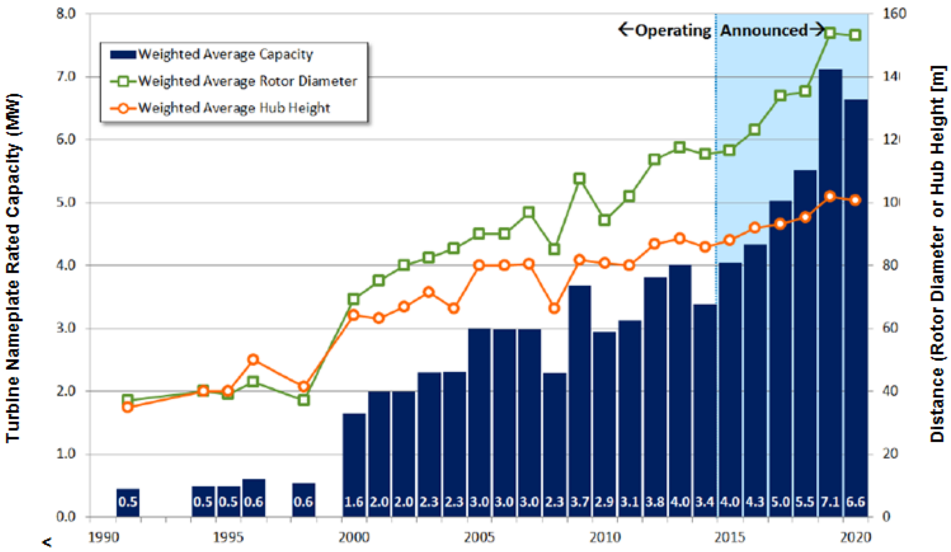


Figure 1. Offshore wind turbines average power evolution [5]

For the last years the dominant technology has been the geared drive train induction generator (DFIG), while direct drive (DD) trains still represent a small share of the offshore wind market. Nevertheless, DD trains are a promising solution, as they show higher reliability and lower maintenance costs than geared options, thereby this technology is called to have a much more important share of the offshore wind market [6]. But, current slow rotating PMGs are huge and heavy machines and this put at risk the technical and economic feasibility of DD turbines in the range of 10 MW. Moreover one of the problems associated to PMGs is the high volatility in the price of the rare earth materials used for constructing the excitation magnets. For example in 2011 rare earth prices reached a top of more than 20 times its previous 5 year average. Additionally the geographical concentration of rare earths production in China worries to the industry [6].

The size of electric generators, as indicated in the expression below, is mainly determined by the torque (*T*), being this proportional to the rotor volume (V) and the airgap shear stress (σ). This stress is proportional to the average airgap magnetic flux (*B*) and to the linear current density (*A*).

$$P = T \cdot \omega \rightarrow T \propto V \cdot \sigma = V \cdot B \cdot A$$

Conventional high power DD wind generators have huge torque due to their low rotational speed (ω). "B" is limited by material properties, with typical maximum values of 0.9-1 T. "A" depends on factors as the stator slot depth, packing factor of copper is slots or cooling/ventilation system. As previously commented these limitations makes high power DD conventional wind generators heavy and bulky.

The use of superconducting materials in field winding permits to achieve much stronger magnetic fields (*B*). Additionally as the armature teeth can be removed more space for AC stator winding can be gained and thus higher linear current densities (*A*) can be reached. Therefore, for a given torque, shear stress higher than in conventional generators can be obtained, with the result of machines with lower volumes and weights of active parts.

Thus the use of superconducting materials in DD generators arise as a promising solution for achieving reliable, lightweight and higher power rate WTs for the offshore market [3]

Superconducting generators (SCG) for wind turbines are an active R&D field. Several wind generator concepts, currently at different development stages, have been proposed, as those of General Electric [7], AMSC [8], RISO-DTU [9] or AML [10]. It is more than remarkable the EcoSwing [11] EC funded project that pursues to construct a 2 MW superconducting generator and install it in an already existing wind turbine.

Nevertheless, some of these concepts face certain technical and economic barriers that could complicate their industrial feasibility for the offshore wind sector. The feasibility of concepts based on conventional pool boiling cryogenic cooling systems is debateable for offshore locations. These systems require huge amounts of cryogenic fluids, as LN2, GHe or LNe, and very complex cryostats and cooling circuits. Complex rotary joints can be also required to exchange huge amounts of cryogen liquids between stationary and rotating parts [12]. SCGs based on LTS wires, as NbTi, require very low operating temperatures, in the range of 1.8-4.2 K, thereby the efficiency of the cooling cycle working at such temperatures is very low, in the range of 0.3%. Beside this, some concepts are based on still expensive and with limited commercial availability materials, such as 2G HTS wires, or materials without attractive cost reduction perspectives such as 1G HTS wires.

1.2.2 SUPRAPOWER project outline and objectives

SUPRAPOWER (SUPerconducting, Reliable, lightweight, And more POWERful offshore wind turbine) is a research project funded by the EU FP7 programme that started in December 2012 and finished in May 2017, with a budget of 5,398,019.03€, being 3,891,058.45€ funded by the EU.

Tecnalia Research and Innovation has leaded a project consortium constituted by 8 top-class European companies and institutions. Industrial partners are a wind farms O&M services company (Ingeteam Services SA), a wind energy engineering (Solute Ingenieros), a superconducting wire developer (Columbus Superconductors SpA) and an offshore engineering company (D2M Engineering SAS). In addition to the coordinator, research partners are a laboratory with deep experience in superconductivity (IEE, Slovak Academy of Science), a university (University of Southampton) and a national institute expert in cryogenics (Karlsruher Institut fuer Technologie-KIT). They also took part as partners during part of the project Acciona Energía, Acciona Windpower and Oerlikon-Leyvold.

The project was conceived to provide an important breakthrough in offshore wind sector by designing an innovative, lightweight, robust and reliable 10 MW offshore wind turbine based on an MgB_2 superconducting generator, taking into account all the essential aspects of electric conversion, integration and manufacturability.

One of the objectives was experimentally validating the superconducting generator concept with a scale machine designed and built specifically for this purpose. To keep the maximum similitude between the model and the full scale generator, the scaling down was obtained by reducing the number of poles, maintaining the size of the superconducting field coils identical both in full generator and in small scale machine. The most innovative full scale generator features (superconducting coils, cooling systems, cryostat and quench detection) are similar, too. This resulted in a scale machine which fulfils the basic performance parameters of the 10 MW machine, but with a substantial reduction of diameter, weight and power permitting to test it in actual size laboratory benches.

SUPRAPOWER project overall objectives were as follows:

- To reduce the head mass, size and cost of offshore wind turbines by means of a compact superconducting generator.
- To reduce operating, maintenance and transportation costs and to increase life cycle using an innovative direct drive system.
- To increase the reliability and efficiency of high power wind turbines through a drive-train specific integration in nacelle.
- To maximize the power conversion and wind response of the wind turbine by means of dedicated control systems/procedures.
- To facilitate the development of the offshore wind potential and support its drastic increase.

And the specific aimed impacts were the followings:

- Reduction of the LCoE of the offshore wind by means of a higher power rate lightweight superconducting generator. This cost reduction could permit to achieve the offshore wind sector market perspectives.

- 30% weight reduction with respect to a permanent magnet generator. This permits easier installation processes, reduces vessels and crane costs and decreases mechanical requirements for foundations and floating platforms.
- Elimination of the gearbox that permits a more reliable and efficient drivetrain.
- Low maintenance with respect to other superconducting solutions thanks to use of a cryogenics liquids free cooling system.
- High on site efficiency (95%).
- Provide a wind generator independent from the rare earth materials market, which recently have shown high price volatility.

1.3 DESCRIPTION OF THE MAIN S&T RESULTS/FOREGROUNDS

As it has been explained before the main aim of SUPRAPOWER is developing a novel 10 MW superconducting generator and integrating it in an offshore wind turbine taking into account O&M and marine operations. The validation of the generator concept is done through a scale machine, which innovative features as superconducting and cryogenic implementation, modularity and quench detection system are equal or similar in both 10 MW and scale machines

SUPRAPOWER was organized in five R&D work packages, and two more related to dissemination and exploitation (WP6) and management (WP7).

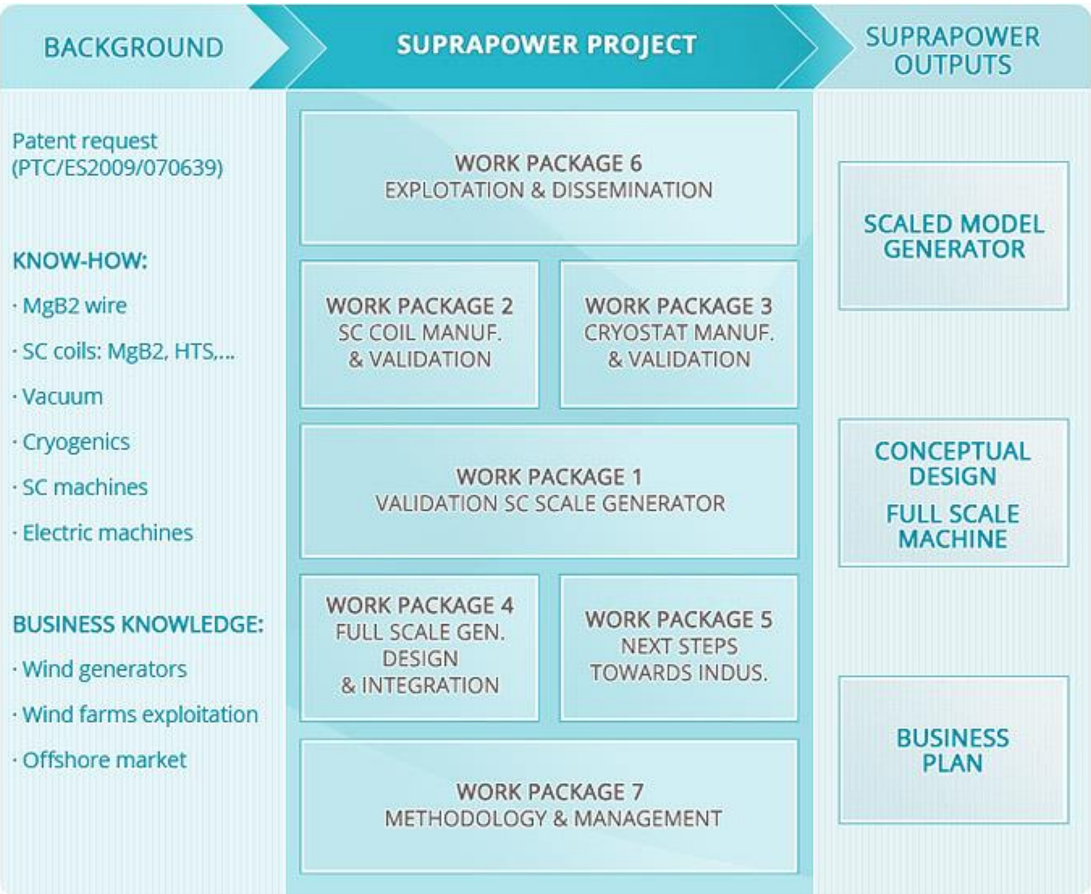


Figure 2. SUPRAPOWER project work packages

The main objectives of the technical work packages are as follows:

- WP1 Validations of the superconducting scale machine: the objective of this WP is the design, construction and test of a scale machine intended to validate the concept of the 10 MW superconducting generator.
- WP2 Design and validation of the superconducting coil based on MgB_2 wire: this WP is intended to the development and design of the superconducting coil of the 10 MW generator.
- WP3 Design and validation of the modular rotating cryostat: this WP aims to develop the cooling concept of the generator including the cryostats of the superconducting coils

- WP4 Integration of the full scale superconducting generator in the wind turbine: this WP is the starting point of the project with the design of a new concept of 10 MW generator, all the developments in the other WPs are related to the generator concept defined in WP4. This WP is also intended to the integration of the generator in a 10 MW wind turbine both fixed and floating.
- WP5 Next steps towards the industrialization of the new wind turbine: this WP includes the analysis of O&M and marine operations of wind turbine based on the developed superconducting generator. As part of this WP improvements in the critical components of the generator will be analysed and finally a business plan will be developed.

The main scientific and technical results obtained in SUPRAPOWER are highly interconnected, thus next summary has not been organized by work packages but by the technical explanation of the developed 10 MW SCG concept.

1.3.1 10 MW superconducting generator

1.3.1.1 Superconducting generator concept

One of the main objectives and outcomes of SUPRAPOWER is the design of an innovative 10 MW lightweight, robust and reliable superconducting generator that permits to scale up wind turbines up to 10 MW and beyond and that overcomes some of the presented barriers of other SCG concepts.

The patented generator concept (EP2521252 B1) is a low speed salient pole synchronous machine [13]. It is a partially superconducting generator, superconducting MgB_2 wires at cryogenic temperature are used in the field coils while copper wires at ambient temperature in the armature coils. The cooling system uses a cryogen free topology that does not use liquids at cryogenic temperatures. It has a warm iron rotor configuration, which consists on one modular cryostat per pole that encloses only the superconducting coil (at cryogenic temperature) while the iron of the pole remains at room temperature, thus minimizing the mass to be cooled down and facilitating the repair and maintenance works onsite. Heat is extracted by conduction through a thermal collector inside a cryostat which links all the modules. This is cooled by conduction by two-stage Gifford-McMahon (GM) cryocoolers which rotate jointly with the rotor.

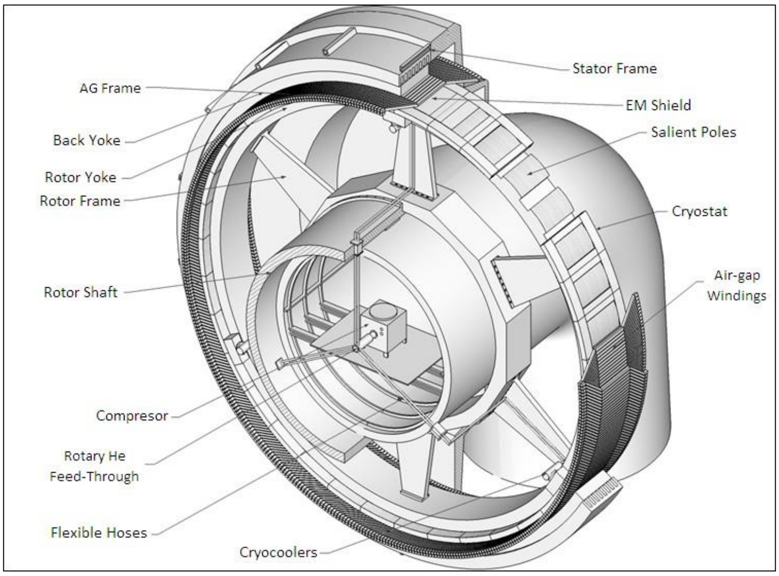


Figure 3. Superconducting generator concept patented by TECNALIA (EP 2521252)

This design is intended to achieve much higher magnetic field in the airgap than conventional generators, which involves volume and mass reduction. MgB_2 wire has been selected as it shows a cost-performance ratio more competitive than other HTS wires. The cryogen free topology that avoids the use of cryogenic liquids, simplifies the installation in the nacelle of a wind turbine and it also increase the reliability of the system.

1.3.1.2 10 MW superconducting generator design

On the basis of this patented concept a 10 MW, 8.1 rpm and 48 poles based on MgB_2 field coils has been designed. Initially, an 11.9 m airgap diameter and 60 poles generator was designed [14] and after several iterations and optimizations 10.1 m airgap diameter and 48 poles generator design has been selected. The design of the SCG requires putting special focus on the design of superconducting coils and cryostats, described in detail in sections 1.3.2 and 1.3.3 of this report.

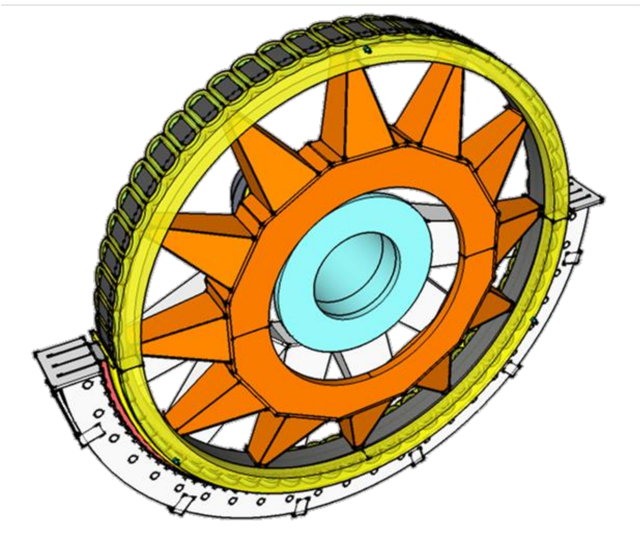


Figure 4. 3D view of the 10 MW SUPRAPOWER generator

The electromagnetic layout of the SCG is similar to the one of conventional synchronous salient pole generators. The position of the stator is external to the rotor. As it can be appreciated in Figure 5 one of the main geometrical constrains for the SCG is a polar pitch of 660 mm (distance between poles), this value is higher than in conventional salient poles machines because it is conditioned by the coil (in green) and modular cryostat (in blue) dimensions. Polar pitch influences highly on the design of the generator and determines the diameter of the airgap.

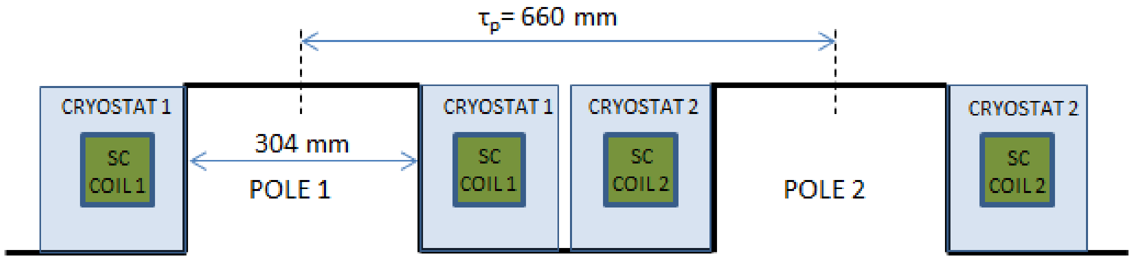


Figure 5. General electromagnetic layout

Electromagnetic Finite Element Analyses (FEM) at no load, nominal load and in shortcircuit conditions have been done in order to study the generator steady state and transient performance. Due to the symmetry of the generator, the simulation model has been reduced to 1/24 of the machine, which covers 2 poles. Figure 6 shows the obtained no load characteristic, as it can be appreciated the generator starts saturation with a field current of approximately 50 A, while around 70 A are required for obtaining the rated voltage of 2,280 V in the stator winding terminals.

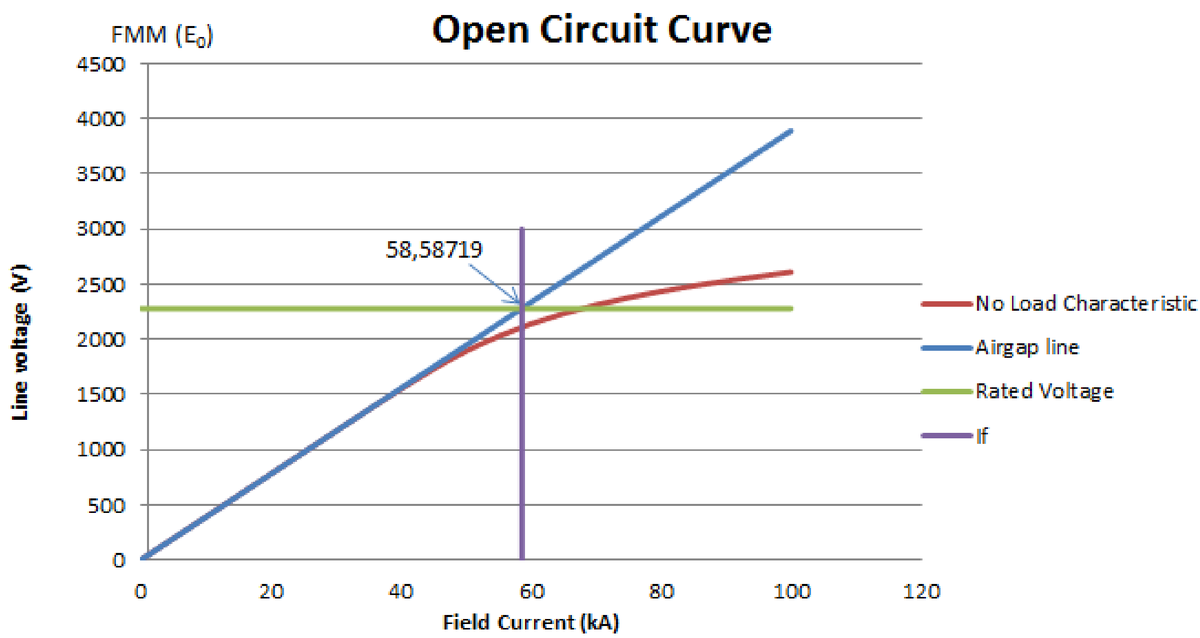


Figure 6. No load characteristics

A magnetic field map corresponding to 2 poles at 10 MW nominal power with 0.95 power factor in the generator is shown Figure 7 The iron poles are the most saturated parts with a maximum value of 2.36 T (not taking in account the pole tips) and the peak magnetic field in the superconducting coils is 1.37 T. The interpolar leaked flux represents the 12.5% of the total flux.

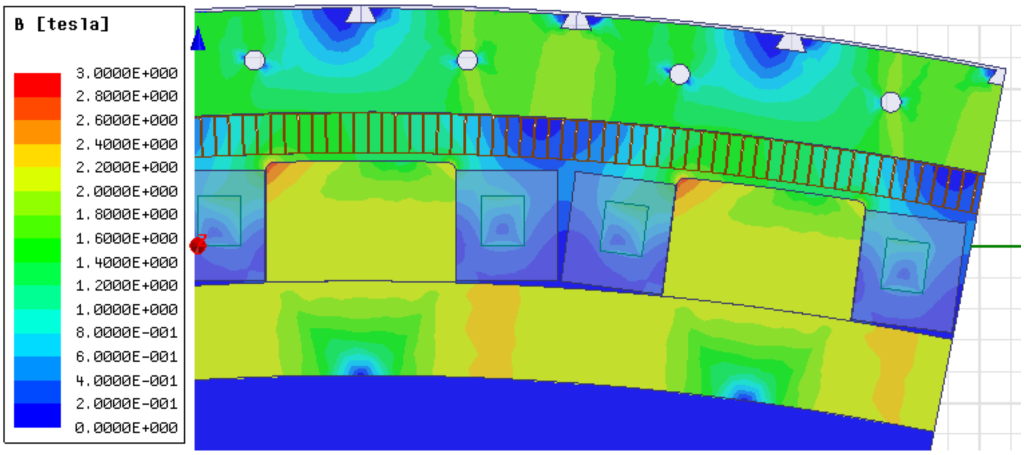


Figure 7. Magnetic field map of 2 poles.

The magnetic field in the airgap has been extensively studied as it is one of the most relevant parameters to design an electric machine. Figure 8 shows the magnetic field along a polar pitch measured in the diameter of the middle radius of the airgap winding (10.16 m), a peak value of 1.5 T has been obtained.

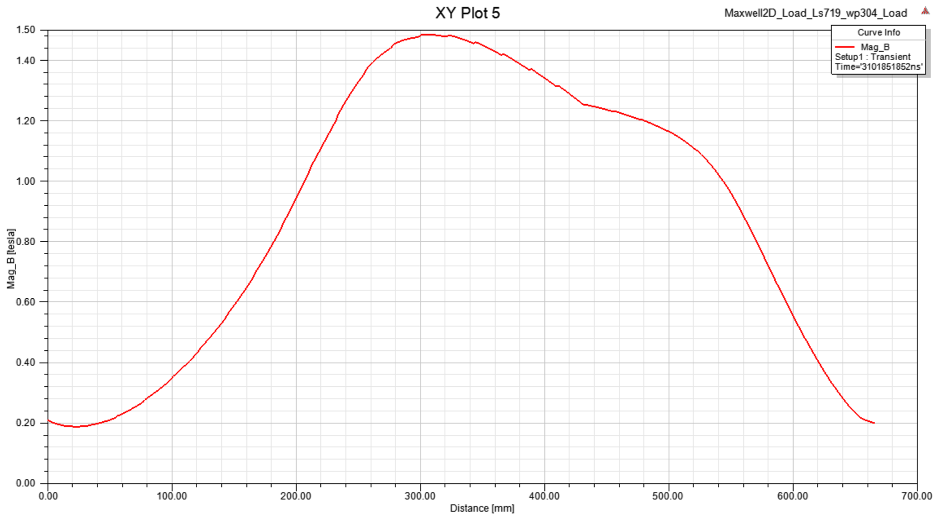


Figure 8. Magnetic field in midplane of airgap winding

In order to evaluate the characteristics and advantages of the SCG, a DD PMG of same power and similar characteristics has been defined, following when possible the same criteria used for the design of the SCG. The resulting PMG is 10 MW 8.1 rpm machine with 360 $Nd_2Fe_{14}B$ poles, 11.9 m airgap diameter and 1.795 m stack length. Next table shows the main parameters of the two versions of the SCG and the PMG.

Parameter	SCG 1stversion	SCG optimized	PMG
Power	10 MW	10 MW	10 MW
Speed	8.1 rpm	8.1 rpm	8.1 rpm
Torque	11.8 MN·m	11.8 MN·m	11.8 MN·m
Number of poles	60	48	360
Frequency	4.05	3.24 Hz	24.3 Hz
Location of armature	External	External	External

Parameter	SCG 1st version	SCG optimized	PMG
Field source	MgB_2 coil	MgB_2 coil	NdFeB magnet
Field source operating temp.	20 K	20 K	373 K
Armature winding	Copper, Class F	Copper, Class F	Copper, Class F
Armature diameter	11.9 m	10.10 m	11.90 m
Gross magnetic core length	548 mm	744 mm	1,794 mm
Polar pitch	612 mm	660 mm	100 mm
Specific shear stress in airgap	112 kPa	112 kPa	30 kPa
Rated voltage	2,280 V	2,280 V	1,725 V
Rated current	2,665 A	2,665 A	3,523 A
Armature current density	2.7 A/mm^2	3 A/mm^2	3 A/mm^2
Armature current load	120 kA/m	120 kA/m	65 kA/m
Mechanical airgap	15 mm	15 mm	15 mm
Armature winding cooling	Forced air	Forced air	Forced air
Induction peak value in airgap	1.5 T	1.5 T	0.79 T
Pole body height / width	200 / 290 mm	191 / 304 mm	42 / 70 mm
Efficiency at rated power	95.2 %	95.2 %	94.5 %

Table 1. Main parameters of the 10 MW SCG and PMG

The armature, the static part of this generator, basically consists on a magnetic core, a copper winding and an external fixing frame. The armature doesn´t have any magnetic teeth, as these would be saturated due to the high magnetic fields generated by the superconducting coils. Hence an airgap winding configuration has been chosen. Unlike conventional armatures, the most important constraint is that the magnetic core has no slots to hold the air gap winding and to transmit electromagnetic forces from the winding to the magnetic core, therefore specific solution to fix the armature coils must be used. As an inherent consequence of the no use of teeth, the weight of the armature is reduced and there is more space for the winding. The magnetic core is made of a stack of 0.5 mm of M45 magnetic Silicon steel sheets packaged with pressure disks and isolated bolts, which show 5.31 W/kg losses at 1.5 T. One layer lap winding of 3 kV class isolation level copper coils with identical coil span has been chosen.

The rotor of the SCG basically consists on iron back yoke and poles, superconducting coils, cryostats and cryocoolers. The back yoke and poles are made of cast low carbon Steel AISI 1008. Each field coil is housed in a modular cryostat concentrically placed around the pole. Superconducting coils and cooling systems are explained in detail in next sections.

As indicated in Table 1 the calculated onsite efficiency of the SCG, taking into account the power consumption of all the auxiliary elements as compressors and cryocoolers, is around 95.2% at the rated power, while the PMG one is around 94.5%. It is remarkable that the efficiency curve of the SCG is slightly above the PMG for all the power range. Cost estimation has been done on the basis of MgB_2 wire cost of 3 €/m. Armature Cu coil cost of 50 €/kg and iron cost of 5.5-8 €/kg have been considered, depending on the component and current commercial costs of the auxiliary components. An overall SCG active parts cost of 307 k€/MW has been obtained, while the cost estimated for the PMG with NdFeB magnets price of 39 €/kg (November 2013) is 313 k€/MW. The SCG has a huge margin for further cost reduction driven by the MgB_2 wire performance improvement and the industrialization of the manufacturing process.

1.3.2 MgB2 superconducting coils

1.3.2.1 Superconducting wire

Columbus Superconductors SpA with the collaboration of IEE has designed and manufactured a specific MgB_2 wire for magnet applications. It consists in a 3 x 0.5 mm^2 superconducting tape with 19 filaments embedded in a Ni matrix. The tape is produced with the Powders In Tube (PIT) manufacturing process in single batch length between 1.5 and 3 km [15].

Parameter	**Value**
Number of MgB_2 filaments	19
Filling factor around (without stabilizer)	24.1%
Dimensions without copper	3.00 x 0.50 mm
Copper strip dimensions	3.00 x 0.2 mm
Dimensions with copper (bare)	3.00 x 0.70 mm
Insulation	Dacron 62.5 µm
Dimensions with copper (insulated)	3.125 x 0.825 mm
Ic @ μ_0H= 1.8 T, 20 K	150 A
dIc/dB @ μ_0H =1.8 T, 20 K	100 A/T
Jce,wire (A/mm^2) @ μ_0H = 1.8 T, 20 K	58.18 A/mm^2
dJce/dB (A/mm^2) @ μ_0H =1.8 T, 20 K	38.79 A/ mm^2/T
Minimum bending diameter	150 mm
Cost	3-4 €/m

Table 2. Main parameters of the MgB_2 used in SUPRAPOWER

To enhance the thermal stability of the wire and of the devices in which it's implemented, a high purity copper strip is soldered on the tape surface after the final heat treatment of the wire. All the issues related to the perfect alignment of the copper strip on the tape surface have been solved by optimizing the soldering process and now this strip can be perfectly aligned and soldered as shown in Figure 9.

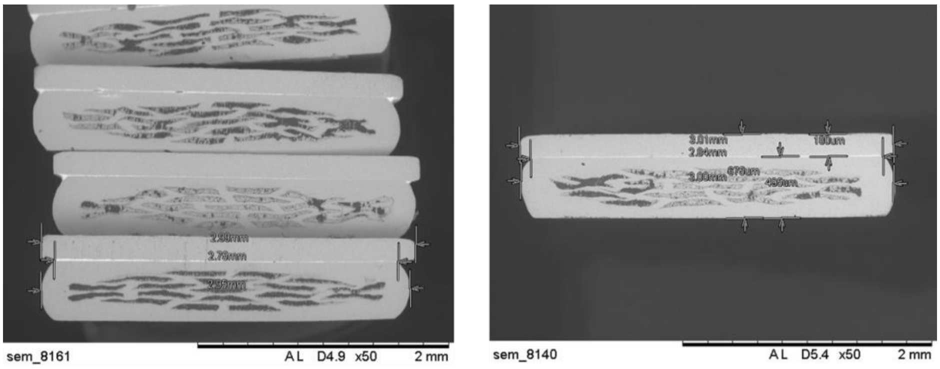


Figure 9. SEM images showing the perfect alignment between the copper strip and the MgB2 tape after the optimization of the soldering process

Strain tolerance of the tape subjected to stress and bending has been extensively studied. In particular, the practical limit of bending diameter is 150 mm with the copper outside [16]. Typical critical current values obtained with the magnetic field orthogonal to the tape surface are plotted in Figure 10. Cost-performance ratio is in the range of 20 €/kA m and Columbus anticipates an improvement of this ratio based on the enhancement of the performance mainly due to new precursors, better process implementation, and manufacturing costs reduction due to economies of scale [17].

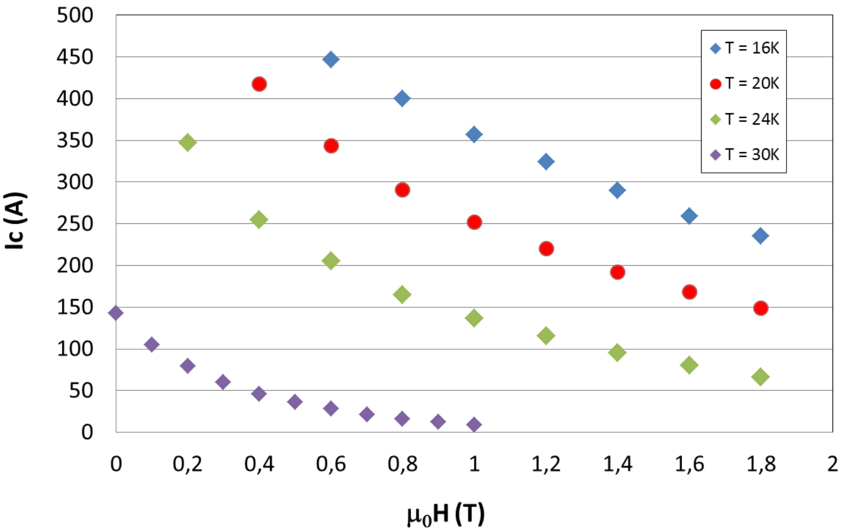


Figure 10. Critical current characterization vs field at different temperatures

The main details of the MgB2 wire can be found in “D2.1 Improved MgB2 wire” SUPRAPOWER project public deliverable.[18]

IEE has analysed the perspectives of improving the critical current at relatively low fields (1-1.5 T) by working on the precursors powder quality in the MgB_2 composition and a different synthesis route. Several wire architectures have been also analysed implementing the results about the powders, increasing the filling factor of the wire the strength of the metal sheaths of the wires. Finally a new wire configuration shown in Figure 11 has been proposed to be implemented for future intermediate magnetic field application, as the one of SUPRAPOWER.

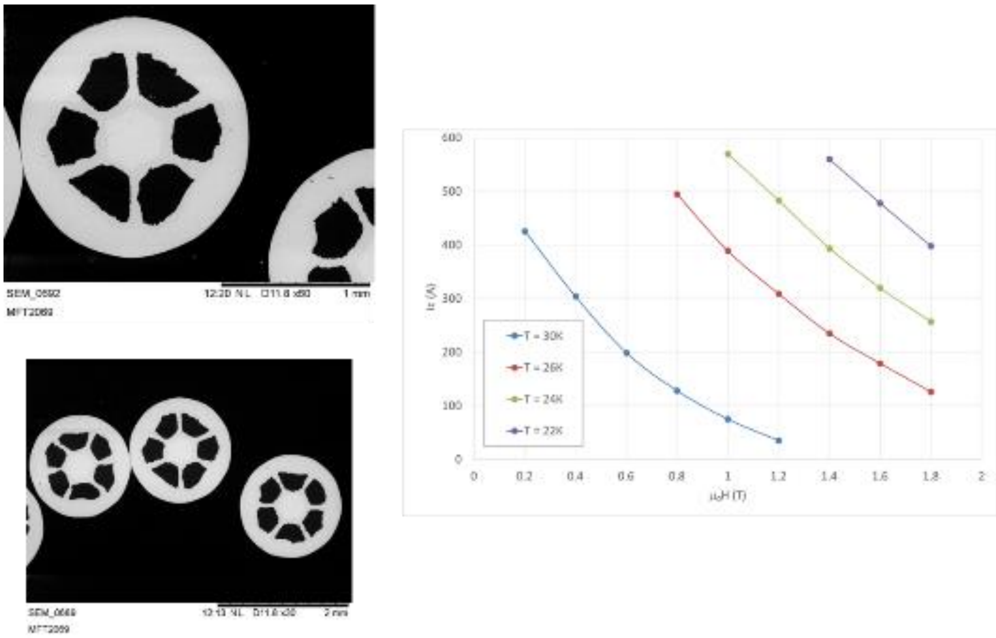


Figure 11. Cross section and critical current versus external field of new developed round wire with a diameter of 1.5mm manufactured by COLUMBUS

The critical current of this wire (1.5 mm diameter) has been analysed at different operating temperatures as shown in the graph of Figure 11. At 20K and 1.8T field the critical current is higher than 600 A, three times higher in comparison with the tape used in the scale machine. This improvement could permit to simplifying the SC coil by reducing the length of MgB_2 wire need and in consequence the number of turns of the coil. Finally this would permit further reduction of the weight and volume of the SCG. All the details of this study have been reported in "D5.1 Improvements in the critical components of the 10 MW SCG" SUPRAPOWER project public deliverable [20].

In conjunction with the experimental work performed in the prototype pancake coils during the project, a series of simulations were performed at University of Southampton to understand better the behaviour of the winding under external magnetic fields. The influence of a ferromagnetic metal matrix in the magnetic field inside the filaments of an MgB_2 tape was analysed for different filament configurations. The results showed that the reduction of the critical current would be 1% - 2% depending on the magnetic field applied. The analysis was extended to the case of a SC coil based on the scaled machine coil designs. The determination of the load line of the coil, considering it as a bulk ferromagnet, leads to an underestimation of the critical current of the coil. If the filaments are not considered ferromagnetic, a reduction of the average magnetic field in the coil is observed. For the stack of 9 double pancake coils the magnetic field values and load-line of the coil can be determined using a pure non-ferromagnetic model without obtaining significant differences which saves computational time.[21]

Additionally, modelling analysis to study the mechanisms that change the MQE in superconducting coils was done using two models: a FULL 3D and a CM. It has been seen that for a given set of parameters the MQE of the coil can be in the order of magnitude of that predicted by 1D analytic equation. The MQE is strongly affected by the thermal conductivity of the insulation and can increase the MQE of the coil of few orders of magnitude from 1D to 3D, due to the change in the volume of the MPZ.

However the change of the thermal conductivity of the coil on its own does not explain the change in trend in the MQE observed experimentally in a solenoid coil [22]. Only a smooth transition from 1D to 3D is observed in the simulations. To obtain the transition observed experimentally, cooling needs to be added from a boundary layer. This induces the transition due to the movement of the hotspot to an adjacent turn of where the heat is deposited due to the effect of cooling. Only the FULL 3D model was able to produce the transition while the CM model overestimates the MQE values. Therefore, the FULL 3D model is preferable to study the quench processes even if it has a higher computational costs, since there are mechanisms that cannot be reproduced with the CM [23]

Figure 12(Left) shows the average axial (full lines) and radial (dashed lines) magnetic fields in the filaments, produced by a 70 turns double pancake, as a function Iop for the three analysed models: Full ferro (squares), Ferro (circles) and Non-ferro (no symbols). The values are taken from the filaments where the maximum field was produced. Ic(B) for different temperatures in the MgB_2 conductor used in the coil manufacture together with the predicted load-line of the SC4 prototype (spheres) are also included. Figure 12 (Right) shows MQE as a function of 1 - j obtained experimentally (triangles) and numerically using the FULL 3D model (squares) and CM (circles) when the heater is moved to the outer layer and a boundary layer with T = T0 is added to the solenoid

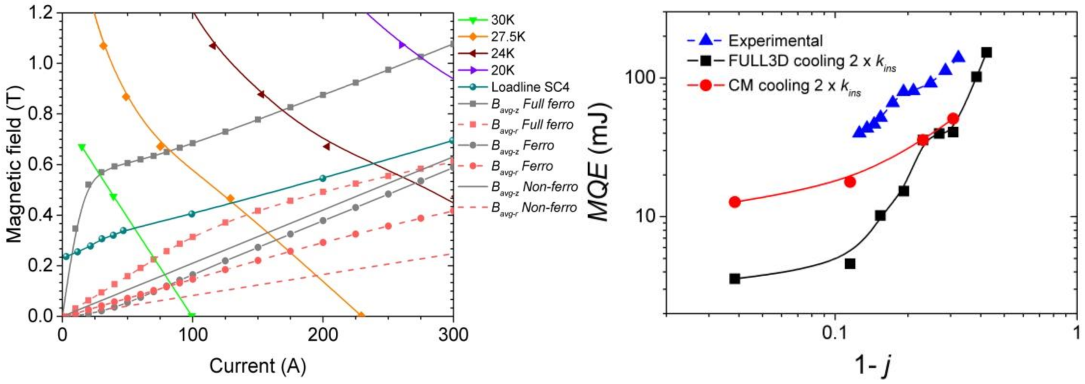


Figure 12. Results of the anlysis of the behaviour of the winding under external magnetic fields

1.3.2.2 Superconducting coil design

Field coils are constituted by a stack of 9 racetrack MgB_2 double pancake (DP) coils connected in series as shown in Figure 13. Each DP is made of two identical layers of MgB_2 wire wound in opposite direction without splices and with an oxygen free copper sheet placed between the two layers to assure the refrigeration of the wire. Once wound, the DP is vacuum impregnated with Araldit F resin. The DP coils are stacked between two 8 mm coppers caps and they are connected in series through specific electric joints. The Cu inserts of the 9 DPs are thermally connected through Cu laps to the upper and lower caps, which are connected to the thermal collector to extract the heat from the coils.

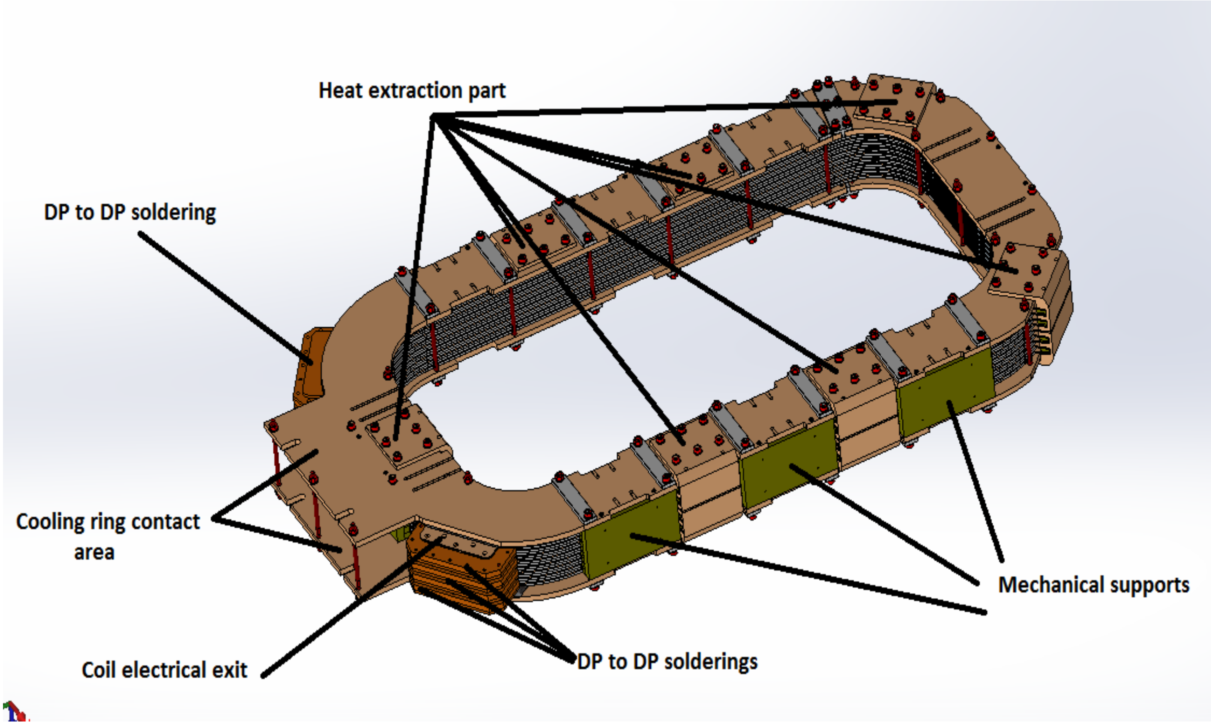


Figure 13. MgB2 field coil design

The main parameters and dimensions of the coil are described in Table 3. Throughout the SUPRAPOWER project lifetime the coil design has been updated and improved according to the experimental findings.

Parameter	Value
Total number of DPs	9
Insulation layers between DPs	G11
Number of Insulation layers	8
Thickness of insulation layer	0.2 mm
Number of Cu caps	2
Thickness of Cu cap	8 mm
Total MgB_2 wire length	3200 m
Turns per DP	145
DP total height	8.40 mm
Coil body straight section length	622 mm
Coil end parts straight section length	185 mm
Coil inner / outer radius	100.20 mm / 165 mm
Coil total height	93,6 mm
Impregnation	Araldit F (VPI)

Table 3. MgB2 field coil main parameters

The design of the coil has been supported by electromagnetic and thermal simulations carried out by the University of Southampton and Tecnalia [24]. One of the most important design aspects is thermal behaviour of the coil given that heat is extracted by conduction from one connection point to the cryocooler. Figure 14 presents the thermal distribution inside the coil, and for each DP. Temperature gradients are below 0.1 K showing a good thermal stabilization that the Cu insert provide inside each DP. The models have been later validated by the experimental results.

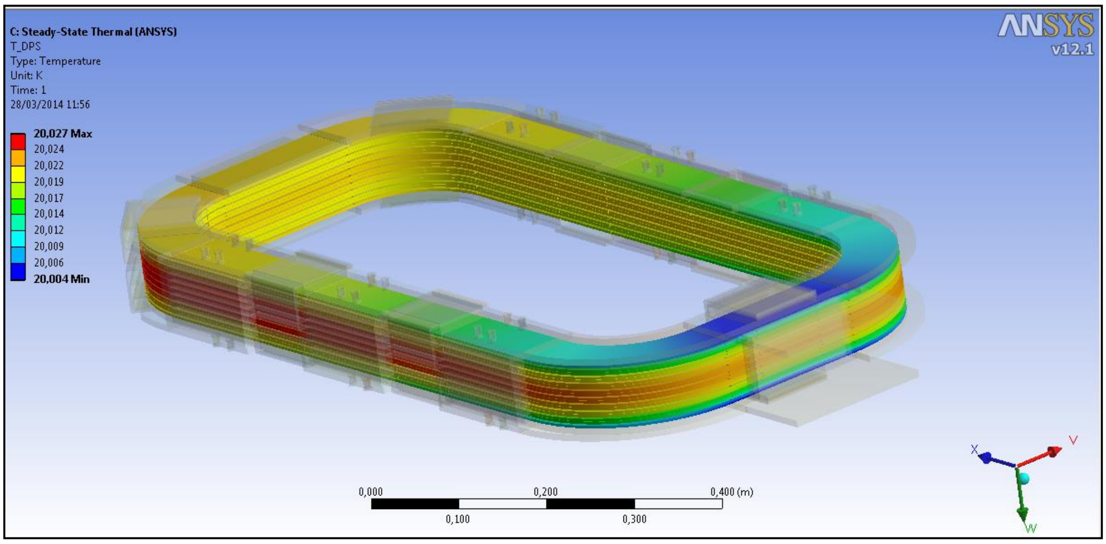


Figure 14. Thermal distribution inside the coil

1.3.2.3 Initial Small test coils

Before any full size coils were constructed, two small test coils were produced to validate the design and manufacturing process (see Figure 15). First, a circular, 1 layer, 7 turns coil was built to analyse the wire behaviour under specific winding diameter and cryogen free refrigeration [25]. Second, a circular, 30 turns DP coil was built to validate the winding, impregnation and test procedures to be applied in the real scale DP. These were tested in a general purpose cryostat at same working conditions. The manufacturing process and test results of this last coil are available in the SUPRAPOWER's public deliverable “D2.3 Report on Design and manufacturing of an MgB_2 coil”.[24]

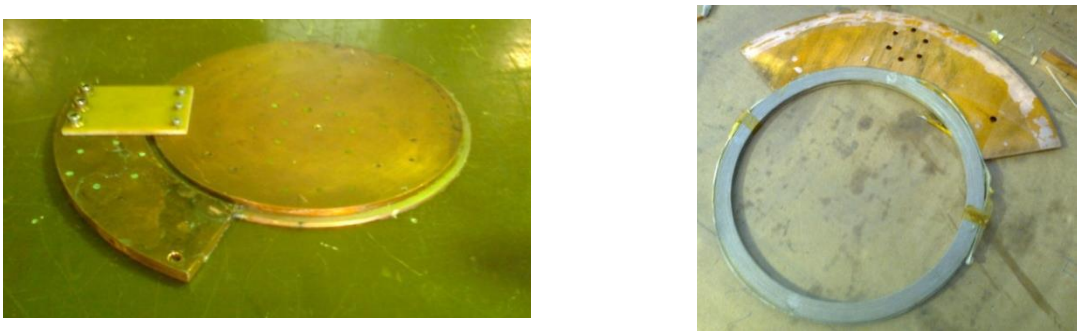


Figure 15. (left) 7 turns coil (right) 30 turn double pancacke coil

1.3.2.4 First MgB2 real scale double pancake coil

After this small size coil, a first real scale DP coil (Figure 16 left) was manufactured by Tecnalia at CIEMAT's facilities in Madrid.

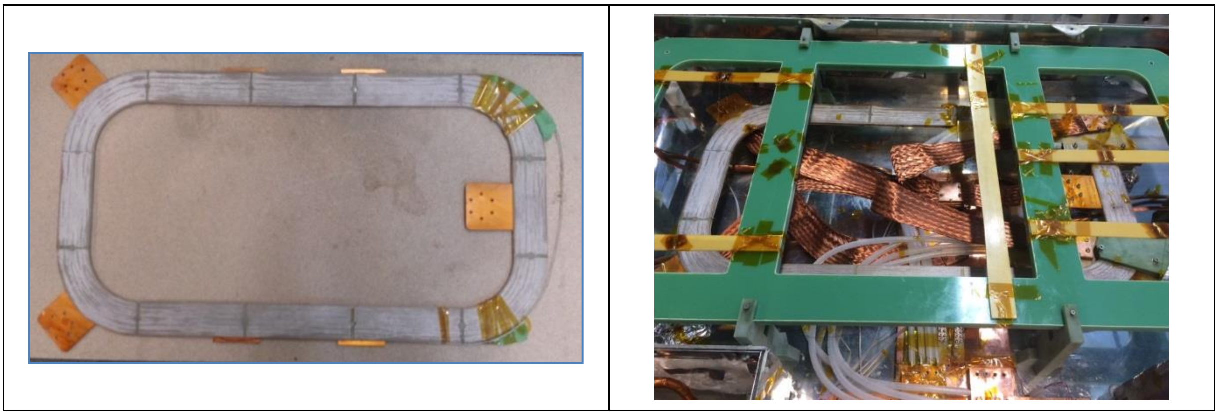


Figure 16. (left) DP coil first prototype (righ) Experimental assembly of the DP coil

The DP has been extensively tested in a laboratory cryostat at Tecnalia [26]. All the details of this work are available in [26] and in “D2.4 SUPRAPOWER Test report of the MgB2 coil” public report [27].

The transition to superconducting state during the cooling down of the DP has been recorded with 0.9 A applied current. Similar test has been carried out switching off the cryocooler in order to register the transition to resistive state during warming. Through the analysis of the obtained results it is estimated that the average transition in the coil is at 35.7 K. Figure 17 presents the overall coil *V-I* characteristic obtained at 30 K (m. Voltage measurements are fitted by using the power law (2),

$$E = E_0 \left(\frac{I}{I_c}\right)^n \text{ (2)} \qquad (2)$$

where *E* is the electric field measured between the two ends of the coil, E_0 is the criteria for the critical current, *I* the transport current and the critical current I_c(B,T) and *n*(B,T) the fit parameters. I_c of 91.79 A, 133.59 A and 146.26 A have been obtained at 30 K, 28.5 K and 27.5 K respectively. The fitted *n* value is about 10 for the overall coil at the studied temperatures.

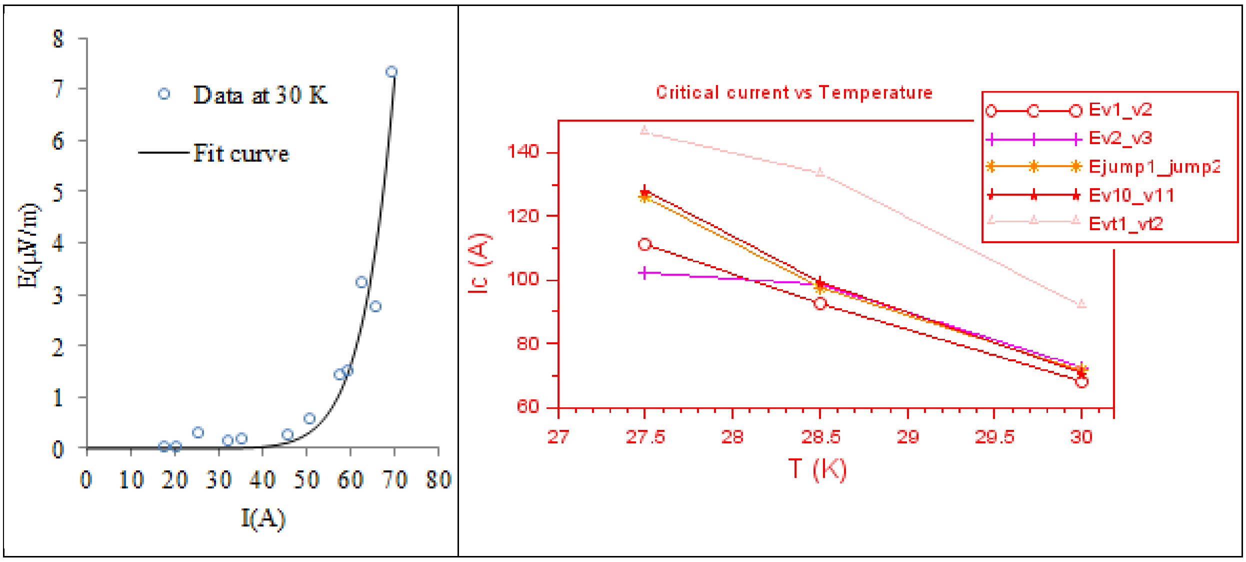


Figure 17. DP coil (lef) V-I characteristic (right) Critical current at sevaral temperatures

Figure 17 (right) shows the thermal evolution of I_c for several segments of the coil (v1-v2, v2-v3, jump1-jump2, v10.v11) and for the overall coil (vt1-vt2). I_c presents a similar trend for all the segments and for the overall coil with the exception of the lowest temperature for V2-V3. These I_c values are consistent with the expected results derived from the calculated load lines.

Finally it is concluded that the electrical behaviour of the DP, the obtained critical current and thermal behaviour as expected and according to the electromagnetic and thermal simulations carried out.

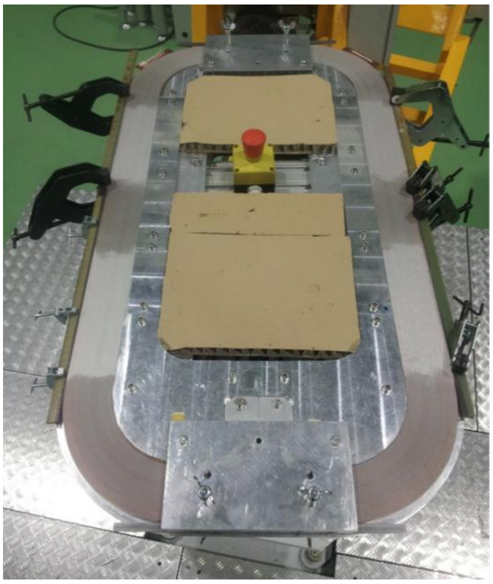
1.3.2.5 Manufacturing and test of the scale machine MgB_2 field coils

Once validated the first DP, Columbus and TECNALIA has manufactured and tested the 2 superconducting coils (see Figure 13) of the magnetic rotating validator (see 1.3.4 section).

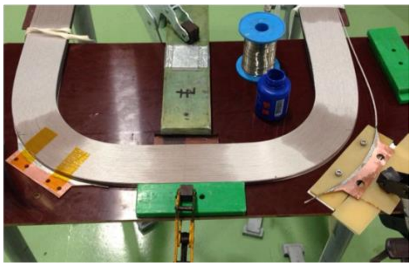
The process to manufacture the complete DP ready to be assembled in the coil is quite complex. Once the winding is finished (about 360 meter of tape in two layers with 72 turns each one, by using the same procedure as in deliverable D2.3 [24]). Then the tape 2 ends are electrically connect the copper pieces that perform as electrical exists, this is done by soldering the copper pieces to the tape of the external turns (Figure 18).

Throughout the project lifetime the manufacturing process and the design of the coils have been updated according to the obtained experimental results. Thus for example the electrical connections were improved, copper pieces for thermal connections were slightly redesigned to improve the manufacturability and the impregnations process was modified so that to impregnate 9 DPs at time, while the first DPs were impregnated one by one.

Next figure shows some of the steps of the manufacturing and assembly sequence

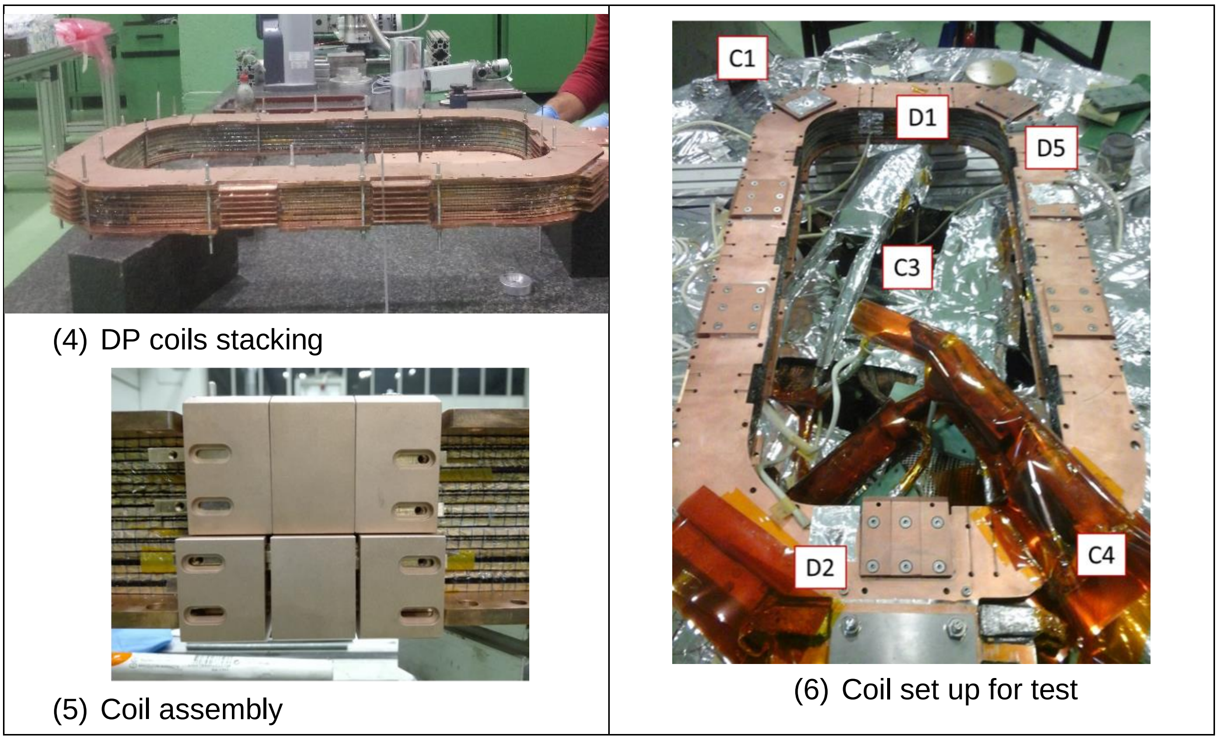


(1) winding



(2) terminal soldering

(3) impregnation



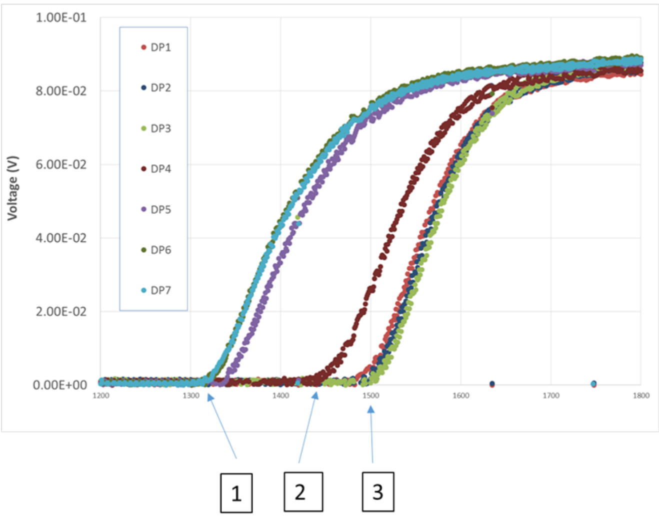
(4) DP coils stacking

(5) Coil assembly

(6) Coil set up for test

Figure 18. MgB_2 field coils manufacturing sequence

The two coils have been extensively tested in a laboratory cryostat before its assembly inside the modular cryostat of the scale machine. Test results in the first coil have shown a very homogenous thermal behaviour, with less than 0.6 K difference between the opposite ends of the coil (see Figure 19). It has been found that one of the DPs is damaged (Figure 20 shows the transition of DP num. 7) while the other DPs perform as expected.



Temperatures at the transition points

	C1 T(K)	D2 T(K)
1	34.3	34.4
2	34.7	34.9
3	34.9	35.1

Figure 19. Transition of DPs while warming up

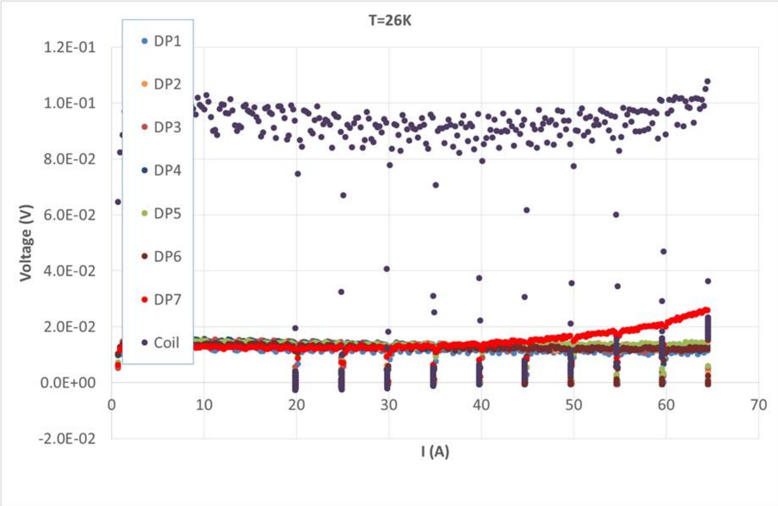


Figure 20. Voltage acquisition ramping the current at 26

Finally, even though one DP performance has not been as desired due to some manufacturing defects, it has been concluded that the developed coils are suitable for operating in a 10 MW wind turbine. These coils have then assembled in the scale machine (see 1.3.4 section).

1.3.2.6 Quench detection and protection system

The quench detection and protection systems are essential elements to protect the SCG in case of quench. This aspect has been extensively studied for both the SCG and the scale machine.[19] [28]

The quench detection system that has been designed, described in detail in [28], is based on the resistive voltage measurement and is a redundant system with three levels of protections.

- First level: threshold voltage, measured in the power supply terminals, which will work only in case of failure of the other two protection levels.
- Second level: comparison of two coils voltage, only different in case of quench.
- Third level: threshold voltage of the resistive voltage of the inductor circuit. Inductor’s circuit current and voltage are measured and then the inductive voltage component is calculated and subtracted.

The quench detection systems have been implemented in the National Instrument CompactRIO hardware platform. A protection system has been developed by Tecnalia for the scale machine. The system is based on the fast discharge on a dump resistor as soon as the quench is detected and switching off at the same time the power supply that feeds the coils. The resistor bank is constituted by 2 group of resistances serial connect as shown in, one is mounted on the back yoke that rotates jointly with the rotor and the other one is a stationary resistors bank connected to the coils through the slip rings. This topology permits to protect the coils even in case of a fail in the slip rings.

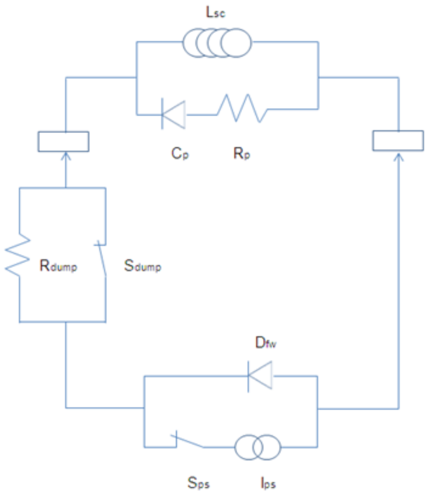


Figure 21. (Left) Quench protection scheme (Right) Stationary resistors bank

The protection of the rotor circuit with a simple dump resistor connected in parallel is valid for the case of the scale machine, however as explained in [19] it is not totally satisfactory for the 10 MW SCG due to the large discharge time, which could yield in hot spot in case of poorly refrigerated segments, so that solutions for MW scale machines must be further studied.

1.3.3 Cooling system and cryostats

On the basis of the initial concept developed in the patent, KIT in collaboration with Tecnalia has designed the SCG cooling system and cryostats. Warm rotor iron configuration with one modular cryostat per coil has been chosen as the best option although other alternatives have been also considered. This configuration needs lower cooling power as the rotor poles are kept at room temperature and the modularity facilitates the repair and maintenance works onsite. The main drawback of this solution is a higher polar pitch than in conventional generators.

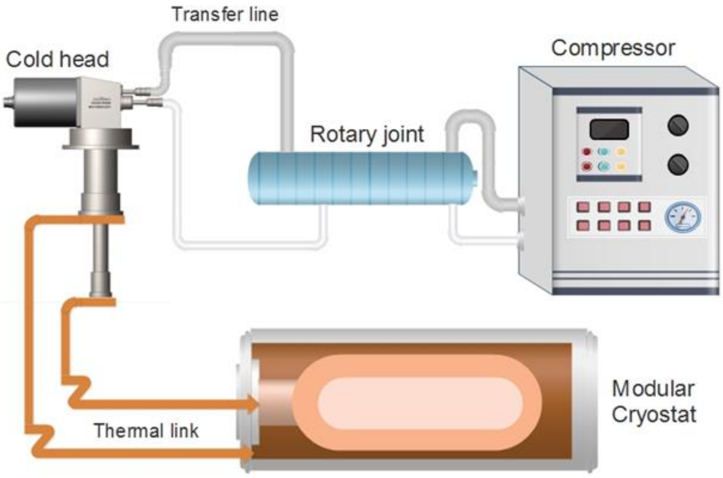


Figure 22. Cooling scheme [29]

Superconducting coils are contained in 48 modular cryogen-free cryostats, one per coil. Heat is extracted by conduction through a thermal collector which links all the modules. This is cooled by conduction by two-stage GM cryocoolers which rotate jointly with the rotor. In contrast to pool boiling cooling system, only a small quantity of He gas is required for the thermodynamic cycle of the cryocoolers. This He circulates in a close circuit between the rotating cold heads and the stationary He compressors, which are connected by mean of a rotary joint as shown in Figure 22

The thermal collector consists of two high conductivity thermal circuits enclosed by a cryostat (called non modular cryostat). One is connected to the cryocoolers first stage and to the active cooled shield (Temperature ~80 K), and the other to the second stage of the cryocoolers and to the superconducting coils, maintaining them to their operation temperature at about 20 K.

A rectangular shape modular cryostat has been chosen according to the warm iron pole configuration and in accordance with the coil and pole dimensions and space restrictions. It is mainly constituted by a stainless steel vacuum vessel, a copper active cooled shield with a multi-layer insulation (MLI) of approximately 20 layers and the support structure. The support structure is a key component of the modular cryostat, 8 Ti-6A1-4V titanium rods have been adopted for the connection from active cooled shield to the superconducting coil and another 8 titanium rods from the shield to the vacuum vessel. This support structure is replicated in four locations along the cryostat, resulting 64 titanium rods per module. [30]

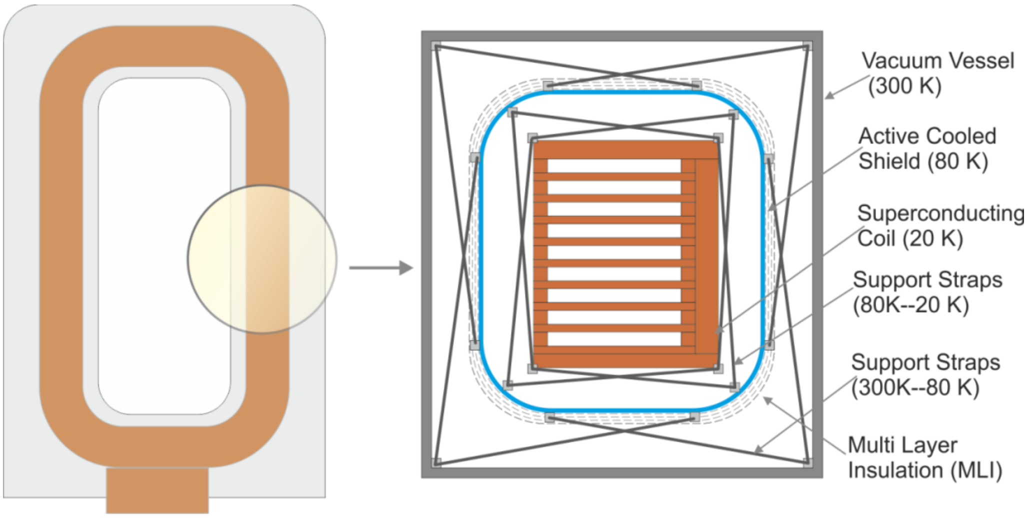


Figure 23. Cross sectional view of the modular cryostat design [30]

1.3.3.1 First modular cryostat

As a first step KIT has constructed one modular cryostat to experimentally test the thermal behaviour of one dummy coil inside the cryostat and validate the cryostat design. This first dummy modular cryostat basically follows the same design criteria of the SCG cryostat. Design details and test results of this dummy cryostat are available in “D3.3 First modular cryostat” [31] and “D3.4 Test results report of the first modular cryostat”, SUPRAPOWER’s public deliverables.

As it can be appreacited in Figure 24, the main difference of this cryostat respect to the ones of the SCG or scale machine, is that it integrates the GM cryocooler. The cryocooler is connected with flexible copper bridges, which act as thermal anchor fitting the displacement caused by the thermal contractions. The support structure is also slightly different but based on the same concept of using sets of titanium rods. A copper dummy coil has beeen constructed to emulate the cold mass and heaters has been installed to emualte the coil AC looses.

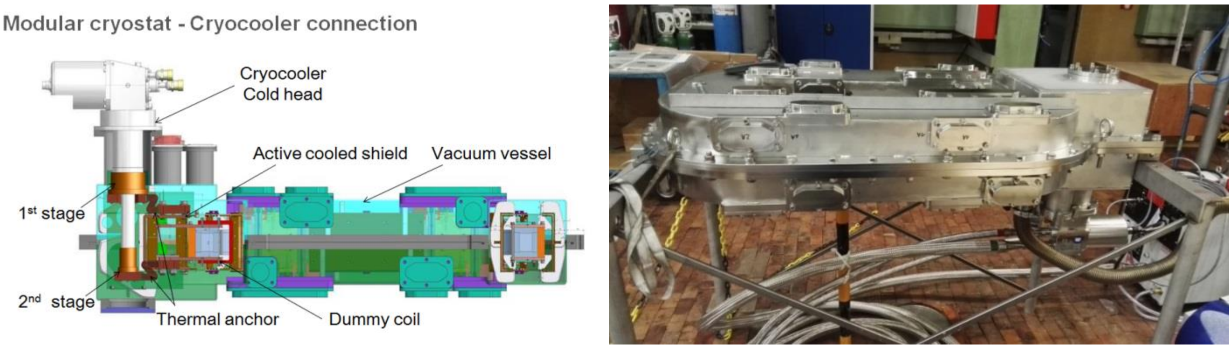


Figure 24. (left) Modular dummy cryostat concept (right) developed dummay cryostat under test

Figure 25 shows both the measured and simulated temperature profile versus time during cooling down of the cryostat. It took about 20 hours for the first stage thermal anchor to reach the lowest temperature, which is around 33 K. The second stage thermal anchor together with the linked dummy coil required 56.5 hours to reach the lowest temperature, which was around 9.8 K and 9 K respectively.

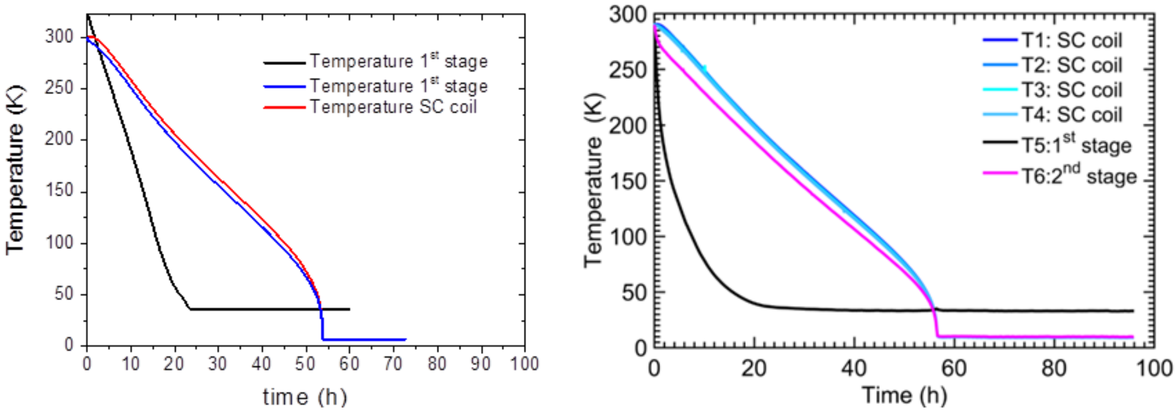


Figure 25. Evolution of temperature as a function of time (left) in the simulations by Southampton (right) and the experimantal results by KIT

1.3.3.2 Design and manufacturing of the cryostats of the scale machine

On the basis of the modular cryostats design, which is exactly the same for the 10 MW SCG and the scale machine, KIT has designed and constructed the cryostats of the SM.

As it can be appreciated in Figure 26, the cryostat of the thermal link, so called non-modular cryostat, adopts a pipe design and a copper bar is used to thermally connect the two modular cryostats and the cryocooler. Both, the vacuum vessel and the thermal shield have a concentric half ring shape in order to achieve an easy assembly. This pipe concept is also valid for the non-modular cryostat of the 10 MW superconducting wind turbine.

The thermal shield made of copper and vacuum jacket made of stainless steel also adopts semi-circle. The cold head of the cryocooler is located in the middle of the semi-circle pipes.

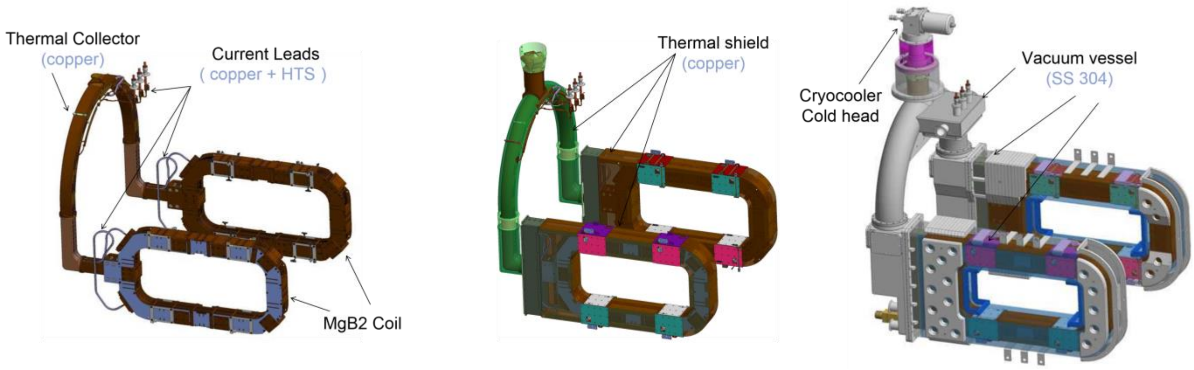


Figure 26. CAD model of the cryostat for the rotating magnetic validator

On the basis of the design showed in Figure 26, KIT has constructed 2 modular cryostats, one per coil, and the so called non modular cryostat.

Figure 27 (left) shows the manufactured modular cryostats. In order to save space, the modular cryostat adopts the welding approach instead of flange connections as proposed in the prototype modular cryostat. As it can be appreciated there are several steel stiffeners in the inner and outer part of the chamber, intended to give mechanical rigidity to the cryostat to prevent deformations during the assembly and welding process. After the assembly of the coil in the cryostat and welding the upper and lower parts of the vacuum chamber, these stiffeners have been cut. Figure 27 (right) shows the vacuum vessel and radiation shield of the non modular cryostat. The shield together with the thermal link can be inserted into the vacuum vessel through a shove circulation

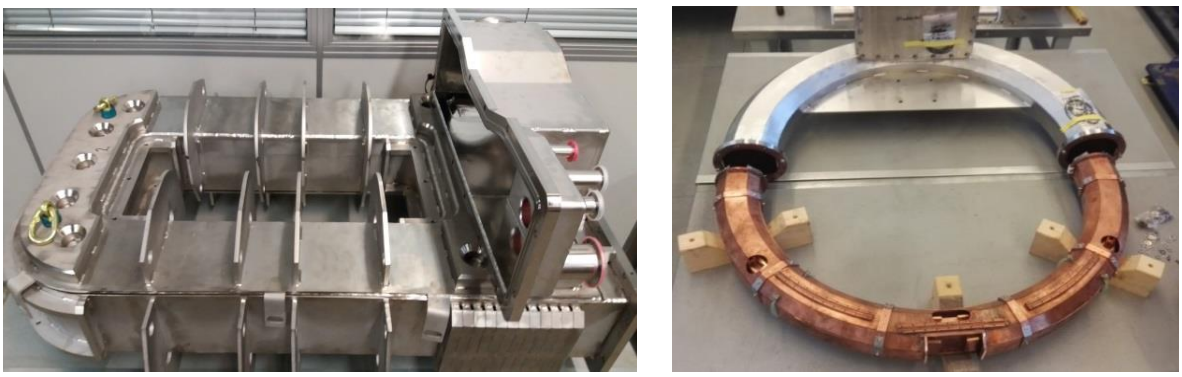


Figure 27. (left) Modular cryostat before coil assembly (right) Therma link and non modular cryostat

1.3.3.3 Rotary joint

The helium rotary union (RHU) is the element prepared to work in the G-M cryocooler to transfer the helium gas between the rotating cold head and the stationary helium compressor, as shown in Figure 22.

The main functionality of the RHU is to connect the stationary part of the machine with the rotary one. It has three parts: gas helium feed-through to connect the cold head with the compressor, slip rings to power electrically the cold heads and optical fibre feed-through to transmit measurement and control signal. The RHU contains two flows of GHe at approximately room temperature, one from the stationary He compressor to the cryocooler (at a higher pressure of about 25 bar) and the other one back from the cryocooler to the He compressor (at a lower pressure of about 8 bar).

As it is explained in [33], two versions of the RHU have been constructed. The first version showed insufficient sealing during the pressure tests, so that a second version has been constructed. The optimised second version of the RHU has successfully reached the specification and design objectives.

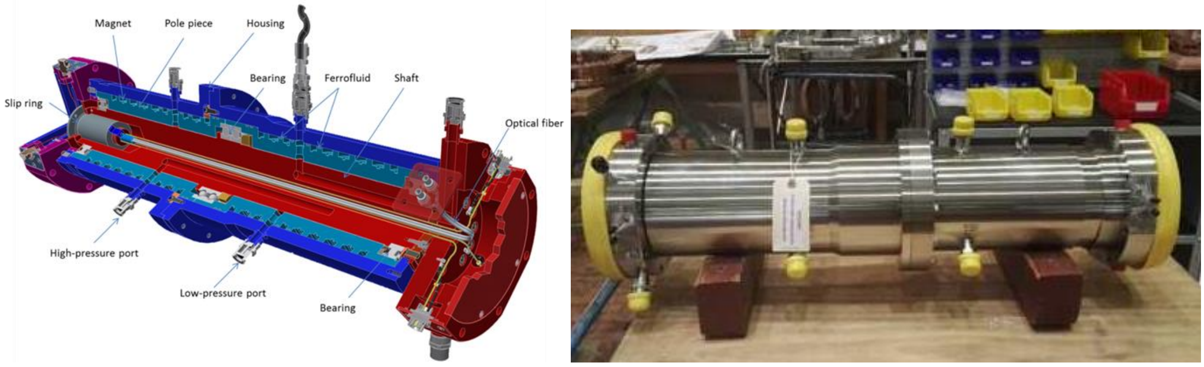


Figure 28. 2nd version of the rotary joint

Figure 28 illustrates a cutaway view of the second version of the RHU, which includes a mid-span bearing to provide a more robust configuration than the first version. The sealing between the stationary and rotating part inside the joint is realized by means of ferrofluid. The rotating seal consists of a permanent magnet, pole pieces, and ferrofluid. The pole pieces and the shaft concentrate magnetic flux from the magnet into a narrow gap region surrounding the shaft. The ferrofluid is attracted to the region known as “stage” forming rings that generate a hermetic seal. Each ferrofluid ring or stage has a pressure capacity of a 70-340 mbar typically.

After manufacturing and assembling the prototype RHU, series of tests have been performed to examine its performance. Figure 29 shows the picture of the test bench used to check the behaviour of the RHU.

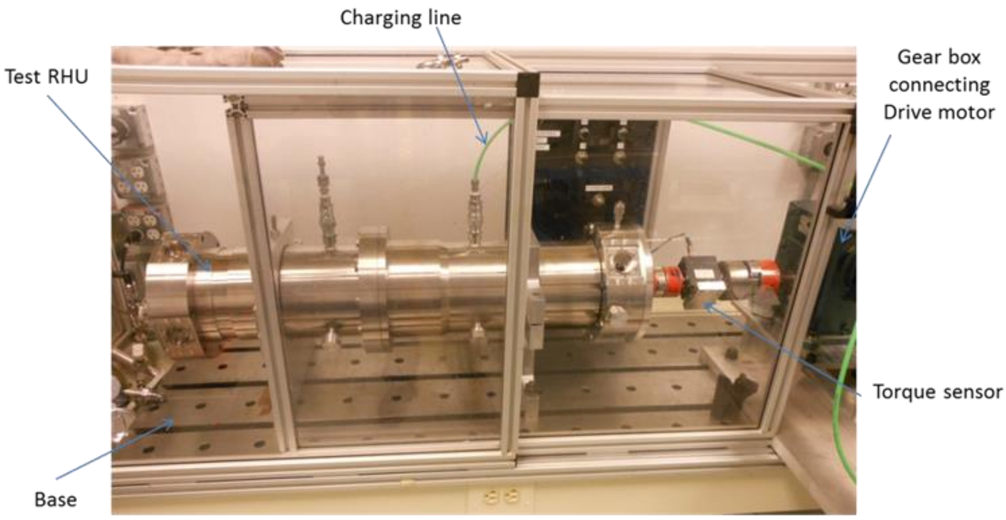


Figure 29. RHU under qualification tests

As it can be seen in Figure 30, no noticeable pressure drop has been observed in both helium lines. The leak rate of the RHU has been tested under stationary conditions using a leak detector. The measured leak rate of both helium lines at specified pressure is smaller than the sensor limit of the detector, which is $1.0\cdot10^{-9}$ mbar·l/s.

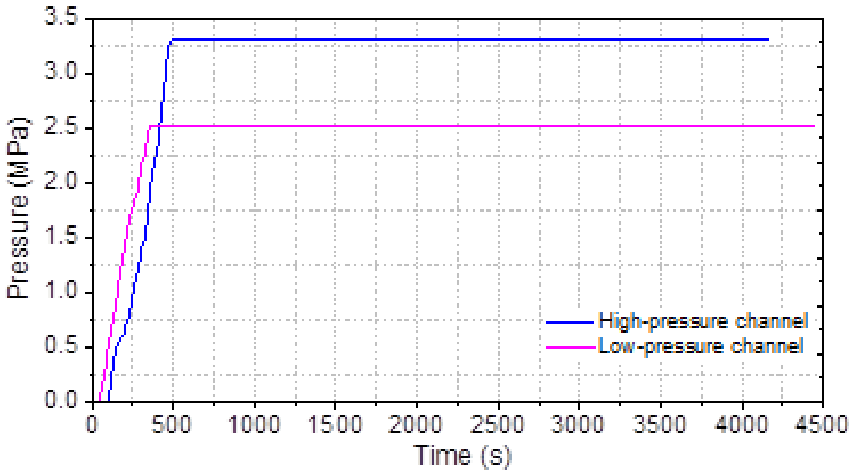


Figure 30. Measured pressure in the RHU as function of time

Figure 31 presents the measured running torque of the RHU at a rotation speed of 150 rpm. The results have been recorded after 24 hours and 48 hours, respectively. After starting the unit, the running torque first rapidly increases to a peak value and then gradually reduces to a stable state. Since the torque transducer has a measurement range up to 50 N·m, the actual peak torque is not illustrated. However, using curve fitting it has been estimated that the maximum starting torque is 57 N·m and 62.5 N·m after a time period of 24 hours and 48 hours, respectively. The normal running torque of the RHU was around 23 N·m. These torque characteristics are very relevant for the selection of the appropriate AC motor to drive the RHU.

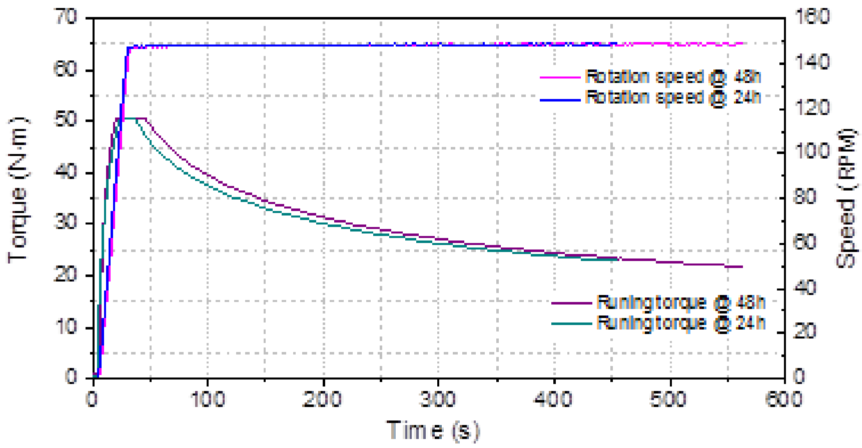


Figure 31. Measured running torque and roation speed of the RHU

After this test the rotary joint has been validated. The design and manufacturing details and test results are available in “D3.5 Rotary joint: specifications, construction and test results” SUPRAPOWER’s public deliverable [33].

1.3.4 Scale Machine: Rotating Magnetic Validator

1.3.4.1 Scale machine design

At first it was studies the possibility to design and construct a scale generator (SG) in the range of 500 kW (see Figure 32). To keep the maximum similitude between the model and the full scale generator, the power reduction was obtained by reducing the number of poles from 48 to 4, maintaining the size of the SC rotor coils identical both in full and small scale generator. However this option was finally discarded due to the complexity and high cost of constructing 4 superconducting coils and cryostats and mainly due to the very high cost of the bench needed to test a 500 kW superconducting machine.

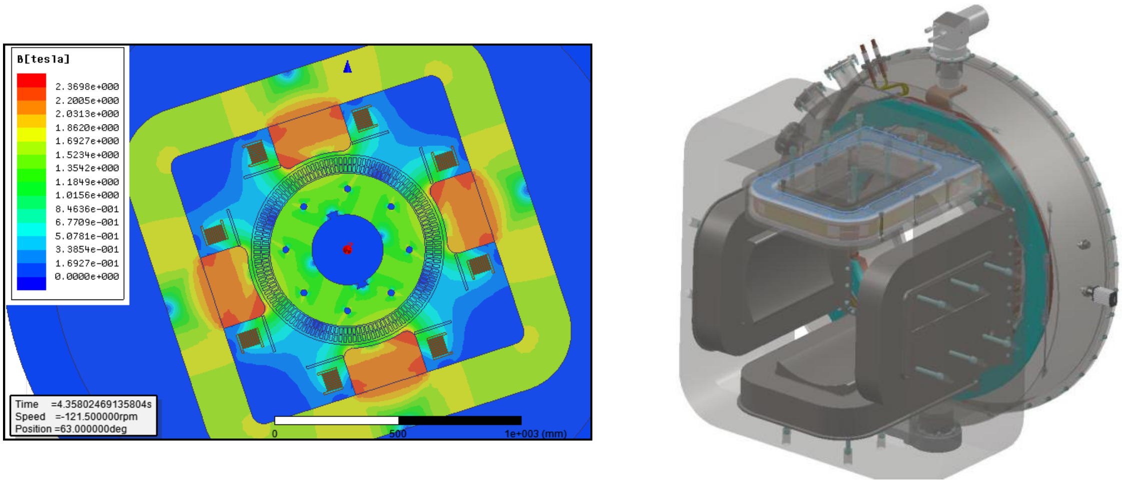
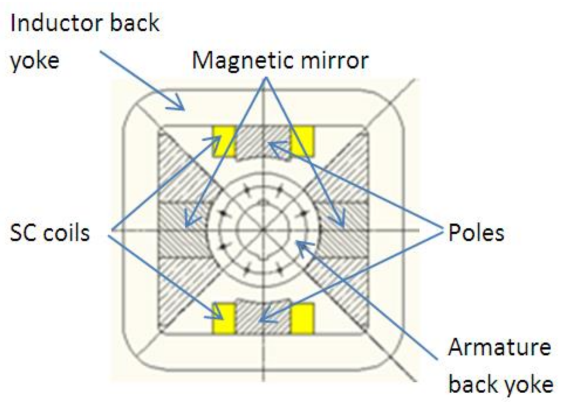


Figure 32. 1st version of the scale generator

On the basis of the first version a second scale machine (SM) has been designed overcoming the above mentioned problems but without relaxing its objectives. The final design of the SM (Figure 34) is rotating magnetic machine that basically consists on a rotating external rotor with 2 superconducting field coils, each one enclosed in a modular cryostat around an iron pole at room temperature. Heat is extracted by conduction through a thermal collector that links both coils. Modular cryostats, coils and poles have the same size and are operated at similar conditions as the 10 MW SCG ones. The cooling concept is the same of the SCG, with the same cryocoolers rotating with the rotor and a rotary joint that links a stationary He compressor with the cryocoolers.

It incorporates a magnetic mirror (Figure 33 left) in order to reproduce with the highest possible accuracy the magnetic behaviour and mechanical stresses of the rotating coils and cryostats inside the iron armature that were calculated for the 10MW SCG and SG (1st version). The magnetic mirror is constituted by 2 pieces made of soft ferromagnetic material that operate in non-saturated conditions. Thus it is establish the same boundary conditions in the air-gap region and in the inter-pole space when the magnetic mirror is not saturated.

The armature is not wounded so that this machine can be tested in much simpler test bench of 15 kW. The armature incorporates 4 test coils wounded in the armature magnetic core in order to measure the polar and interpolar leakage flux. This SM can be tested in a 15 kW test bench, which highly facilitates de experimental activity.



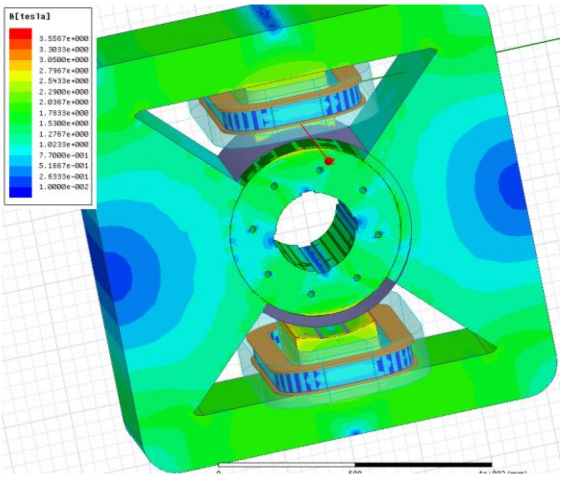


Figure 33. (left) SM electromagnetic layout (right) Magnetic field map of the SM

Electromagnetic 2D and 3D FEM analysis has been applied to the SM in order to validate the magnetostatic performance of the generator concept. A complete map of magnetic field in the whole SM is shown in Figure 33. The most saturated parts are magnetic poles, with a maximum value of 2.36 T. The peak magnetic field value in the SC coils is 1.24 T, located in the lower part of the straight section of the coil. This latest aspect has been studied in the detail as the magnetic field determines the performance of the SC wire.

On this basis the SM detail design has been completed as shown in Figure 34

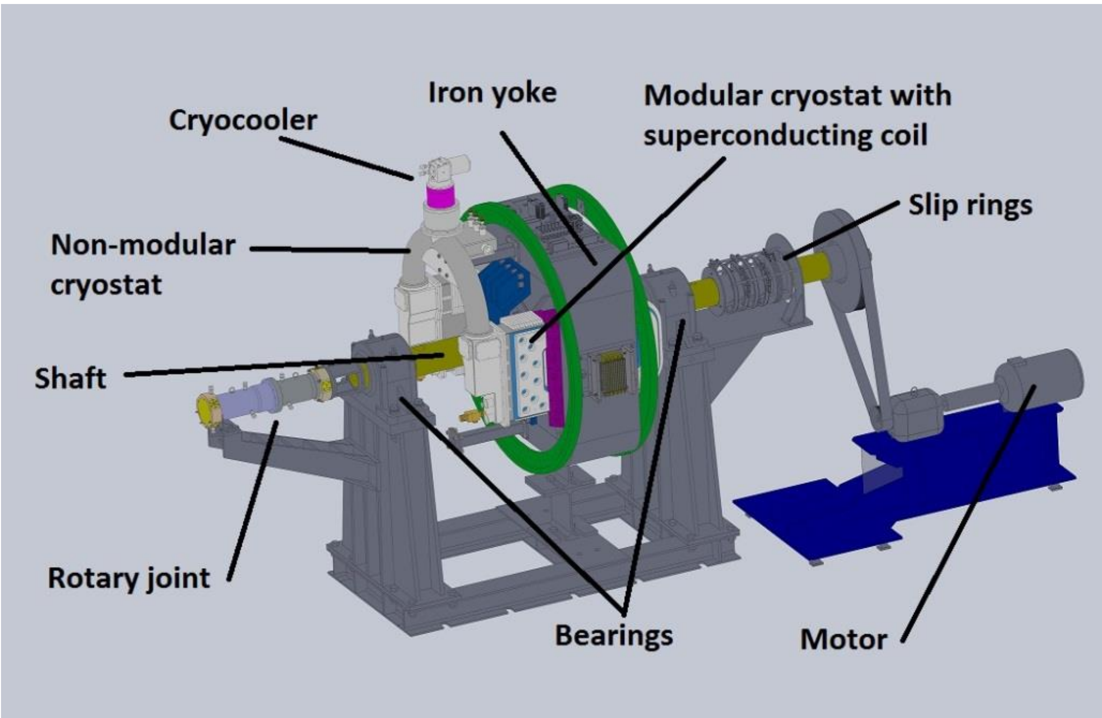


Figure 34. 3D model of the scale machine

1.3.4.2 Scale machine construction and test

First of all, the elements of the scale machine has been constructed, including the superconducting coils and cryostats that as previously described has been directly constructed by the project consortium. Figure 35 shows some of the main components of the scale machine

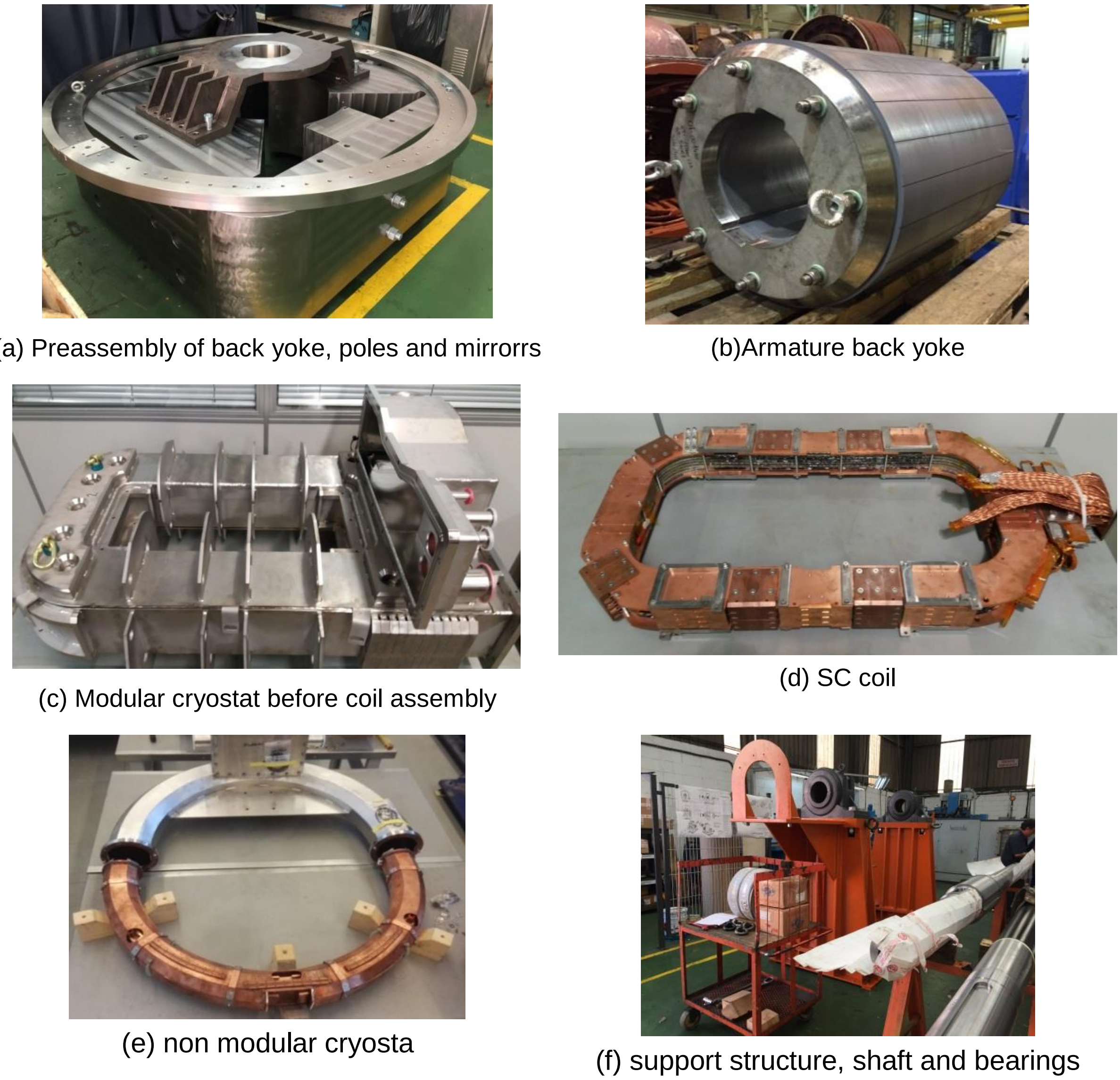


Figure 35. Main componentes of the SM

As part of the scale machine it has also been implemented the quench detection and protection system that has been previously described in 1.3.2.6. The quench detection is system is implemented in a control hardware that also monitors the main parameters of the scale machine as temperature, magnetic field, current and voltage signals. This hardware rotates jointly with the rotor and the signals are transmitted to a stationary PC through the fibre optics link of the rotary joint.

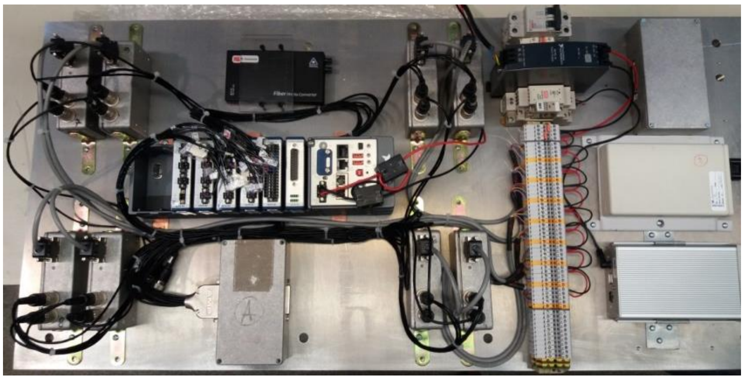


Figure 36. (left) stationary quench resistors (b) control hardware electrical panel

Once manufactured all the elements next assembly sequence has been followed:

- Assembly of the coils inside the modular cryostats. This is one of the critical steps of the mounting process as the parts tolerances are very tight and it is necessary to handle all the components to avoid damages and undesired heat entrance points.

(a) Support straps adjustment (b) MLI blankets installation (c) vacuum test after welding

Figure 37. Pictures of the assmbly process of the coil inside the cryostat

- Assembly of Set 1 and Set 2:
  - Set 1: formed by the shaft, stator assembly, 2 mirrors, 2 bearings and their supports.
  - Set 2: formed by the rotor back yoke, 2 poles and coils inside the modular cryostats
- Assembly of both sets in the support bench and then mounting of other components as slip rings, balancing rings and measuring coils.

Figure 38. Picture of the assembly of the electromagnetic elements in the saft and bench

- Assembly of the rotary joint
- Assembly of non-modular cryostat and its balancing pieces

Figure 39. Non modular cryostat mounting sequence

Figure 40 shows the scale machine fully assembled and under vacuum and cooling tests.

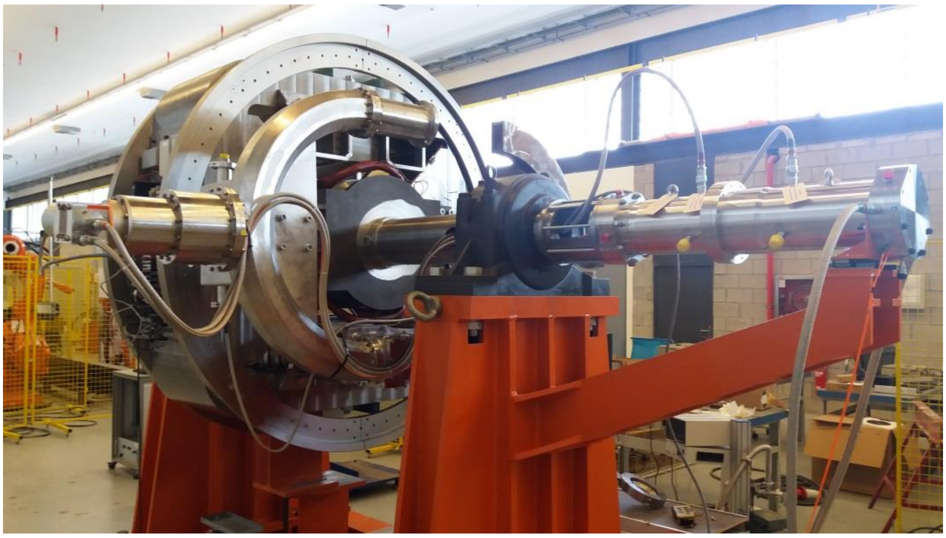


Figure 40. Scale machine fully assembled

All the details of the constructions and assembly of the scale machine have been included in "D1.4 Superconducting Electromagnetic Scale Machine" SUPRAPOWER's public deliverable. [34]

The SM allows the experimental validation of the main innovative aspects and components at full scale of the 10 MW SCG. First of all, the test of the cooling system permits to probe the mechanical design of the cryostats, the good operation of the rotary joint and cryocoolers in rotation, the behaviour and efficiency of the overall heat extraction circuit and the capability of achieving the 20 K operating temperature in the coils. SC coils can be tested in rotation and under similar working conditions (I, B, T) to the SCG ones. The quench detection and protection system can also be tested and validated. Finally, test coils in the stator allows to check if the magnetic flux generated by the field coils in the airgap and the interpolar zones correspond to the values calculated and obtained in 3D electromagnetic FEM simulations, thus permitting to validate the electromagnetic design approach.

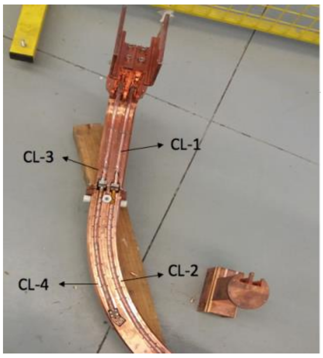
The test protocol, test results and conclusions have been reported in "D1.5 Test results report of the scale machine" SUPRAPOWER's public deliverable [35].

Static vacuum and cooling tests have been carried in the SM to check the cryostat vacuum performance, the correct functioning of the cooling system including rotary join (in stationary position) and the temperature distribution in the Cu thermal circuits. A residual pressure of $9.4 \cdot 10^{-4}$ mbar has been obtained by means of a turbomecular pump and before switching on the cryocooler. Next, the cryocooler was connected and the temperature in the ration shield of the cryostat was registered (see Table 4). These results have permitted to conclude that the system, including the rotary joint, performed as expected.

Day / time	Temperature (K)	Pressure (mbar)
Day 1 / 10:00	305	1050
Day 2 / 13:50	309	9.4×10^{-4}
Day 2 / 17:55	148.8	1.9×10^{-6}
Day 3 / 11:31	51.89	1.3×10^{-6}

Table 4. Temperature in the radiation shield registered during cooling down

Cooling systems based on cryogen-free GM cryocoolers has very limited heat extraction power. Due to this it is indispensable to have a good current lead design with almost no heat transport or generation. First design of current leads was based on four SC Sumitomo BSCCO tapes (DI-BSCCO) Type HT, twisted along stainless steel capillary tubes. This design resulted not valid because of potential damages during tape twisting due curvature restrictions. In the new design the SC tapes have been directly soldered to the Cu terminals. Tapes have been inserted inside a Cu film with tubular form, which acts as current alternative path in case of quench.



T= 77 K	CURRENT LEADS (CL)			
	CL-1	CL-2	CL-3	CL-4
I_c	197.41	68.43	276.52	261.47
n	2.82	3.12	3.93	7.89

Figure 41. (left) Current leads (right) Fit coefficients of each current leads, Ic and "n"

Current leads have been tested under liquid nitrogen (LN_2) before assembling them in the scale machine. Table in Figure 41 right summarizes the results obtained after the fit. Critical currents (I_c) are below the expected ones (around 600 A) according to the manufacturer data. Also the "n" values are low, with the exception of CL-, which could be due to the handling, soldering of the tape to the Cu terminal or to a short current transfer path. Eventually, a direct damage of the tapes could explain such low coefficients, as in the case of CL-2. These results show that a new CL-2 has to be manufactured and tested. The rest of the CLs, despite the performance is not as good as expected, could be good enough to energize the SC coil.

At the time of writing this report, the SC coils and the cryogen free cooling concepts have been successfully tested. Due to the complexity of the system, several components have required redesigns during the tests. Finally, taking into account these difficulties, the test results have not permitted to completely validate the scale machine. Additional R&D work must be done for validating the scale machine.

It has been concluded that the developed generator shows technical benefits in comparison to direct drive PMGs and at a very competitive cost. However, the development of the SCG still requires further R&D, validation and demonstration activities.

Some future R&D working lines have been identified. The improvement of the MgB_2 wire performance would permit to improve the SC coil by reducing the amount of wire needed. This would permit to ease the design and manufacturing process of the coil and would yield in more available space inside the cryostat, which is also considered as an important improvement. Some wire improvements have been analysed in SUPRAPOWER and summarised in section 1.3.2.1. The cooling system is based on heat extraction through conduction, which avoids the use of cryogenic liquids. However, this implies complex and very tough tolerances heat extractions circuits, which are made of a material (OFE Cu) difficult to mechanize with precision. The improvement of the heat extraction circuits would permit to ease the assembly of the system and increase its reliability. The design and manufacturing of the current leads should be improved, as they are key component for the validation of the system.

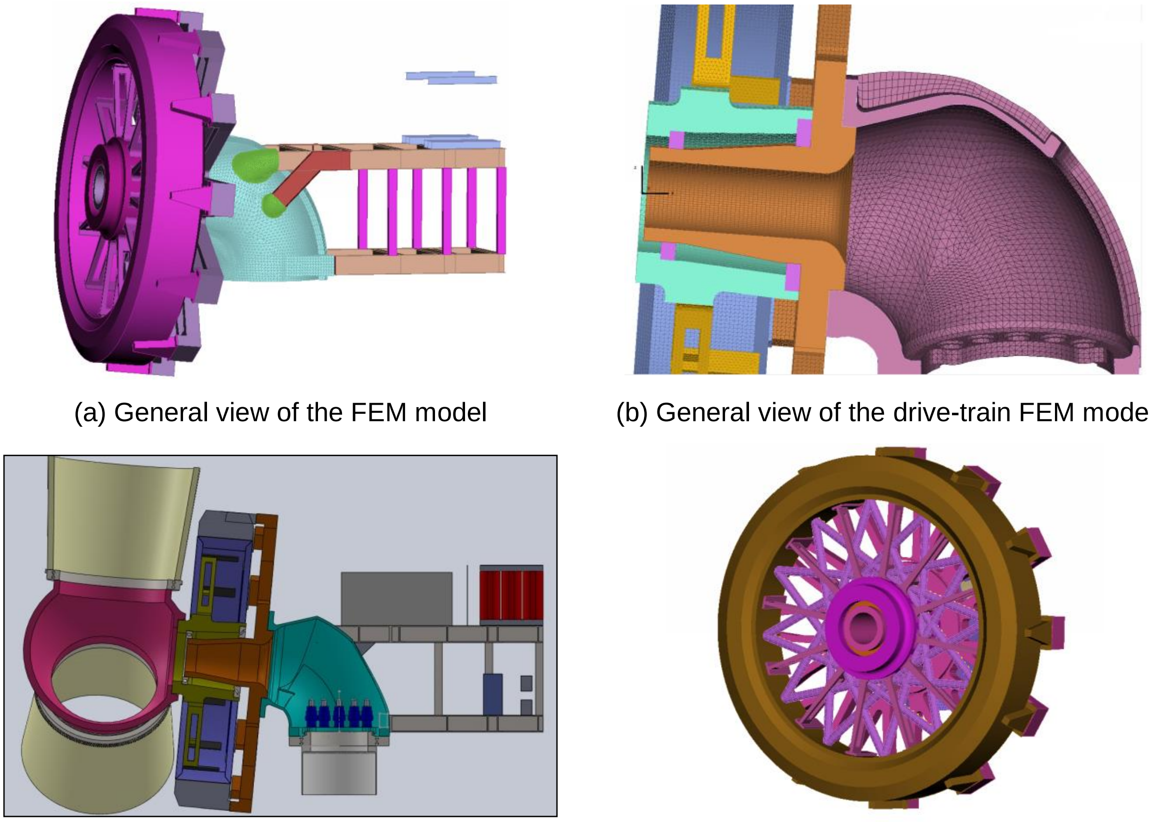
1.3.5 10 MW superconducting generator wind turbine

1.3.5.1 Integration of the full scale SCG in both fixed and floating offshore wind turbines

R&D studies of the integration of both PMG and SCG in both flxed and floating WTs have been carried out by SOLUTE to evaluate the effect of the generator weight reduction on the rest of the turbine structural components.

First of all, as there were none or few available references of blades for 10 MW turbines, a special blade design has been performed with the aim of having lower weight. This concept has been extrapolated form NREL-5MW blade with no changes in aerodynamical profiles but with an optimization in weight. As a result, the Solute Hybrid Blade of 92.5m (SHB-92.5) made of glass fibre and carbon fibre has been released.

On the basis of this blade and the SCG, the drive train has been dimensioned with the main aims of reducing manufacturing hours, reducing the overall weight and offering a clean load path. The mechanical integration of DD generators of very large diameter requires different solutions than geared drive trains. The mainframe of a geared drive nacelle is substituted by a component named goose neck that attaches the generator to the WT tower, as shown in Figure 42.



(a) General view of the FEM model

(b) General view of the drive-train FEM model

(c) General view of the RNA FEM model

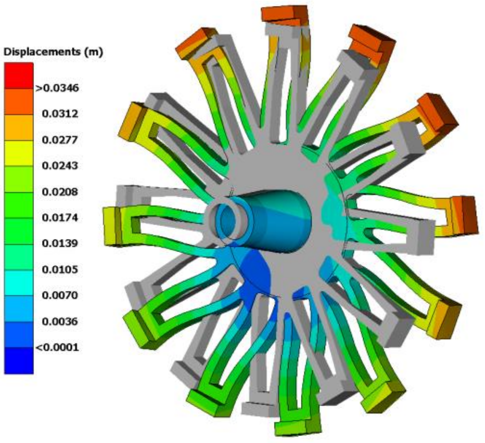
(d) General view of the generator FEM model

Figure 42. General view of the RNA elements of the FEM model

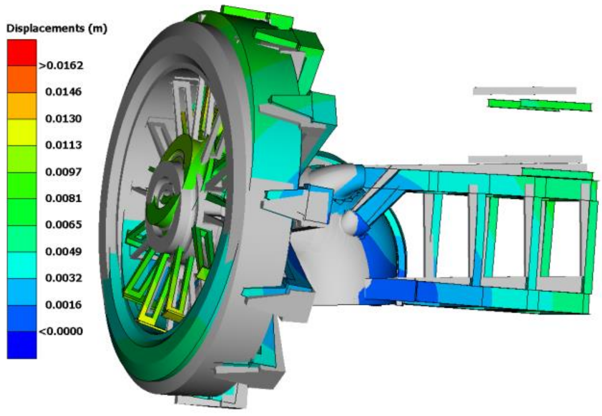
The pitch system is located out of the hub to reduce its weight and size and also to ease maintenance operations. All the electromagnetic elements and the support structure of the SCG are designed so that can be divided into smaller parts to facilitate transportation and assembly operations. The generator rotor support is directly connected to hub, while the stator support offers a connection to the goose neck. It supports the whole drive train and nacelle rear structures, while it offers a connection with the yaw system and tower, offering a load path for the loads coming from the drive train. The hub, rotor and stator supports and the goose neck have been simulated as cast iron.

On the basis of the Rotor nacelle assembly (RNA) design, the tower and the fixed offshore substructure monopile has been designed. The main aim of this design process is to avoid rotor frequency (1P), designing a structure (tower plus monopile) with a first FA (Fore Aft) natural frequency 20% above 1P, i.e., around 0.17Hz. With a hub height of 125m above MSL (Medium See Level) the tower is 110m height and is supported by a monopile that stands 10.8m above MSL. Final calculated 1st FA frequency of the system (tower plus monopile) is 0.184Hz.

With the metocean analysis of the selected location [37], and considering a set of load cases (15 cases), which, according to experience, are the usual driving ones, the offshore loads analysis, following IEC 61400-3 standard has been performed. As a result, extreme and fatigue loads along the wind turbine have been obtained. Comparing this final loads with the PMG ones, main conclusion is that at RNA loads doesn't differs too much, but along the tower, with a lower THM, loads decrease significantly (-10%). A strength analysis has been conducted, taking into consideration the aforementioned loads for fatigue and extreme conditions. As result some little reinforcements have been applied at goose neck, shaft and shaft support.



Displacement map (m). Max. Mx shortcircuit Stator support.



Displacement map (m). Max. My in hub centre Load Case

Figure 43. Fixed 10 MW turbine FEM strength analysis

The results of these studies, shown in Table 5 and Table 6, bring 25.6% weight reduction of the active parts of the SCG. The weight reduction of the THM is of 7.2%, this drop in the percentage is because the aerodynamic forces in a 10 MW turbine have more influence on the support structure than the weight of the active parts of the generator. It has been also evaluated that the achieved THM reduction permits an 11% reduction of the tower weight and 9% of the monopile.

Component	**Material**	**SCG**	**PMG**	**Difference**
		Weight (t)	**Weight (t)**	**%**
Goose neck	Ductile cast iron	108.5	108.5	0%
Shaft	Ductile cast iron	84.5	84.5	0%
Shaft support	Ductile cast iron	10.4	10.4	0%
Stator+Rotor active	**-**	163	219	-25.6%
Stator support	Ductile cast iron	227.2	249.3	-8.9%
Rotor support	Ductile cast iron	20.8	24.5	-15.1%
Rear frame	Steel s355j2+n	32	32	0%
Transformer	-	2.3	2.3	0%
Blades	Composite	117	117	0%
Hub	Ductile cast iron	178	178	0%
Pitch bearing	Steel s355j2+n	71	71	0%
Pitch drive	Steel s355j2+n	11.7	11.7	0%
Yaw system	Steel s355j2+n	33	33	0%
	TOTAL	**1059.4**	**1141.2**	**-7.2%**

Table 5. Weight comparison of the top head mass of SCG and PMG 10 MW fixed wind turbines

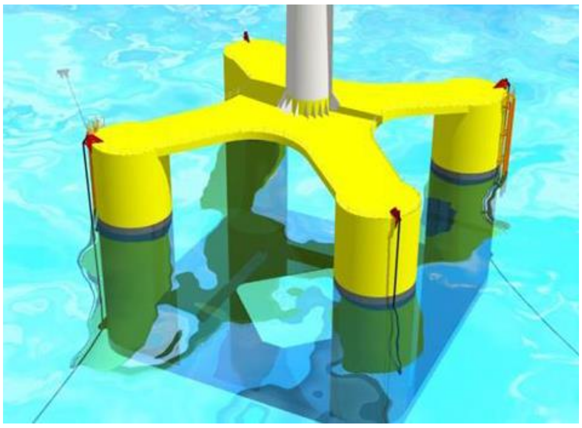
Component	Material	SCG	PMG	Difference
		Weight (t)	**Weight (t)**	**%**
Tower	Steel s355j2+n	741.4	841.3	-11.9%
Substructure	Steel s355j2+n	600.0	662.4	-9.4%
	TOTAL	**1341.4**	**1503.7**	**-10.8 %**

Table 6. Weigh comparison of tower and substructure of SCG and PMG 10 MW fixed wind turbines

Finally it has been estimated that this weight reduction could lead to cost shaving of 0.5-1 M€ respect to a PMG, even though at higher cost of the SCG (unless for the first units introduced in the market).

It has also been analysed the integration of the SCG in a floating platform. Nautilus floating platform [36] has been taken as reference, as this platform is intended for 5 MW wind turbines, Tecnalia has made the redesign and main calculation for adapting the platform to the 10 MW, SCG scaling the 5 MW design for a 10 MW turbine. Dimensions have been calculated so that the floater could withstand maximum overturning moment along turbine life time and basic constrains for manufacturing, load-out and assembly process have been also taken into account. Then, mooring and hydrodynamics have been checked. Mooring have been designed by quasi-static methodology for 100 years return period, most representative mooring parameters have been obtained, such as chain diameter, length and anchor weight. Hydrodynamic features have been set by diffraction/radiation software, obtaining added mass, damping and stiffness coefficients which are essential to feed the numerical model used for dynamic simulations.

Furthermore stability and local strength have also been analysed. Stability and structure have been checked according to DNV standards. Then the final design has been validated by coupling codes, analysing a wide range of design load cases.



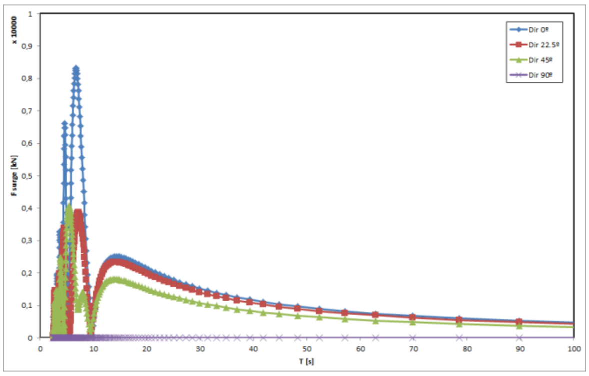


Figure 44. Nautilus platform sketch and example of calculations: forces in X axis for the 10 MW floating platfor,

The same wind turbine used for fixed structure has been used for the floating one, so that to get a good comparison between both substructures. As floating substructures show higher inertial loads than fixed ones, the tower model has been reinforced accordingly. Obtained total tower mass is 898 tons, i.e, comparing with fixed turbine tower, it shows a 33% increase of mass and a final 1st FA frequency (tower plus floater) of 0.225Hz. Taking into account the calculated floating platform mass of 12,991 tons, the overall mass, tower plus floater, is 13,889 tons. It is estimated that the mass of the floater is in the range of 3-5% less than for the case of PMG base turbine. Load calculation studies have been performed for the same metoceanic conditions and load cases as for fixed substructure, checking that loads in the mooring lines, base of the tower, floater movements, etc are in the allowable limits.

1.3.5.2 Marine operations analysis

To analyse the feasibility of a 10 MW SCG offshore WT it is also necessary to investigate and analyse transport, assembly and installation procedures and asses the benefits at this respect of the obtained weight reduction. All the technical details and results of this study are available in “D5.2 Study of transport, assembly and installation of offshore 10 MW superconducting generator” SUPRAPOWER’s public deliverable [37].

On the basis of main Rules and Guidelines for marine operations, the previously presented fixed WT and floating WT configurations have been studied, including: marine operations, required installations vessels, preliminary hydrodynamic analysis and hazard identification.

Marine operations have been assessed for both configurations and several options have been considered defining the process step by step from the harbour to the offshore project area. Then, based on preliminary assumptions on foundations and on the characteristics of the WT and the SCG (mainly weights and dimensions), the installation vessels have been analysed, highlighting the ones able to install the new 10MW SCG WT. As an example Figure 45 and Figure 46 shows part of the transport and installation sequence for fixed and floating foundations respectively [37].

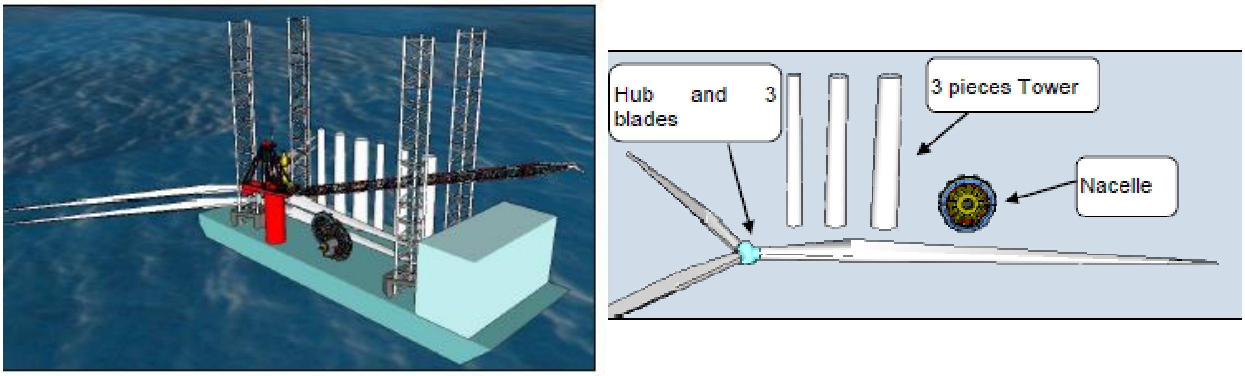


Figure 45. (left) Deck Load on a WTIV with Pre-Assembled rotor configuration (2 WTG in that instance); (righ) Assembled rotor, nacelle without hub and tower in three pieces

In general terms, it has been concluded that the transportation and the installation of the SUPRAPOWER’s WT can be realised with present-day equipment and with no major differences compared to existing WTs. It is concluded that thanks to the previously analysed weight reduction, a slight cost reduction could be achieved respect to a PMG WT. It has been estimate that the cost range for the installation of a 100 MW wind farm in the selected locations, with fixed foundations, could be in the range of 4-4.8 M€ and 28 to 26 days of installation time for the case of SCG WTs. While for the case of PMG WTs it has been estimated a cost in the range of 4.5-5 M€ and 27-38 days installation time.

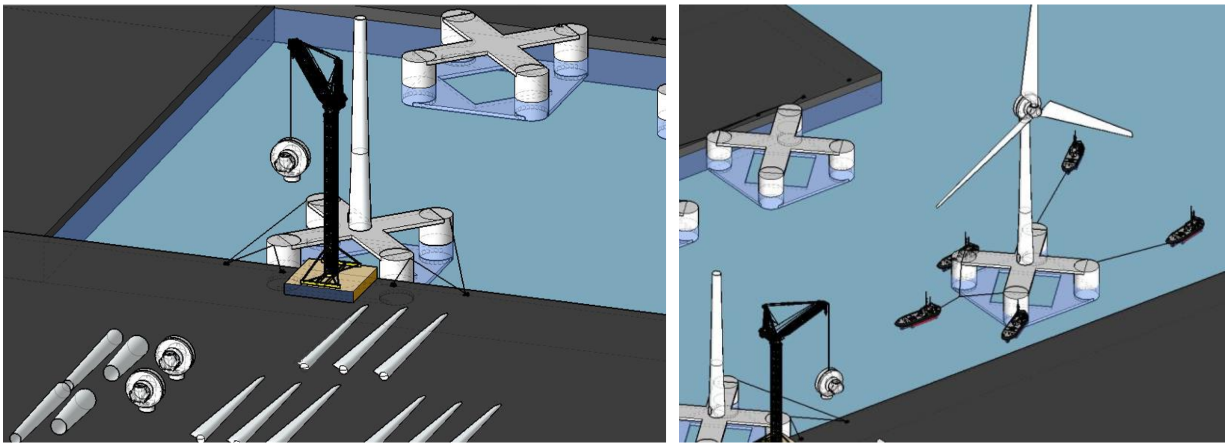


Figure 46. Harbour assembling of floating WT installation sequence

The general conclusion that these analysis shows is that even if the SUPRAPOWER's 10MW wind turbine is more powerful and hence bigger than current WTs (4.8 MW mean installed power rating [1][5]), all the transportation, installation and assembly operations on both fixed and floating foundations can be performed with classic and existing means. All the operations can be performed following existing methodologies, with existing wind farm offshore means (vessels, cranes, tugs), by crews already trained and familiar with these classic tasks.

The safety considerations of the installation of the fixed and floating foundation WT have been analysed considering the means and procedures previously defined. A Hazard Identification (HAZID) method has been applied following the marine operation Rules & Guidelines, assessing the Severity and Frequency of all possible risks, defining the possible preventive and protective measures that may reduce them. Finally each risk has been classified in 3 different critically categories ranging from acceptable or low risk, to unacceptable or high risk. All the details of this study can be reached in [37].

Main HAZID conclusions are that typical superconductive risks, mainly related to the high pressure Helium, can be well mitigated and prevented, reducing these risks to low levels. On the other hand marine operations are similar than for other same sizes wind turbines, well known and mastered, with no additional risks.

1.3.5.1 Operation, maintenance and reliability analysis

O&M represents an important cost in the life cycle of an offshore wind turbine, indeed scaling up the power of the wind turbines could contribute to reduce these cost per MWh. Due to relevance of this aspect and the novelty of the superconducting technology, Ingeteam has carried out a study of the reliability, availability and maintainability of the SCG 10 MW WT, intended to evaluate the impact of the SCG in the O&M strategy and costs. Then a risk assessment of the O&M operations has been completed and on the basis of these outputs a Criticality Analysis has been completed. Finally, once identified the most critical components the maintenance strategy has been defined. Some details of these studies can be found in [38] and [39].

Sub-Systems	Reliability (Fails per year)	Availability (Downtime hours per failure)
Control System	3,92	3,41
Generator (Exc. SC)	2,72	4,78
Power Electronics	2,29	4,37
Pitch System	2,29	3,64
Yaw System	1,83	3,48
Blade System	0,98	13,68
Electric System	0,65	4,34
Backing vacuum pumps/system	0,4	1
Cooling System	0,39	3,7
Rotary joint (Cryocooling)	0,34	-
Brake System	0,21	4,22
Cryocooler Helium gas compressor	0,17	-
Transformer	0,12	23,53
Chiller (cryocooling system)	0,12	-
Switchgear	0,1	22,9
HV pumps	0,09	2
Vacuum gauge	0,09	4
HV gates	0,09	4
Cryocooler cold head	0,06	-
Quench protection & detection Sys.	0,04	0,43
Main Bearing	0,03	113,18
Auxiliaries	0,03	1,17
Nacelle	0,01	5,11
Superconducting coils	0,01	472

Figure 47. Rliability and availability analysis

The risk Assessment has shown few added risks between a PMG and SCG, which are related with very low temperatures and higher radiation generated by the powerful magnetic fields generated by the SC field coils.

1.6 Generator					
Radiation due to high magnetic fields generated by superconductors.	H: C A: 1	Risk: High	*Always block the rotor movement when working in generator. The Wind Turbine should be shut off from the ground and before climbing to the nacelle to avoid the most of the radiation.*	H: C A: 3	Risk: Medium
Electric shock due to induction of generator	H: C A: 1	Risk: High	*Always block the rotor movement when working in generator.*	H: C A: 4	Risk: Low
Electric shock in the generator	H: C A: 1	Risk: High	*Follow the 5 Electric Golden Rules and legislation.*	H: C A: 4	Risk: Low
Skin injury due to very cold temperatures in the cryocooling system. (Cold head, cryostats and Helium connectors)	H: C A: 3	Risk: Medium	*The cryocooling and vacuum systems have to be switched off in EVERY operation in the general or this dedicated sub-system. Note that it is not enough switching off the electrical system.*	H: C A: 4	Risk: Low
Skin and eyes injuries due to contact with ferrofluid from Rotatory Joint	H: B A: 3	Risk: Medium	*Always use protective gloves and safety glasses when manipulating the rotatory joint.*	H: B A: 4	Risk: Low
Asphyxia due to Helium breathing	H: C A: 1	Risk: High	*Always close main valves and use the bypass valves when operation with the helium subsystem: isolate the element to work in. Be aware of the tubes routing.*	H: C A: 4	Risk: Low

Figure 48. HAZID assesment of the 10 MW SCG

On the basis of this data a Criticality Analysis has been carried out analyzing the following factor:

Criticality = Failure Rate x *Impact of Failure*

Impact of Failure = Failure effects + Downtime + Repair Cost + Means Needed + Safety Impact & Environmental Impact

The analysis has shown the need of taking special care with the SCG, the Pitch System, the Blade System, the Power Electronics and the Yaw System. Superconducting elements, the cooling and vacuum systems have been deeply studied. It is clear that introducing more elements into a system decreases its reliability. Although in this case the number of elements introduced is high, they are theoretically not very critical. An exception is the rotatory joint (see Figure 49), but an alternative to eliminate this "Middle-High" critical element has been analyzed in [20].

Rotatory joint

Fail Rate						
5	MID	MID-High	HIGH	Very HIGH	Very HIGH	Very HIGH
4	MID-Low	MID	MID-High	HIGH	Very HIGH	Very HIGH
3	LOW	MID-Low	MID	~~MID-High~~	HIGH	Very HIGH
2	Very LOW	LOW	MID-Low	MID	MID-High	HIGH
1	Very LOW	Very LOW	LOW	MID-Low	MID	MID-High
Impact Failure	1-50	51-100	101-150	151-200	201 - 250	251 - 300

Figure 49. Criticality analysis of the rotary joint

All the elements introduced related with the superconducting System have never been used in a similar application and least of all in such a harsh environment. The forces and vibrations to endure are also much noteworthy inside a wind turbine than in the most common applications for these technologies as MRI or magnets for scientific facilities. With this in mind, it seems logical that in the first prototypes and commercial units of this potential product, an in-depth study of behavior should be performed, requiring much more often and detailed maintenance and check visits than the theoretically needed. The modular design of the SCG, avoiding the need of using the most expensive and with low availability vessels is definitely an advantage that reduces significantly the "Impact of the Failure".

Finally, with all this data and the best practices on offshore wind power O&M strategies, some guidelines have been produced for the Maintenance Strategies of a wind farm equipped with SUPRAPOWER technology WTs. The most critical components identified in the Critically Analysis will need a Condition Monitoring Systems so that to apply a predictive maintenance strategy. Preventive Maintenance periods, required tasks and means have been assessed for each maintenance period. For each of these tasks, the logistics (boats, vessels, helicopters, forecasting…) needed to perform all the operations were studied to achieve the highest availability of the plant with the less Operational Expenditure. Figure 50 shows the maintenance strategy

Maintenance Type	Denomination	Length	Technicians	Vessels
Standard Maintenance Operations	Standard M.O.	8h (1 day)	2 (O&M specialist)	1
High Voltage Maintenance Operations	High Volt. M.O.	8h (1 day)	2 (Specialized in H.V.)	1
Bearings Maintenance Operations	Bearings M.O.	24h (3 days)	3 (O&M specialist)	1
Blades Maintenance Operations	Blades M.O.	8h (1 day)	3 (Specialized in Blades works)	1
Large Maintenance Operations	Large M.O.	24h (3 days)	3 (O&M specialist)	1

Year	Intervention	Hours	Days	Technicians
Year 1, 3, 7, 9, 11, 13, 17 & 19	Standard M.O.	8	1	2
	Total	**8**	**1**	**2**
Year 2, 4, 6, 8, 12, 14, 16 & 18	Standard M.O.	8	1	2
	High Voltage M.O.	8	1	2
	Blades M.O.	8	1	3
	Large M.O.	24	3	3
	Total	**48**	**6**	**10**
Year 5, 10, 15 & 20	Standard M.O.	8	1	2
	High Voltage M.O.	8	1	2
	Bearings M.O.	24	3	3
	Blades M.O.	8	1	3
	Large M.O.	24	3	3
	Total	**72**	**9**	**13**

Figure 50. (up) Maintenance interventions (down) preventive interventions

It has been estimated that installation, O&M, decommissioning and all other marine operations do not complicate due to the use of a SCG and moreover 0.9 M€ savings could be achieved in this field. This cost reduction is achieved thanks to the modularity and lighter weights of the components of the WT, which permit to have faster marine operations.

1.4 Project potential impact and dissemination activities

1.4.1 SUPRAPOWER potential impact

SUPRAPOWER (www.suprapowe-fp7.eu) is research project funded by the EU FP7 programme that started in December 2012 and finished in May 2017. The project was conceived to provide an important breakthrough in offshore wind industrial solutions by designing an innovative, lightweight, robust and reliable 10 MW class offshore wind turbine based on an MgB_2 superconducting generator, taking into account all the essential aspects of electric conversion, integration and manufacturability.

New Superconducting wind generator

The main outcome of SUPRAPOWER project is a novel 10 MW superconducting generator. This generator has been patented (EP2521252 B1) both in Europe (Spain, Germany, UK and France) and in the USA. The patented concept has been developed in detail and validated through a scale machine.

This generator is a low speed salient poles synchronous machine. It is a partially superconducting generator (SCG), superconducting MgB_2 wires at cryogenic temperature are used in the field coils while copper wires at ambient temperature in the armature coils. The cooling system uses a cryogen free topology that does not use liquids at cryogenic temperatures. It has a warm iron rotor configuration, which consists on one modular cryostat per pole that encloses only the superconducting coil while the iron of the pole remains at room temperature. Heat is extracted by conduction through a thermal collector inside a cryostat which links all the modules. This is cooled by conduction by two-stage Gifford-McMahon (GM) cryocoolers which rotate jointly with the rotor.

This generator concept gives answer to the need of cost effective and more power wind turbines, while overcomes some of the challenges faced by other previously developed superconducting generator concepts. On the one hand, the selected superconducting material, $MgB_{2,}$ shows a much lower cost performance ratio than other HTS materials. On the other hand, the cooling system uses a cryogen free topology that does not use liquids at cryogenic temperatures, which highly simplifies the required cooling installation and minimizes the maintenance operations. Additionally, the modular design of the superconducting and cryogenics developments makes more feasible and less costly the corrective maintenance operations, which could be needed in case of a major failure.

The design process has also taken into considerations marine operations and O&M aspects, as they both represent a significant fraction of the offshore wind turbines LCoE. It has been concluded that using a novel SCG, which uses a technology never used before in wind turbines and least of all offshore, do not bring significant additional risks.

The SCG onsite efficiency, taking into account the power consumption of all the auxiliary elements as compressors and cryocoolers, is around 95.2% at the rated power, while the PMG one is around 94.5%. It is remarkable that the efficiency curve of the SCG is slightly above the PMG for all the power range.

SCG active parts cost has been estimated in 307 k€/MW, with current MgB_2 costs, while the cost estimated for the PMG with NdFeB magnets price of 39 €/kg is 313 k€/MW. Thus the developed SCG is already cost competitive and with a huge margin for further cost reduction driven by the MgB_2 wire performance improvement and industrialization of the manufacturing process.

This generator concept has been experimentally validated with a scale magnetic rotating machine designed and built specifically for this purpose. Main innovative features as superconducting and cryogenic implementation, modularity and quench detection system are equal or similar in both 10 MW and scale machines. Superconducting coils and cryogen free cooling system have been extensively investigated and as result real scale coils, modular cryostat and cooling systems have been constructed and experimentally validated by the consortium. At the time of writing this report the test of the scale machine was in progress.

It has been concluded that the developed generator shows technical benefits in comparison to direct drive PMGs and at a very competitive cost. However, the development of the SCG still requires further R&D, validation and demonstration activities

Facilitate more power and reliable wind turbines for LCoE reduction

As it has been explained before higher power rate wind turbines are pointed out as the innovation with higher Levelized Cost of Energy (LCoE) reduction potential. The state-of-the-art shows that both geared and direct-drive wind generators are difficult to scale up to 10 MW and beyond due to their huge size and weight.

Indeed, the development of large scale offshore wind turbines in the range of 10-20 MW and the improvement of the reliability through use of new materials, advance rotor design and control and monitoring systems, were relevant objectives of the "Investing in the Development of Low Carbon Technologies (SET-Plan),Technology Roadmap published by the EC in 2009".

The SUPRAPOWER 10 MW SCG highly contributes towards these objectives by facilitating the development of cost effective large and reliable wind turbines.

It has been studies the integration of the 10 MW SCG in both flxed and floating wind turbines to evaluate the effect of the generator weight reduction on the rest of the turbine structural components. The obtained results have been compared with a permanent magnets generator (PMG) wind turbine so that to be able to quantify the benefits. The developed SCG shows 25.6% weight reduction of the active parts respect PMG. The weight reduction of the tower head mass (including nacelle and blades) is of 7.2%. Finally it has been evaluated that the achieved head mass reduction permits an 11% reduction of the tower weight and 9% of the foundations (monopile). It has been calculated that cost savings in the range of 0.5-1 M€ could be reached thank to materials savings in the structural part of the wind turbine. For the case of floating wind turbines it estimated that a 3-5% weight reduction could be obtained in the floating platform thanks to the reduction of weight of the turbine.

Transportation, installation and assembly, O&M, decommissioning and all other marine operations, on both fixed and floating foundations do not complicate due to the use of SCG. All the operations can be performed with classic and existing means and with already applied methodologies, so that there are not drawbacks related to using superconducting technology in the generator. It has been estimate that the cost range for the installation of a 100 MW wind farm in a representative locations, with fixed foundations 10 MW SCG wind turbine, could be in the range of 4-4.8 M€ and 28 to 36 days of installation time, which is the range of 5-10% less than for the case of using PMGs. Moreover the direct drive topology contributes to increase the reliability of the turbine and O&M cost can also be reduced driven by faster marine operations thanks to the modularity and lighter parts of the generator. It has been estimated that 0.7 M€ savings could be achieved related to improved reliability and maintainability.

A critically analysis has shown that the most critical components are conventional ones as power electronics, blade system or yaw mechanism. An exception is the Helium rotary joint that has been identified as medium-high critical component, so that the reliability and performance of this component in offshore conditions should be demonstrated.

As conclusion the developed SCG can significantly contribute to the reduction of the LCoE of offshore wind. Nevertheless there is still R&D work to be done for the development and demonstration of a 10 MW SCG offshore wind turbine.

Finally facilitating the deployment and development of more cost effective offshore wind farms, contributes to EU targets of having at least 27% share of electricity produced by renewable sources, as indicated by the 2030 Climate Energy Package, “A policy framework for climate and energy in the period from 2020 to 2030”.

Exploitable foreground

As result of the project the project consortium has achieved the following exploitable foreground, that in certain cases have applications also in other sectors. The main exploitable results are the followings:

- 10 MW superconducting generator (main beneficiary: Tecnalia). This is the main results of the project and the other obtained results give additional value to the patent. The exploitation strategy is the IP commercialization after the project end.
- MgB_2 wire (main beneficiary: Columbus). The strategy is direct sales to Coil and high current cable manufactures. The wire developed in the project can have further applications than those related to generators.
- MgB_2 coils (main beneficiaries: Columbus, Tecnalia). On the one hand the strategy is manufacturing coils for generators manufacturers. On the other hand the strategy also considers providing to third parties services for the design and manufacturing of superconducting coils.
- Cryogen free cooling system & Rotary joint (main beneficiary: KIT). The strategy is the commercialization of the IP and/or provision of R&D services.
- Design of 10 MW turbines. Integration of superconducting machines (main beneficiary: Solute). The exploitation strategy is offering high quality and specific engineering services regarding wind turbines & offshore.
- O&M procedures for 10 MW wind turbines (main beneficiary: Ingeteam).The exploitation strategy is providing services for high power wind turbines offered under “Trade Secret”.
- Marine operations procedures for 10 MW wind turbines (main beneficiary: D2M). The strategy is the exploitation of the gained knowledge by providing services in the field of marine operations for offshore wind turbine or other marine renewables.

1.4.2 Dissemination activities

During SUPRAPOWER project dissemination and communications have been an essential activity and extensive effort has been made to disseminate the superconducting generator concept, its associated results and in general terms the results of the project. During the first part of the project dissemination material was mainly focus to the communication of the project objectives and background, while the second part has been focused to communicating the project results and to the exploitation of the foreground. After the end of the project some further activities will be carried out in order to disseminate the final results.

During the project lifetime more dissemination activities than those initially planned have been carried out. As a summary 2 press release have been produced, the consortium has taken part in 23 conferences and 13 articles have been published in peer review magazines. Next table shows a summary of these activities.

Dissemination type	Planned Indicators	Achieved indicators
Press releases	2	2
Contribution to international Conferences	8	23
Scientific articles	4	13
Non-scientific articles(1)	2	2
Workshops	2	2
Brochures (2)	2	2
Website (number of visitors)	200 per month 10000 totally	14.008

(1) No scientific or peer-review articles (DYNA, Spanish magazine of the engineers and Nations Instruments magazine). Articles written by third parties have not been considered.

(2) Instead of brochures 2 roll up posters were prepared

Two workshops have been organised. The first one was held in April 2015 in Bilbao, Spain as a side event of the Bilbao Marine Energy week (www.bilbaomarinenergy.com). This workshop was focused on High power electric generators for cost reduction of offshore wind. Its aim was to provide an overview about trends towards high power wind turbines based on both conventional and superconducting electric generators and get feedback from industry and academia.

The second has been held in May 2017 at TECNALIA's facilities in Bilbao, Spain. The workshop has presented the main results achieved and lessons learnt during the project and it has included a visit to the scale machine. The event has also brought main European research initiatives in the field of superconducting generators for wind energy. This event has taken place at TECNALIA's facilities in Bilbao, Spain.

The project web site (www.suprapower-fp7.eu) has been a key tool for the dissemination of project objectives and results. In the public are of the web site several articles and presentations are available, including all the presentations of the 2 workshops of the project. Moreover, it also has 13 deliverables, which are made public as soon as approved by the European Commission. The project web site will be kept active at least one year more after the end of the project.

All the dissemination activities have been reported in "D6.3 Dissemination Material" public deliverable", which is available in the project website.

1.5 GLOSSARY OF TERMS

AC: Alternating current

DC: Direct Current

DD: Direct Drive

DP: Double Pancake

EC: European Commission.

FEM: Finite Elements Analysis Method

GM: Gifford-McMahon

HTS: High Temperature Superconductor

IEA: International Energy Agency.

LCoE: Levelized Cost of Energy

LTS: Low Temperature Superconductor

MLI: multi-layer insulation

O&M: Operation and Maintenance

PM: Permanent Magnets

PMG: Permanent Magnets Generator

RHU: Rotary helium union

SC: Superconducting

SC coil: Superconducting coil

SC wire: Superconducting wire

SCG: Superconducting Generator

THM: Tower Head Mass

WP: Work Package

WT: Wind turbine

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1.7 Annex 1: Coordinator contact details

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1.8 Annex 2: List of beneficiaries

Participant organisation name	Short Name	Country
Tecnalia Research & Innovation. Contact: Iker Marino (coordinator) iker.marino@tecnalia.com	TECNALIA	Spain
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1.9 ANNEX 3: PROJECT LOGO

The following 2 logos have been used along the project lifetime:

suprapower

Superconducting light generator
for large offshore wind turbines

suprapower

1.10 ANNEX 4: PROJECT WEBSITE

SUPRAPOWER project website is http://www.suprapower-fp7.eu/

2. USE AND DISSEMINATION OF THE FOREGROUND

This section contains the plan for the use and dissemination of the foreground (PUDF). Deliverable **"D6.4 Plan For the Use and Dissemination of the Foreground**" submitted in M54, already includes a detailed report of the dissemination measures and an exploitation plan for the foreground of the project. This section of the final report basically reproduces the most relevant contents of this deliverable, but using the reporting format required by the EC.

The PUDB basically contains 2 sections:

- Section A (Public): dissemination measures, activities and publications carried out during the lifetime of the project
- Section B (Confidential): exploitation Plan, which contains the strategy for the management and protection of the intellectual property rights and for the optimal exploitation of the project results

2.1 SECTION A: DISSEMINATION (PUBLIC)

2.1.1 Summary of the dissemination strategy

SUPRAPOWER dissemination plan was developed at the start of the project and it has been applied through all the project lifetime. This plan sets the dissemination strategy and defines the activities to carry out to achieve the objectives of the strategy.

As a short summary, SUPRAPOWER's dissemination activity gives answer to the following questions:

Why – the purpose

A primary output from the SUPRAPOWER project will be the validation of the superconductivity applied to a wind turbine generator through a small scale machine. As wind energy is a new field of applications for superconducting technologies, it is essential to disseminate results in order to make this technology more familiar and to remove mistrust among the wind energy community, including lead industrial players, funding agencies and investors. Dissemination will permit to show the performance, reliability and competitiveness of the new concept developed in this project.

<u>What you plan to disseminate – key messages:</u>

The key messages that best define the project in a short, simple and clear manner are the followings:

"Logo Claim"

Suprapower: Superconducting light generator for large offshore wind turbines

"Objective"

Suprapower aims to develop a new concept of an innovative, lightweight, robust and reliable wind turbine for offshore applications using superconducting technologies.

"Extended Objective":

The main objective of SUPRAPOWER is the design of an innovative, lightweight, robust and reliable 10 MW class offshore wind turbine based on a superconducting (MgB_2) generator. This design will be validated with a scale magnetic machine with main innovative components equal or similar to the 10 MW generator.

Other important messages related to Suprapower that could be useful for communicating the project objective and benefits and offshore wind sector context are as follows:

"Suprapower answers to the demands of offshore wind industry"

Suprapower is intended to address the difficulty of further scaling up today's geared and direct-drive permanent magnets generators and the need to find new solutions that provide better scalability

"Suprapower main benefits"

"**Suprapower strives to reduce turbine head mass, size and cost of offshore wind turbines in about a 30% by means of a light weight superconducting generator"**

"Suprapower aims to reduce O&M and transportation costs and increase life cycle using an innovative direct drive system"

"Suprapower pursues to increase the reliability and efficiency of high power wind turbines by means of drive-train specific integration in the nacelle."

<u>To whom – the target audience</u>

The dissemination of Suprapower is mainly targeted to:

- Wind energy agents: wind turbines and generator manufacturers, auxiliary industry
- Stakeholders: manufacturers, utilities, promoters, governments, scientific society, funding agencies and the investment partners.
- Decision makers.

- Project partners: the internal communications is fundamental for the project execution.

How – the method

The methods and tools used for the Suprapower project dissemination:

- Participation in national and international events and conferences mainly focused on wind energy and applied superconductivity.
- Scientific publications.
- Publications in non-technical media.
- Workshops.
- Public Project deliverables.
- Web page.
- Leaflets.

When – the timing

Dissemination activity has been carried out during all the project lifetime from December 2012 to May 2017.

At first stage the dissemination activity will be focused on the communication of the project as a whole (main objectives, partners, etc) and as the project goes forward, it will be more focused on communicating project results.

2.1.2 Report of Dissemination activities

During SUPRAPOWER project dissemination and communications have been an essential activity and extensive effort has been made to disseminate the superconducting generator concept, its associated results and in general terms the results of the project. During the first part of the project dissemination material was mainly focus to the communication of the project objectives and background, while the second part has been focused to communicating the project results and to the exploitation of the foreground. After the end of the project some further activities will be carried out in order to disseminate the final results.

As a summary 2 press release have been produced, the consortium has taken part in more than 22 conferences, 8 articles have been published in peer review magazines and 2 workshops have been organized.

Next table summarises the scientific publications and the main activities carried out

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	Superconducting light generator for large offshore wind turbines	S Sanz et alt	Journal of Physics: Conference Series	Vol. 507/ Issue 3	Institute of Physics Publishing	United Kingdom	2014	032040	10.1088/1742-6596/507/3/032040	Yes
2	Tensile and bending strain tolerance of ex-situ MgB2/Ni/Cu tape superconductor	Kovac, P et al	IEEE Transactions on Applied Superconductivity	Vol. 25/ Issue 2	Institute of Electrical and Electronics Engineers Inc.	United States	2015	1-7	10.1109/TASC.2014.2379723	No
3	Study of the potential of three different MgB2 tapes for application in cylindrical coils operating at 20 K	J Pitel et al	Superconductor Science and Technology	Vol. 28/ Issue 5	Institute of Physics Publishing	United Kingdom	2016	055012	doi.org/10.1088/0953-2048/28/5/055012	No
4	Properties of MgB2 wires made by internal magnesium diffusion into different boron powders	P Kováč et al	Superconductor Science and Technology	Vol. 28/ ssue 9	Institute of Physics Publishing	United Kingdom	01/09/2015	095014	10.1088/0953-2048/28/9/095014	No
5	Conceptual design and thermal analysis of a modular cryostat for one single coil of a 10 MW offshore superconducting wind turbine	J sun et al	IOP Conference Series: Materials Science and Engineering	Vol. 101	Institute of Physics	United Kingdom	18/12/2015	012088	10.1088/1757-899X/101/1/012088	Yes
6	Lightweight MgB2 superconducting 10 MW wind generator	I Marino et al	Superconductor Science and Technology	Vol. 29/Issue 2	Institute of Physics Publishing	United Kingdom	01/02/2016	024005	10.1088/0953-2048/29/2/024005	No

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
7	Experimental Study and Simulation of Quench in MgB2 Coils for Wind Generators	S Sanz, et al	IEEE Transactions on Applied Superconductivity	Vol. 26/Issue 3	Institute of Electrical and Electronics Engineers Inc.	United States	01/04/2016	1-5	10.1109/TASC.2016.2518578	No
8	Design and Testing of Real-Scale MgB2 Coils for SUPRAPOWER 10-MW Wind Generators	G. Sarmiento, et al	IEEE Transactions on Applied Superconductivity	Vol. 26/Issue 3	Institute of Electrical and Electronics Engineers Inc.	United States	01/04/2016	1-6	10.1109/TASC.2016.2524460	No
9	Influence of the Internal Architecture of MgB2 Conductors in the Load Line of Magnet Coils	J. Pelegrin et al	IEEE Transactions on Applied Superconductivity	Vol. 26/Issue 3	Institute of Electrical and Electronics Engineers Inc.	United States	01/04/2016	1-5	10.1109/TASC.2016.2529851	No
10	Bending strain tolerance of MgB2 superconducting wires	P. Kovac , et al	Superconductor Science and Technology	Vol. 29/Issue 4	Institute of Physics Publishing	United Kingdom	01/04/2016	045002	doi.org/10.1088/0953-2048/29/4/045002	No
11	Mathematical model to determine the dimensions of superconducting cylindrical coils with a given central field – the case study for MgB2 conductors with isotropic I c (B) characteristic	Jozef Pitel, et al	Physica C: Superconductivity and its Applications	Vol. 527	Elsevier	Netherlands	01/08/2016	104-113	https://doi.org/10.1016/j.physc.2016.06.009	No

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
12	Filamentary MgB2 Wires With Low Magnetization AC Losses	P. Kovac , et al	IEEE Transactions on Applied Superconductivity	Vol. 26/Issue 6	Institute of Electrical and Electronics Engineers Inc.	United States	2016	1-5	10.1109/TASC.2016.2544825	No
13	Preliminary test of the prototype modular cryostat for a 10 MW offshore superconducting wind turbine	J. sun, et al	IOP Conference Series: Materials Science and Engineering	Vol. 171	Institute of Physics	United Kingdom	2017	012121	10.1088/1757-899X/171/1/012121	Si

Next table shows the list of dissemination activities

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	Oral presentation to a wider public	FUNDACION TECNALIA RESEARCH & INNOVATION	SUPRAPOWER Project	07/05/2013	Jornadas Técnicas de Vacío 2013 - Oerlikon Leybold, Barcelona, Spain	Industry		Spain

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
2	Oral presentation to a scientific event	FUNDACION TECNALIA RESEARCH & INNOVATION	Superconducting light generator for large offshore wind turbines	16/09/2013	EUCAS 2013, Genoa, Italy	Scientific community (higher education, Research)		International Event
3	Oral presentation to a scientific event	Institute of Electrical Engineering, Slovak Academy of Sciences	Properties of MgB2 wires with variable barriers and metallic sheaths	16/09/2013	EUCAS 2013, Genoa, Italy	Scientific community (higher education, Research)		International
4	Oral presentation to a wider public	Karlsruher Institut fuer Technologie	SUPRAPOWER, a new project towards high power wind generators using superconductivity	23/10/2013	12th International Workshop on Large-Scale Integration of Wind Power, London, UK	Scientific community (higher education, Research) - Industry		International
5	Posters	FUNDACION TECNALIA RESEARCH & INNOVATION	Superconducting light generator for large offshore wind turbines	19/11/2013	EWEA Offshore 2013, Frankurt, Germany	Industry		International - Europe
6	Posters	FUNDACION TECNALIA RESEARCH & INNOVATION	Design, optimization and integration of a direct drive superconducting generato4r for large offshore wind turbines	10/03/2014	EWEA 2014, Barcelona, Spain	Industry		International-Europe
7	Oral presentation to a wider public	FUNDACION TECNALIA RESEARCH & INNOVATION	Application of MgB2 in Superconducting Wind Turbine Generators	10/03/2014	EWEA 2014, Barcelona, Spain	Industry		Internationa- Europe

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
8	Oral presentation to a wider public	FUNDACION TECNALIA RESEARCH & INNOVATION	Superconducting, reliable, lightweight and more powerful offshore wind turbine.	12/03/2014	ZIEHL 2014, Bonn, Germany	Scientific community (higher education, Research) - Industry		Germany
9	Oral presentation to a wider public	FUNDACION TECNALIA RESEARCH & INNOVATION	SUPRAPOWER Project	06/05/2014	Jornadas Técnicas de Vacío 2013 - Oerlikon Leybold, Barcelona, Spain	Industry		Spain
10	Oral presentation to a scientific event	Karlsruher Institut fuer Technologie	SUPRAPOWER: a superconducting solution for large power wind generators	10/08/2014	ASC2014, Charlote, USA	Scientific community (higher education, Research)		International
11	Posters	UNIVERSITY OF SOUTHAMPTON	A new numerical analysis for superconducting coils using the real winding path	10/08/2014	ASC2014, Charlote, USA	Scientific community (higher education, Research)		International
12	Organisation of Workshops	FUNDACION TECNALIA RESEARCH & INNOVATION	High power electric generators for cost reduction of offshore wind	20/04/2015	Bilbao Exhibition Center, Bilbao	Scientific community (higher education, Research) - Industry	50	International: mainly Spain, Germany and UK

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
13	Oral presentation to a scientific event	Karlsruher Institut fuer Technologie	Conceptual design and thermal analysis of a modular cryostat for one single coil of a 10 MW offshore superconducting wind turbine	28/06/2015	CEC-ICMC 2015, Tucson, Arizona, USA	Scientific community (higher education, Research)		International
14	Oral presentation to a scientific event	FUNDACION TECNALIA RESEARCH & INNOVATION	Design and Testing of Real Scale MgB2 Coils for SUPRAPOWER 10 MW Wind Generators	06/11/2015	EUCAS 2015, Lyon, France	Scientific community (higher education, Research)		International
15	Posters	FUNDACION TECNALIA RESEARCH & INNOVATION	Experimental study and simulation of quench in MgB2 coils for wind generators for SUPRAPOWER	06/11/2015	EUCAS 2015, Lyon, France	Scientific community (higher education, Research)		International
16	Oral presentation to a scientific event	Institute of Electrical Engineering, Slovak Academy of Sciences	Filamentary MgB2 wires with low AC losses	06/11/2015	EUCAS 2015, Lyon, France	Scientific community (higher education, Research)		International
17	Posters	UNIVERSITY OF SOUTHAMPTON	Influence of the internal architecture of MgB2 conductors in the load-line of magnet coils.	06/11/2015	EUCAS 2015, Lyon, France	Scientific community (higher education, Research)		International
18	Oral presentation to a scientific event	Karlsruher Institut fuer Technologie	A new numerical analysis for superconducting coils using the real winding path	23/11/2015	ACASC 2015, Hangzhou, China	Scientific community (higher education, Research) - Industry		Mainly Japan, Korea, China, India, Turkey and other Asian countries

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
19	Oral presentation to a wider public	Karlsruher Institut fuer Technologie	Modular cryostat for a 10 MW offshore superconducting wind turbine	18/11/2015	DKV 2015, Dresden, Germany	Scientific community (higher education, Research) - Industry		Germany
20	Oral presentation to a scientific event	Karlsruher Institut fuer Technologie	Preliminary test of the prototype modular cryostat for one single coil of a 10 MW offshore superconducting wind turbine	08/03/2016	ICEC 2016, New Delhi, India	Scientific community (higher education, Research) – Industry		International
21	Oral presentation to a wider public	Columbus Superconductors SpA	MgB2: from research to a commercial production plant (With focus on SUPRAPOWER)	20/04/2016	Superconducting Generators- A fresh breeze in renewables, Osnabrück, Denmark	Scientific community (higher education, Research) - Industry		Europe
22	Oral presentation to a wider public	Karlsruher Institut fuer Technologie	SUPRAPOWER and other Superconducting Devices for the Optimization of Renewable Electric Power Systems	20/04/2016	Superconducting Generators- A fresh breeze in renewables, Osnabrück, Denmark	Scientific community (higher education, Research) - Industry		Europe
23	Posters	UNIVERSITY OF SOUTHAMPTON	The Use of a Winding Model Instead of Effective Continuum Model Can Lead to a Drastic Reduction of MQE in Superconducting Coils	04/09/2016	ASC 2016, Denver, USA	Scientific community (higher education, Research)		International

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
24	Oral presentation to a wider public	FUNDACION TECNALIA RESEARCH & INNOVATION	SUPRAPOWER project: Suprapower Superconducting 10MW lightweight generator for offshore wind turbines?.	21/11/2016	The wind Energy Sector European Challenge. Workshop & Conferences, Barcelona, Spain	Scientific community (higher education, Research) - Industry		Europe
25	Oral presentation to a wider public	INGETEAM SERVICE SA	Towards 10MW Turbines trough nacelle weight reduction	21/11/2016	The wind Energy Sector European Challenge. Workshop & Conferences, Barcelona, Spain	Scientific community (higher education, Research) - Industry		Europe
26	Oral presentation to a scientific event	FUNDACION TECNALIA RESEARCH & INNOVATION	SUPRAPOWER Project: Towards a 10 MW MgB2 Wind Power Generator	13/12/2016	ISS 2016, Tokyo, Japan	Scientific community (higher education, Research) - Industry		International- Mainly Japan and Asia
27	Posters	D2M ENGINEERING SAS	Superconducting light weight generator for large offshore wind turbines	20/03/2017	SEAENERGY 2017, Le Havre, France	Industry		International, Europe
28	Oral presentation to a scientific event	Karlsruher Institut fuer Technologie	Prototype modular cryostat utilized for 10 MW offshore superconducting wind turbine	16/05/2017	14th Cryogenics 2017 IIR international conference, Dresden, Germany	Scientific community (higher education, Research) - Industry		International

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
29	Organisation of Workshops	FUNDACION TECNALIA RESEARCH & INNOVATION	Superconducting generators for offshore wind turbines	31/05/2017	Tecnalia, Bilbao, Spain	Scientific community (higher education, Research) - Industry	50	International: Mainly Spain, Uk, Germany, Italy

2.1.3 Public Deliverables

SUPRAPOWER project includes 13 public deliverables that as soon as are approved by the European Commission are published in the website.

“Deliverables published in the website
D2.1 Improved MgB_2 wire
D2.3 Report on the design and manufacturing of an MgB_2 coil
D2.4 Test report of the MgB_2 coil
D3.3 First modular cryostat
D3.4 Test results report of the first modular
D6.1 Dissemination Plan
D7.2 Quality Assurance Plan

Table 7. Public Deliverables available in the website

Next table shows deliverables that will be published in the website as soon as are officially accepted by the European Commission

Deliverables to be published in the website
D1.4 Superconducting electromagnetic scale machine
D1.5 Test results report of the scale machine
D3.5 Test report of the rotary join
D5.1 Study of improvements for components of SCG
D5.2 Study of transport, assembly and installation of 10 MW SCG
D7.7 Final report Public Summary

Table 8. Public Deliverables to be publishes in the website when approved by the EC

2.2 SECTION B: FOREGROUND (CONFIDENTIAL)

2.2.1 Part B1: List of applications for patents, trademarks, registered designs,..

In this section the exploitable results of the SUPRAPOWER project are identified. Template B1 table shows the intellectual property rights that have been applied for or registered. Only one patent related to the superconducting generator concept has been registered. The patent was applied before the start of the project but it was granted during the project lifetime. The IP protection strategy was defined after the first technical results and the offshore wind market analysis (see Deliverable D6.4 PUDF). As conclusion, it was decided to patent the concept both in the USA and Europe and extend the European patent to those markets with higher market volume or/and offshore wind turbines developers, being Spain, Germany, UK and France.

It has been evaluated the possibility to patent some of the components developed during the project, but it has been concluded that it is not a straight way, so that they will be kept as industrial secret. A patent analysis was performed for the developed rotary joint, but it was concluded the impossibility of patenting it, however not problems to operate are expected.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights	**Confidential** **Click on YES/NO**	**Foreseen embargo date** **dd/mm/yyyy**	**Application reference(s) (e.g. EP123456)**	**Subject or title of application**	**Applicant (s) (as on the application)**
Patents	No		EP2521252	DIRECT-ACTION SUPERCONDUCTING SYNCHRONOUS GENERATOR FOR A WIND TURBINE	FUNDACION TECNALIA RESEARCH & INNOVATION

2.2.2 Part B2: List of exploitable foreground

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	10 MW class lightweight, robust and reliable superconducting generator(SCG).	Yes		New Superconducting Generator concept.	Energy sector: wind turbine or generator manufacturers	0-1 year after the project end	EP2521252 DIRECT-ACTION SUPERCONDUCTING SYNCHRONOUS GENERATOR FOR WIND TURBINE	TECNALIA
Commercial exploitation of R&D results	A new MgB_2 wire with high critical current and good mechanical properties for generators.	Yes		MgB_2 wire for energy sector applications	Superconducting coils and high current cable manufactures	Immediately	Direct Sales	COLUMBUS. Other beneficiary: IEE
General advancement of knowledge	Cryogen-free rotating cryogenic cooling system and rotary joint.	Yes		Design of cryogen free cooling systems and rotary joints	HTS Superconducting rotating application: motors and generators	0-1 year after the project end	IP commercialization and Engineering services	KIT. Other beneficiaries
General advancement of knowledge	Operation and maintenance procedures for large (10 MW) offshore floating and fixed wind turbines, and specialized in superconducting generator turbines.	Yes		O&M procedures for 10 MW machine	Wind Turbine manufacturers (OEMs)(commissioning & warranty), Farm owners / operators (exploitation)	0 - 1 year after the project end. (contracts start years after the wind turbine purchase)	Services offered under Trade Secret	INGETEAM
General advancement of knowledge	Services for marine operations design for large offshore fixed and floating wind turbines.	Yes		Marine operations procedures for 10 MW turbines	Offshore wind farm developers. Marine services and supply vessels companies. Others marine renewable	Time being for French offshore wind farm market. 1 year after the project end for the European market	Support and services subcontractor studies.	D2M

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	Design of 10 MW turbines. Integration of superconducting machines	Yes		Services for the design of large direct drive wind turbines and integration of superconducting generators.	Wind turbine and electric generators manufactures & offshore promoters	After the end of the project	High quality and specific engineering services regarding wind turbines & offshore	SOLUTE

2.2.3 Description of exploitable foreground

Next tables, extracted from deliverable “D6.4 Plan for de Use and Dissemination of the Foreground” submitted in M54, describe the exploitable foreground and the path to market strategy.

2.2.3.1 Path to market ER1: 10 MW Superconducting generator

EXPLOTATION RESULT ER1: 10 MW MgB2 SC generator	
Main Exploiter	**TECNALIA**
Main innovation content	10 MW class lightweight, robust and reliable superconducting generator. TECNALIA holds a patent (PTC/ES2009/070639) on this generator concept in Spain, Germany, UK and the USA. This generator is a direct drive salient poles synchronous machine. It is a partially SCG, MgB_2 wires at cryogenic temperature are used in the field coils while copper wires at ambient temperature are implemented in the armature coils. The cooling system is a cryogen free topology that does not use liquids at cryogenic temperatures. Heat from superconducting coils is extracted by conduction by two stage Gifford-McMahon cryocoolers, which rotate jointly with the rotor. It has a warm iron rotor configuration, which consists on one modular cryostat per pole that encloses only the superconducting coil while the iron of the pole remains at room temperature, thus minimizing the mass to be cooled down. The generator concept has been validated with a scale magnetic machine designed and built specifically for this purpose. The main innovative elements as the superconducting coils, cryostats and cooling system are equal (same size) or similar to the ones of a 10 MW generator, thus these elements have been validated at full scale. It has been analysed that the 10 MW SCG shows a 23% weight reduction respect to permanent magnets generator (PMG) Thanks to this top head mass reduction an 11% reduction of the tower weight is achieve. These improvements make 10 MW turbines more feasible from a technical point of view but can also reduce its cost in more than a 3%. It is remarkable that these improvements have been calculated on the basis of current costs of all the materials and on the basis of obtained results, thus it is estimated that there is huge room for further improvements. Thus the final benefit of SUPRAPOWER generator is the reduction of the LCOE of offshore wind energy.

EXPLOTATION RESULT ER1: 10 MW MgB2 SC generator

Market and its size

The market has been analysed on the basis of the offshore wind market outlook in Europe. It is considered that first superconducting turbines could be installed after 2020.

	2020	2020-2030	2030-2050
Cumulative market (GW)	19	66	350
Market Share	0	0.22%	5.00%
Market volume (GW)	0	0.150	17.5
IP transfer Income (M€)	2.5	0	0
Engineering services (M€)	1.5	1	0
Period Income for turbine sales (M€)	0	37.5	3,281
Royalties (M€)	0	1.875	65.625
Total revenues for Suprapower (M€)	4	2.875	65.625

Assumptions:

- Data extracted from EWEA’s reports; “2050 Facilitating 50% wind energy” and “Wind energy scenarios for 2030”
- An upfront payment in the first year of commercialization is contemplated depend on the final strategy choose (exclusive licensee, minimum sales,…)
- Engineering services are needed for technology customization
- Royalties (5% 2020-2030; 2% 2030-2050) (M€)
- Cost of the generator 250 k€/MW up to 2030 and 187 k€ from 2030 to 250 (25% cost reduction driven industrialization)

<table>
<tr><th colspan="3">EXPLOTATION RESULT ER1: 10 MW MgB2 SC generator</th></tr>
<tr><td rowspan="2">Positioning</td><td>Value proposition</td><td>New SCG generator concept patented, designed and validated in laboratory at significant scale.
The main value of the SCG is the weight reduction of the turbine top head mass. This aspect is fundamental for overcoming some technical barriers for further up scaling current offshore wind turbine, which has been identified as the main driver for cost reduction.</td></tr>
<tr><td>Competitors</td><td>Competitors can be classified in 2 main groups:
<u>Conventional generator technology:</u>
For the last years the dominant technology has been the geared drive train induction generator (DFIG), while direct drive (DD) trains still represent a small share of the offshore wind market. Nevertheless, DD trains are a promising solution, as they show higher reliability and lower maintenance costs than geared options, thereby this technology is called to have a much more important offshore wind market share. But, current slow rotating PMGs are huge and heavy machines and this put at risk the technical and economic feasibility of DD turbines in the range of 10 MW. Moreover one of the main problems associated to PMGs is the high volatility in the price of the rare earth materials used for constructing the excitation magnets. For example in 2011 rare earth prices reached a top of more than 20 times its previous 5 year average. An additional problem is the geographical concentration of rare earths production in China.
<u>Superconducting generators:</u>
Superconducting coils capacity to carry high currents almost without Joule losses permits achieving much higher magnetic inductions than in conventional generators, thus having lighter and more compact machines, with higher power to weight ratio
Superconducting generators (SCG) for wind turbines are an active R&D field. Several wind generator concepts, currently at different development stages, have been proposed, as those of General Electric , AMSC , RISO-DTU or AML. Nevertheless, some of these concepts face certain technical and economic barriers that could complicate their industrial feasibility for the offshore wind sector. The feasibility of concepts based on conventional pool boiling cryogenic cooling systems is debatable for offshore locations. These systems require huge amounts of cryogenic fluids, as LN2, GHe or LNe, and very complex cryostats and cooling circuits. Complex rotary joints can be also required to exchange huge amounts of cryogen liquids between stationary and rotating parts. SCGs based on LTS wires, as NbTi, require very low operating temperatures, in the range of 1.8-4.2 K, thereby the efficiency of the cooling cycle working at such temperatures is very low, in the range of 0.3%. Beside this, some concepts are based on still expensive and with limited commercial availability materials, such as 2G HTS wires, or materials without attractive cost reduction perspectives such as 1G HTS wires.</td></tr>
</table>

EXPLOTATION RESULT ER1: 10 MW MgB2 SC generator		
		More recently EcoSwing EC funded project is aiming demonstration a SCG at 2 MW. EcoSwing project will represents a major progress respect current state of the art as makes a demonstration at real scale never than before. SUPRAPOWER generator is MW class lightweight, robust and reliable superconducting generator that gives answer to offshore sector demands and overcomes some of the presented barriers of other SCG concepts. SUPRAPOWER is based on a industrially available and cost competitive superconducting wire, MgB2 and it uses a cryogen free cooling concept that avoids the uses of cryogenic liquids.
Time to market		The commercialization of the generator could be expected in 10 year time, this time would be required to further develop and industrialize the technology, including a first demonstration prototype at MW scale. From TECNALIA's perspective the IP generated in the project can be transferred after the end of the project.
Marketing strategy		TECNALIA's marketing strategy is the transfer of the IP rights to generator or wind turbine developer, in order to industrialize and commercialize the SCG. As indicated in the table included in market size section, it is considered that at first 50% of the IP could be transferred valuated in 2.5 M€. TECNALIA in conjunction with the IP will offer its own, COLUMBUS and KIT capabilities to develop the key enabling technologies associated to the generator. As indicated in the table included in market size section, it estimated that the income of such services could be in the range of 2.5 M€ for the next 5 years (0,5 Me per year). Marketing strategy will be mainly focused on wind turbine and generator manufacturers, as the followings: Siemens, ENERCON, GE-ALSTOM, Gamesa Electric, ABB, INDAR-Ingeteam, The Switch, ELIN, Leroy Somer, VEM and Winergy among others. It is estimated that wind turbine manufacturers with Direct Drive models would be more receptive to this technology than those focused on geared technologies.
Jobs sustained/created		The development of the superconducting generator that was partially funded by SUPRAPOWER project permitted to create 3 new jobs in TECNALIA. After the transfer of the IP to an industrial partner, the further development and industrialization of the technology could create another 3 new jobs in TECNALIA up to double current superconducting core team. On the other hand the development and exploitation of the superconducting generator could permit to create around 50 new jobs in the industrial partner in the near future but some other new jobs could be created associated to the MgB2 wire manufacturing and other auxiliary components (cryocoolers, vacuum pumps, etc)

EXPLOTATION RESULT ER1: 10 MW MgB2 SC generator	
Project partners involved in the exploitation	TECNALIA as owner of the patent will be the main partner involved in the exploitation, but also COLUMBUS and KIT would be highly involved as they are a supplier of key material and a designer of key technology respectively.
Next steps for commercialisation	After then end of the SUPRAPOWER project the first step is the transfer of the IP to industrial partner, as the presence of the future exploiter of the technology is considered fundamental for any further step. The next technical step should be the design and development of multi-MW scale generator to be implemented in a wind turbine.

2.2.3.2 Path to market ER2: MgB2 wire

EXPLOTATION RESULT ER2: MgB2 wire and coil		
Main Exploiter		**Columbus**
Main innovation content		A new wire has been developed with high critical current, good mechanical properties and the possibilities to add the amount of copper needed for protection and stabilization through the soldering of a copper strip. MgB_2 coils for generators applications design (TECNALIA) and manufacturing capacity
Market and its size		The main market for this wire is the MRI medical system (1.3B$ by 2020 http://www.transparencymarketresearch.com/pressrelease/superconductors-market.htm). There is also a possible future market related to rotating superconducting machine. It is expected Columbus could reach a 1% of market share in 2020-2030 period, that means a net revenue of 13M€.
Positioning	**Competitors**	The main competitors are the LTS materials used since many years in this kind of application, but the advantages of MgB_2 are the possibility to work at higher temperature without the use of cryogenic liquids and with bigger temperature margin. There are few or no competitors in the field of MgB_2 superconducting coils, moreover COLUMBUS is the main manufacturer of this type of wire, so that the capacity of design and manufacturing MgB_2 coils pushes COLUMUBUS to a very competitive position.
Time to market		Wires are ready for commercialization.
Jobs sustained/created		Columbus foresees around 17 new employees for this application in 2020-2030 period. For the case of superconducting coils is market difficult to estimate.
Project partners involved in the exploitation		Additionally to Columbus, Tecnalia could be involved in the market related to the SC generator or electrical rotating machines (including design of coils)
Next steps for commercialisation		Next steps for a deeper implementation in the MRI market is related to further enhancements in the single batch production capability (wire longer that 9 km in a single batch). Regarding superconducting and wire cost performance ratio is currently increasing MgB_2 coils with heat extraction by conduction should still improve before commercialization, but design services are ready for being provided after the project end.

2.2.3.3 Path to market ER4: Cryogen free cooling system & rotary join

EXPLOTATION RESULT ER4: CRYOGEN FREE COOLING SYSTEM & ROTARY JOINT		
Main Exploiter		**KIT, TECNALIA**
Main innovation content		The cryogen-free rotating cryogenic cooling system we developed in SUPRAPOWER project provides a feasible technical solution with simple structure and high availability and reliability. The rotary joint integrated with helium path, current circuit and optical channels makes the G-M cryocooler suited for the rotating cryogenic system, which may extend the potential customers of such G-M cryocoolers.
Market and its size		KIT foresees 2M€ net income for 2017-2020 period, 20 M€ for 2020-2030 and 385M€ for 2030-2050* *2% of inflation is considered
Positioning	**Competitors**	The cryogen-free rotating cooling system eliminates the effort, training and equipment required for the purchase and use of cryogenic liquids. Safety issues associated with the venting of vapour boiling off from the cryogen are, for the most part, eliminated. These advantages are particularly valuable in superconducting wind turbine development where the principal work is not cryogenic research but rather other activities like the generator deign and HTS coil. Properly designed, the cryogen-free system can appear to the end-user as just another utility and extensive training in cryogenics is not required. In offshore applications, the use of cryogen-free systems removes the challenge of dealing with liquids means that the mission lifetime is determined by the reliability of the cryocooler, not the amount of cryogen that can be brought into offshore wind farms
Time to market		After the project end
Jobs sustained/created		9 new jobs could be created in 2017-2020 period
Project partners involved in the exploitation		KIT and Tecnalia
Next steps for commercialisation		TBD

2.2.3.4 Path to market ER5: O&M procedures for 10 MW machine

EXPLOTATION RESULT ER5: O&M procedures for 10 MW machine	
Main Exploiter	**INGETEAM Service – Ingeteam Power Tecnology S.A.**
Main innovation content	New knowledge acquired about Direct Drive Superconductive Synchronous Generators and its characteristics, working mode, reliability, maintainability, critical elements and specific maintenance operations required. This allows Ingeteam to offer the Wind Turbine manufacturers (during commissioning and warranty period) and Wind Farm owners / operators its services, with the confidence of having taken part in the design of the turbine, the specifications for the marine operations and the maintenance plan and strategy that this kind of machine requires. Together with this, Ingeteam have acquired a very valuable know-how in large offshore wind turbines in general. This knowledge can be applied for any future maintenance contracts.
Market and its size	The potential market to offer O&M services on Super conductive 10MW machines is as wide as for the machine itself as each wind turbine has to be maintained. This widens market size to every new offshore emplacement with cost-effective wind resource, not only in the European market starting to be mature but also in the worldwide new comers (China, USA, Japan… http://www.gwec.net/wp-content/uploads/2017/05/Global-Offshore-2016-and-Beyond.pdf). Focusing on the European market, the European wind energy association, Wind Europe, in 2017, talks about a total of 65.6 GW in the planning phase and consequently, potential users of Suprapower Generator equipped wind turbines and thus of O&M specific services. And, what is more important, the innovations and advantages of this generator over the state-of-the-art will enable to multiply the number of sites where a new wind farm becomes profitable. There will be also a portion of onshore market where the advantages of the 10MW superconductive generator could make it profitable, and, for the same reason, those wind farms will also need O&M services. Size of this market is much more complex to determine, and there are no figures for this case.

EXPLOTATION RESULT ER5: O&M procedures for 10 MW machine		
Positioning	**Competitors**	To the date, the main competitors for O&M offshore services are the turbine manufacturers (OEMs: Original Equipment Manufacturers) and the Wind Farm owners / operators in case they have their own O&M service. Anyway, nowadays there are several Independent Service Providers (ISPs) with wide experience in offshore wind farms like: A2Sea, GeoSea, ZITON, All NRG, CWind, Deutsche Windtechnik, Global Wind Service. The competitive advantage is the acquired know-how during Suprapower Project by Ingeteam to operate and maintain a superconductive wind turbine. The only competitor able to achieve this know-how at a first stage would be the licensing manufacturer, which mean that, in case they are also dedicated to wind turbines maintenance, there will be only one more company offering this kind of O&M services. Nowadays, Ingeteam Service experience in offshore operations is not yet as wide as their competitors. The general knowledge acquired by Ingeteam during the project in marine operations and offshore strategies means a very useful source to improve its service offer.
Time to market		0 – 1. Procedures are ready by the date. They need to be detailed once a detailed engineering is done for the complete Wind Turbine. Then, each project has to follow the local legislation and some adaptation will be required according to the site location. Anyway, they will need improvement and optimization, unfortunately this is only possible using first experience feedbacks, so they will improve by doing.
Jobs sustained/created		Each wind 100MW wind farm would require at least 8 permanent technicians, plus 2 extra specialists for the summer maintenance period (5 months) and between 5 to 8 specialists more every 2 years for the same period. Besides this 1 project manager, 1 onshore operations coordinator and 1 analyst engineer will be needed. This means that every 100MW wind farm full-maintenance contracted would mean around 15 net new jobs.
Project partners involved in the exploitation		Ingeteam
Next steps for commercialisation		As it is indicated in “Time to market” point, the generic strategy and procedures are ready, to provide the proper service, a detailed engineering for the turbine will be needed. Once this information is available within a maximum of 2 months specific procedures could be ready. As also mentioned, as superconductivity is a totally brand new technology for wind turbines, several months of more frequent inspections will be required after the installation of first commercial models to optimize and improve the service offered.

2.2.3.5 Path to market ER6: Marine operations procedures for 10 MW turbines

EXPLOTATION RESULT ER6: Marine operations procedures for 10 MW turbines	
Main Exploiter	**D2M**
Main innovation content	Main innovations related to the Suprapower's project are due to the important size of the wind turbine parts (tower, blades, etc.). However, an important part of the project was to demonstrate that all Suprapower's 10MW wind turbine installation and operations can be performed with nowadays existing means (vessel, cranes, etc.), which does not involve any additional costs compared with a classic existing same size wind turbine. Important attention was then paid to the installation procedures, in order to propose realistic operations procedures with existing Jack-up vessels (main offshore wind farm installation vessels) for fixed foundation wind turbines, and with existing tugs for floating foundations wind turbines. Results have shown that, partially thanks to the superconducting light weight generator, installation and operations are possible (lifting and transport operations) for both fixed and floating foundations wind turbines. Dimensions and weights of the 10MW sub parts (blades, tower parts, and nacelle) being significant but not oversized compared to existing offshore wind turbines, and so not oversized for nowadays offshore wind farm marine operations vessels and means. About O&M tasks, all wind turbine access can be done with existing means depending of the type of operation and strategy defined: from supply and work boats (boat landing, heave compensate gangways, etc.) or helicopters (winch transfer of personnel and spare parts). Furthermore, a pooling resources strategy can be planned between different offshore wind farms, whatever wind turbines type and size located in the vicinity as classic means and vessels can be used with Suprapower's new wind turbine. The economic impacts of these observations are essential for the development perspectives of the Suprapower's wind turbine, even more so considering than for the same weight, therefore probably the same foundation sizing, a classic wind turbine will be less powerful. Installation costs per Megawatt will then probably be more competitive for a Suprapower's wind turbine than for a classic wind turbine generator.
Market and its size	The offshore wind farms market is experiencing strong growth these last years, particularly in Europe, but also in others countries worldwide (Japan, China, USA, etc.). In France also recent government policies have defined and allocated offshore wind farm development areas: firstly for fixed foundations wind turbines, and more recently for floating foundations wind turbines. For d2m, which main activities are to provide assistance and services to its Clients, the experiences gained in Suprapower's project is invaluable to support wind developers companies, which are experienced mainly in on

EXPLOTATION RESULT ER6: Marine operations procedures for 10 MW turbines		
		shore wind farms, but having often less knowledge about marine constraints and offshore operations. As a French company, d2m is mainly involved in the French market, in which no offshore wind farm has been built to date, and where there are still many things to do. These new experiences are then new arguments that d2m can directly enhance from the French offshore wind farms developers which are mainly inexperienced in marine operations. Moreover, these new skills can be also useful for other new Renewable Marine Energies, in particular for tidal and wave energies converters devices: all these new technologies are developed by companies which have assistances needs, as their team are not well sized or not competent in all fields. D2M foresees 150k€ net income for 2017-2020 period, 6 M€ for 2020-2030 and 210M€ for 2030-2050* *2% of inflation is considered
Positioning	**Competitors**	There are no French offshore wind farms to date, but several projects for both fixed and floating foundations. There are not really experienced companies in many subjects related to these technologies, and in particular in marine operations dedicated to offshore wind farms. D2M has then a unique knowledge ahead of the French market competition. With its long experience in naval architecture, and marine engineering, D2M can be valuable as a sub-contracting partner.
Time to market		D2M new skills are already used to solicit offshore wind farms developers, and also tidal currents farms developers (often the same companies in the French market). The coming year, D2M will seek to perform subcontract analyses for North Europe offshore wind developers, in order to benefit of the visibility linked to the Suprapower's project.
Jobs sustained/created		The development of D2M's offshore wind farms activities is correlated with the installation of new offshore wind farms, but it is expected that a new full time job can be created for each new wind farm marine operation's subcontract.
Project partners involved in the exploitation		It seems like none of the project partners will be involved in the exploitation of marine operations knowledge, but sharing some economic activities' contacts can be useful and profitable for each one. Moreover, the good relations developed during this project will probably bring new collaborations opportunities, mainly thanks to the different nationalities of the partners

EXPLOTATION RESULT ER6: Marine operations procedures for 10 MW turbines	
Next steps for commercialisation	The preliminary results of marine operations analyses, based on several assumptions, have shown that all marine operations of the Suprapower's wind turbine can be performed with nowadays existing means. The mainly conclusion is that there will be no additional cost for the Suprapower turbine installation and exploitation than for another model of wind turbine. Its development has no need for dedicated means, vessels or new cranes to be built. It is just necessary to have an accurate procedures assessment and description for each new project, adapted on its characteristics (type of foundation, wind farm area location, environmental loads, etc.). Commercialisations of marine operations' analyses are possible from now on for each new offshore wind farm project.

2.2.3.6 Path to market ER7: Design of 10 MW turbines. Integration of superconducting machines

EXPLOTATION RESULT ER7: Design of 10 MW turbines. Integration of superconducting machines		
Main Exploiter		**SOLUTE**
Main innovation content		The scaling of a wind machine up to 10 MW, requires the application of careful studies on the aerodynamics of blades of adequate size. Likewise, the forecast of the use of the 10 MW WTG in offshore location on floating platforms, requires the development of new calculation methodologies not applied until today.
Market and its size		Our target market is the engineering services to promoters and WTG manufacturers, regarding the acquired knowledge in offshore calculations (mechanical, aerodynamics & hydrodynamics issues). We expect a market that allows us to bill 0.3 million euros/year.
Positioning	**Competitors**	Solute can provide very high quality services regarding the Design of big turbines and integration of superconducting machines. We provide our customers optimization of weights, that will suppose big amounts of money to save, and really competitive costs in their WTG´s, platforms,….
Time to market		Solute is already ready to provide the services mentioned that have been acquired in Suprapower Project
Jobs sustained/created		SOLUTE is an engineering consulting, technology service and outsourcing company, that provides a wide range of engineering services to various technology sectors, mainly in wind sector. We have multidisciplinary staff composed by more than 50 engineers belonging to different specialties. With the participation in SUPRAPOWER and the exploitation of the results, we estimate that we can offer engineering services specialized on integration in WTG´s or offshore loads & control simulations that could report us around 4 new jobs in the next two years
Project partners involved in the exploitation		No other partners will be involved in the specific exploitation of our results, but SOLUTE is open to the creation of any consortium with any of its partners in order to develop any project.
Next steps for commercialisation		Solute will promote the activities made in SUPRAPOWER in order to obtain contracts in similar projects regarding offshore, and integration of generators in WTG´s.

3. REPORT ON SOCIETAL IMPACTS

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	308793
Title of Project:	Superconducting, Reliable and More Powerful offshore wind turbine
Name and Title of Coordinator:	Iker Marino Bilbao

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***No***
RESEARCH ON HUMANS	
• Did the project involve children?	**No**
• Did the project involve patients?	**No**
• Did the project involve persons not able to give consent?	**No**
• Did the project involve adult healthy volunteers?	**No**
• Did the project involve Human genetic material?	**No**
• Did the project involve Human biological samples?	**No**
• Did the project involve Human data collection?	**No**
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	**No**
• Did the project involve Human Foetal Tissue / Cells?	**No**
• Did the project involve Human Embryonic Stem Cells (hESCs)?	**No**
• Did the project on human Embryonic Stem Cells involve cells in culture?	**No**
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	**No**
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	**No**
• Did the project involve tracking the location or observation of people?	**No**
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	**No**
• Were those animals transgenic small laboratory animals?	**No**
• Were those animals transgenic farm animals?	**No**
• Were those animals cloned farm animals?	**No**
• Were those animals non-human primates?	**No**
RESEARCH INVOLVING DEVELOPING COUNTRIES	

• Did the project involve the use of local resources (genetic, animal, plant etc)?	**No**
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	**No**
DUAL USE	
• Research having direct military use	**No**
• Research having the potential for terrorist abuse	**No**

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	1	5
Experienced researchers (i.e. PhD holders)	6	29
PhD Students	2	4
Other	3	12

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**7**
Of which, indicate the number of men:	5

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
● No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective → Very effective
❑ Design and implement an equal opportunity policy	○ ○ ○ ○ ○
❑ Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑ Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑ Actions to improve work-life balance	○ ○ ○ ○ ○
○ Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

● No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

● No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

● No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline:

○ Associated discipline:

○ Associated discipline:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ Yes
● No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ●	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ● No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**13**
To how many of these is open access[1] provided?	**3**
How many of these are published in open access journals?	**3**
How many of these are published in open repositories?	**0**
To how many of these is open access not provided?	**10**
Please check all applicable reasons for not providing open access:	
☒ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ☒ no suitable open access journal available ☒ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[2]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**1**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		**0**

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☒	Increase in employment, or	❑	In small & medium-sized enterprises

[1] Open Access is defined as free of charge access for anyone via Internet.
[2] For instance: classification for security project.

❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	☒

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ● No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ● No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☒	Press Release	☒	Coverage in specialist press
❑	Media briefing	☒	Coverage in general (non-specialist) press
❑	TV coverage / report	☒	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
☒	Brochures /posters / flyers	☒	Website for the general public / internet
❑	DVD /Film /Multimedia	☒	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	☒	English
❑	Other language(s)		