# PRESENTING OUR TECHNOLOGY

1st Edition – March 2015

Prepared by

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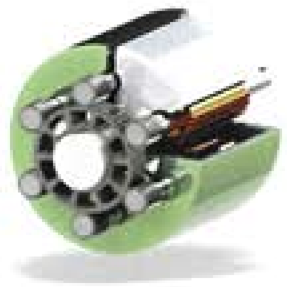

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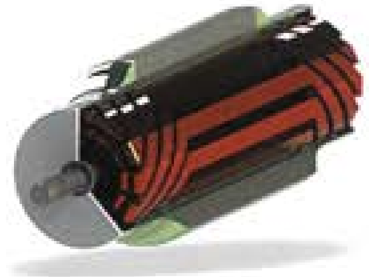

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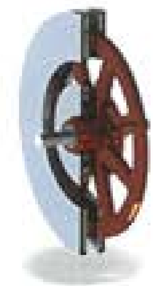


ELECTROMAGNETIC POWER CONVERTERS AND GEARBOXES

Our designs and concepts combine innovations sourced from a range of novel technologies to produce advanced Green Energy solutions. Our technology harnesses the power of highly compressed magnetic field to produce superior reaction and power to weight ratios than other motors and generators. Our technology produces higher total system efficiency.

# GUINA ENERGY TECHNOLOGIES

***Guina Energy Technologies is a privately funded independent research and development company working in the field of electromagnetic phenomena.***

***We are combining the latest technology, advanced materials, improved engineering solutions with new approaches to develop high performance motors and generators.***

***Our aim is the development of highly efficient, power dense and environmentally friendly motor and generator solutions for an energy conscious future.***

# COMPANY LOCATION


***Head Office:***
Level 19, 50 Cavill Avenue
Surfers Paradise, QLD, 4217, Australia

***Research Laboratory:***
Unit 3, 8 Technology Drive
Arundel, QLD, 4215, Australia

# COMPANY HISTORY

**1998** Mr. Ante (Tony) Guina, a Croatian born scientist and the Chairman of Guina Energy Group, commenced research into magnetic and electromagnetic fields in the mid 1990's. The company established an office on the Gold Coast, Australia, for the purpose of furthering this research. In 2004 the company broadened its research focus to include the rapidly advancing fields of Superconductivity and Superconductive Materials. Our first coils and electromagnets were made by HTS-110 Ltd. in New Zealand in 2005. Throughout the history of the company the goal of perfect rotary electromagnetic motors or generators has been constantly pursued.

**2000** In early 2010, Mr. Guina invented his first Electromagnetic Turbine motor (the Alpha-Tron). Since then Mr. Guina has invented coils and solenoids with a series of null regions in the electromagnetic field for use in the Super-Tron series of Electromagnetic Turbine motors and generators. He has also invented all of the other Electromagnetic Turbine motors and generators presented in this document. These motors and generators represent the most advanced and powerful electromagnetic machines, in terms of their power to weight ratio, in the world.

**2010** The Guina Energy Group has a dedicated team of scientists who have contributed to the further perfection of the Coils, Solenoids and Electromagnetic Turbine motor and generator designs. All of Guina's scientists are long term employees dedicated to advancing the company's pioneering research and development.

In 2012, John Kells (**Manager** Development) invented our Electromagnetic Power Converters (internally known as the 'Kells Converters'), required for successful implementation of our Homopolar Electromagnetic Turbine technology, and our Electromagnetic Gearboxes. These inventions were further developed and refined by Dr. Rene Fuger (**Manager** Research) & David Sercombe (**Manager** Project Development) along with the rest of the team.

**2012**

# COMPANY HISTORY

**2012**

In 2012 Dr. Rene Fuger developed the Stray Field Reduction Technology for our Homopolar Electromagnetic Turbines which contains stray magnetic field without using heavy iron or steel shielding, thereby increasing power to weight ratios of our Homopolar Electromagnetic Turbine technology. Also in 2012 our team of scientists developed direct drive generators required for wind turbines and the Electromagnetic Power Convertors necessary for implementation of our entire range of Tron series Electromagnetic Turbine motors and generators. Towards the end of 2012 Mr. Guina invented a second generation of the Tron Electromagnetic Turbine motors and generators (G2). These motors and generators have been further developed by the team to improve power to weight ratios and reduce inter-coil forces resulting, in simplified construction.

**2013**

In late 2013 Mr. Guina invented a new class of AC electrical motors and generators based on sets of concentric racetrack coils. This new geometry significantly reduces the amount of superconducting wire required for a given power level.

**2014**

In 2014, Mr Guina invented the series of Toroidal Motors and Generators, followed by the invention of our Brushless Permanent Magnet motors and generators. Dr. Rene Fuger (**Manager** Research) invented the 4 Pole Permanent Magnet machines (known as the 'Fuger 4-Pole Machines').

David Sercombe (**Manager** Project Development), in conjunction with John Kells (**Manager** Development), developed the windings for our Toroidal and Permanent Magnet Motor (know internally as the 'Sercombe Windings')

**2015**

Research and development of liquid metal current collector technology has been led by Dr. Arkadiy Matsekh (**Manager** Scientific Research) and Dr. Cesimiro Fabian (**Manager** Electromaterials Science & Innovation) with support from the team. The system is referred to internally as the 'Fabian-Matsekh Brush System'.

# MILESTONES AND FUTURE ENDEAVOURS

Since the late 1990's until the end of 2014, the scientists at Guina have spent over 100,000 hours modelling and simulating our ground-breaking motor and generator technologies using Vectorfields Opera 3D, Solidworks and Altium simulation packages.

In addition to the modelling and simulation work, Guina has placed a great emphasis on the physical experimentation and validation of its technology. To date we have:

- Successfully built and tested two superconducting homopolar motors:
  - Our first generation homopolar test motor based on Metal Fibre Brush technology and,
  - Our second generation homopolar test motor that incorporated our proprietary null field regions and our first generation liquid metal current collector technology. This liquid metal current collector technology was developed in-house.
- Validated the use of null field regions in the midst of a high strength background magnetic field in order to create an effective liquid metal current collector.
- Successfully built and tested our first generation liquid metal current collector technology.
- Validated and tested our Electromagnetic Power Converter/Gearbox technology.

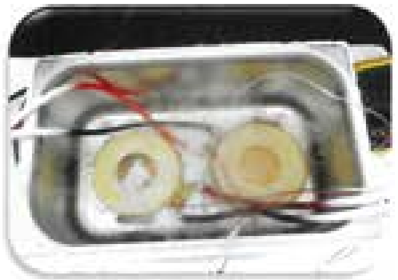
We are currently:

- Developing our second generation liquid metal current collector technology incorporating an enclosed pumped liquid metal recirculation system that will allow higher electrical performance of the current collector as well as utilising the liquid metal material as a coolant.
- Building and developing stator windings for our Brushless Permanent Magnet Technology with a local (Australian) winding company.
- Developing a novel way to liquid cool the stator windings in our Permanent Magnet motors/generators. We aim to achieve a current density in the windings of greater than 11 $A/mm^2$ RMS.
- Developing power electronics to power and control the operation of our permanent magnet motor and generator technology.

# DEVELOPMENT TIMELINE

GUINA ENERGY GROUP

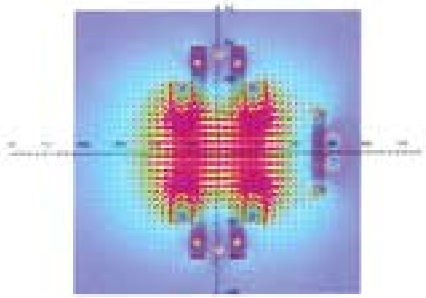
**2005**



The first HTS super-conducting coil is acquired by Guina Energy for physical testing.

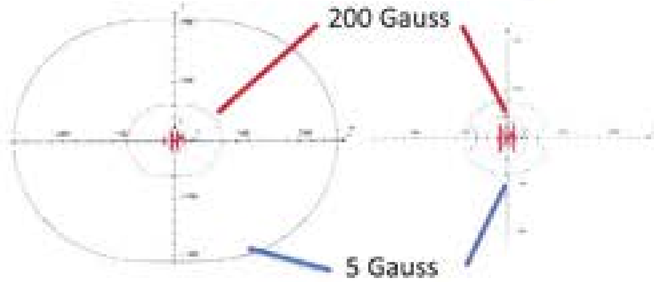
**2010**

Our first Electromagnetic Turbine motor, the Alpha-Tron, is invented.



The null magnetic field regions, created by Guina's novel coil geometry, allows the development of high performance brush systems.

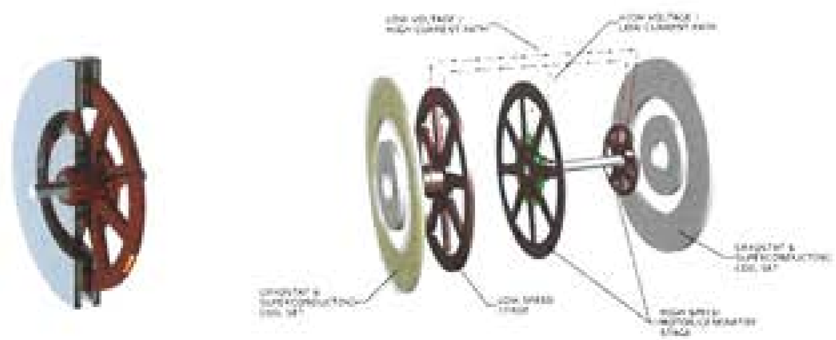
**2011**




Our Stray Field Reduction Technology uses active field shielding coils to significantly reduce the stray field at a fraction of the weight of steel or ferrite based shielding.

**2012**

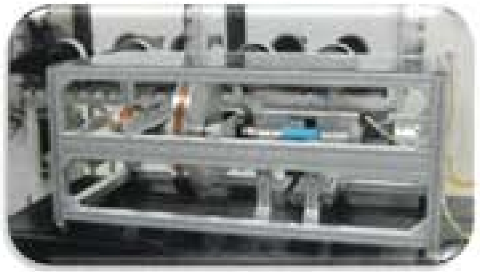
The High Speed Super-Tron Electromagnetic Turbine Generators and Motors, designed by the team at Guina Energy, represent the simplest design implementations that encompass all of our unique technology.



The team at Guina develops a range of Electromagnetic Power Converters. The converters can step up or down shaft speeds in the gearbox implementation or convert DC power levels in the DC-DC Converter implementation.

# DEVELOPMENT TIMELINE

A 2.5 Tesla prototype magnet system is delivered by HTS-110 for testing with our Electromagnetic Turbine assembly developed in house.



Our team of experts lead the research and development of our liquid metal brush technology, including the successful testing of prototype brush systems.

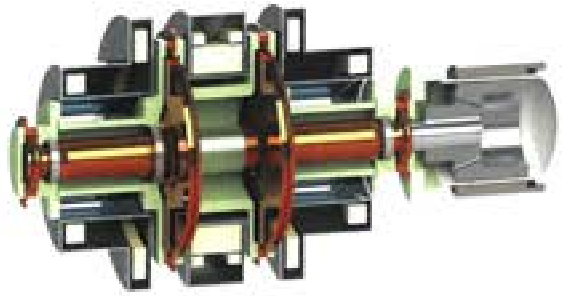
Guina's Toroidal Drive systems are developed by our team. The toroidal stators perfectly contain the magnetic field, allowing the field to be used multiple times.

Guina's Brushless Permanent Magnet technology, featuring high power-to-weight ratios and efficiencies, is added to our range of generators and motors.

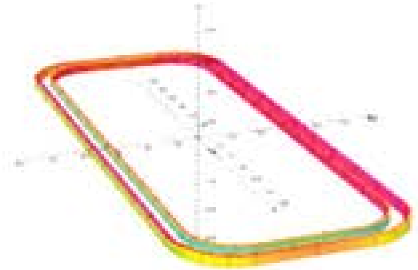
**2013**

**2014**

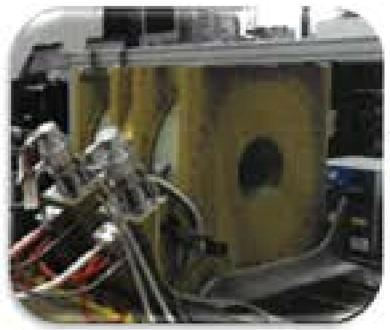
**2015**



The second generation of Tron Electromagnetic Turbine motors and generators (G2) are developed.



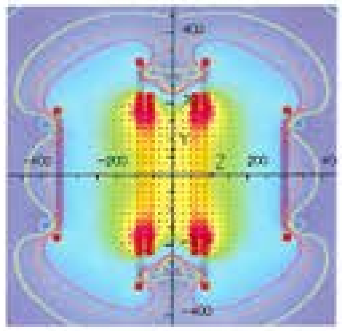
Our "All Pole Drive" generator concept are developed to suit Direct Drive Wind Turbines.

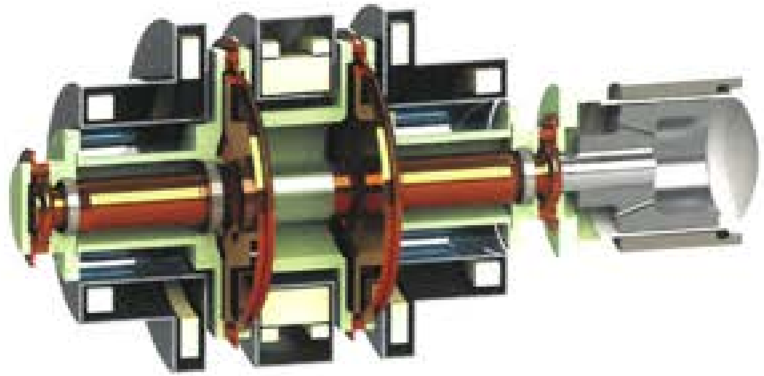


Assembly and testing of our G2 Super-Tron Turbine, including our liquid metal brush system, under real life conditions.

# RESEARCH AREAS

- ***Superconducting magnet designs***





- ***Homopolar motors and generators***

- ***Chemical and electrical behaviour of liquid metal materials***

- ***Superconducting and permanent magnet motors and generators***

- ***Power electronics for motor controllers***

# STAFF MEMBERS

Our team of experts consists of:
- 10 scientific staff members
- 3 non scientific staff members

Our team is represented by 8 nationalities. Team members have significant international work experience.


Our staff members hold university degrees in:
- Mechanical Engineering
- Electrical Engineering
- Natural Science
- Chemical Engineering

Specialization of our scientific staff members:
- Low Temperature Physics
- Superconductivity and Cryogenics
- Electro Chemistry
- Electromagnetic Modelling
- Thermal and Mechanical Modelling

GUINA™ ENERGY GROUP

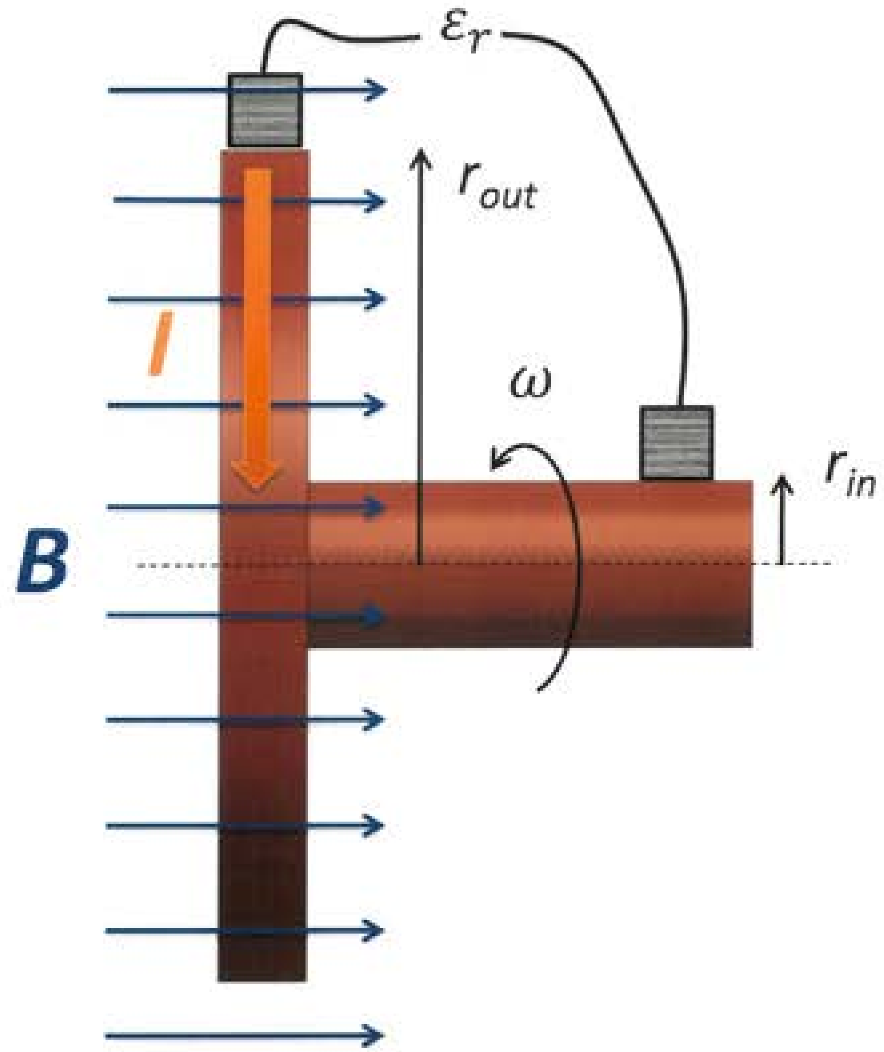
# PRESENTING: HOMOPOLAR MACHINES & THEIR ADVANTAGES

# SECTION OVERVIEW

- History of Homopolar Machines
- Principle of Operation
- Homopolar Fundamentals
- Introduction to Superconductors
- Guina Machine Layout
- Guina Machine Design Advantages
  - Low field Region
  - Active Shielding
  - Liquid Metal Current Collectors
- Alternative Design Layouts

# WHAT IS A HOMOPOLAR MACHINE?

**Disc Type**




- A Conductive Disc in an external magnetic field
- If the disc is rotated in the field then a voltage will be produced between brushes.
- If a voltage is supplied to the brushes such that a current flows then the disc will rotate.
- DC Voltage and Current
- DC Magnetic Field

# HISTORY OF THE HOMOPOLAR MOTOR

**1821** The homopolar motor was the <u>first electrical motor</u> to be built and its operation was demonstrated by Michael Faraday.

**1886** The Scottish electrical engineer George Forbes built a homopolar generator with two disks sitting on the same shaft to <u>increase the voltage</u>.

**1912** Benjamin G. Lamme developed and built a 2 MW generator using copper leaf brushes running at 1200 RPM, 7700 A at 260 V for <u>industrial applications</u>.

**1934 - 1960** Prof. Boris Ugrimoff built the first large scale homopolar generator with <u>liquid metal current collectors</u>.

Westinghouse Electric built a homopolar generator for tube <u>contact welding</u>.

Used as power source for an electromagnetic pump in <u>atomic energy applications</u>.

# HISTORY OF THE HOMOPOLAR MOTOR

**1960's** General Electric's Large Motor and Generator Department built and operated 6 homopolar generators with a nominal power of 10 MW.

**1962** A pulse generator with a NaK circulation system and jet-spray contact was built as a power source for the magnets of a 10 GeV proton synchrotron at the Australian National University, Canberra, Australia.

**1997** Scientist and engineers from the Naval Research Laboratory (NRL) and Naval Surface Warfare Center (NSWC) have shown the feasibility of high-temperature superconducting (based on BISCCO-2223 superconductor) motors for ship propulsion.

**2004** General Atomics, together with the DOE, started a program to develop a superconducting homopolar motor for ship propulsion.

# HOMOPOLAR FUNDAMENTALS

A disc rotating in a homogenous magnetic field produces a DC potential difference (a DC Voltage) between the centre and the edge of the disc.

$$\vec{E} = (\vec{\omega} \times \vec{r}) \times \vec{B} \qquad \varepsilon = \omega \int_{Rin}^{Rout} B(r) r \, dr$$

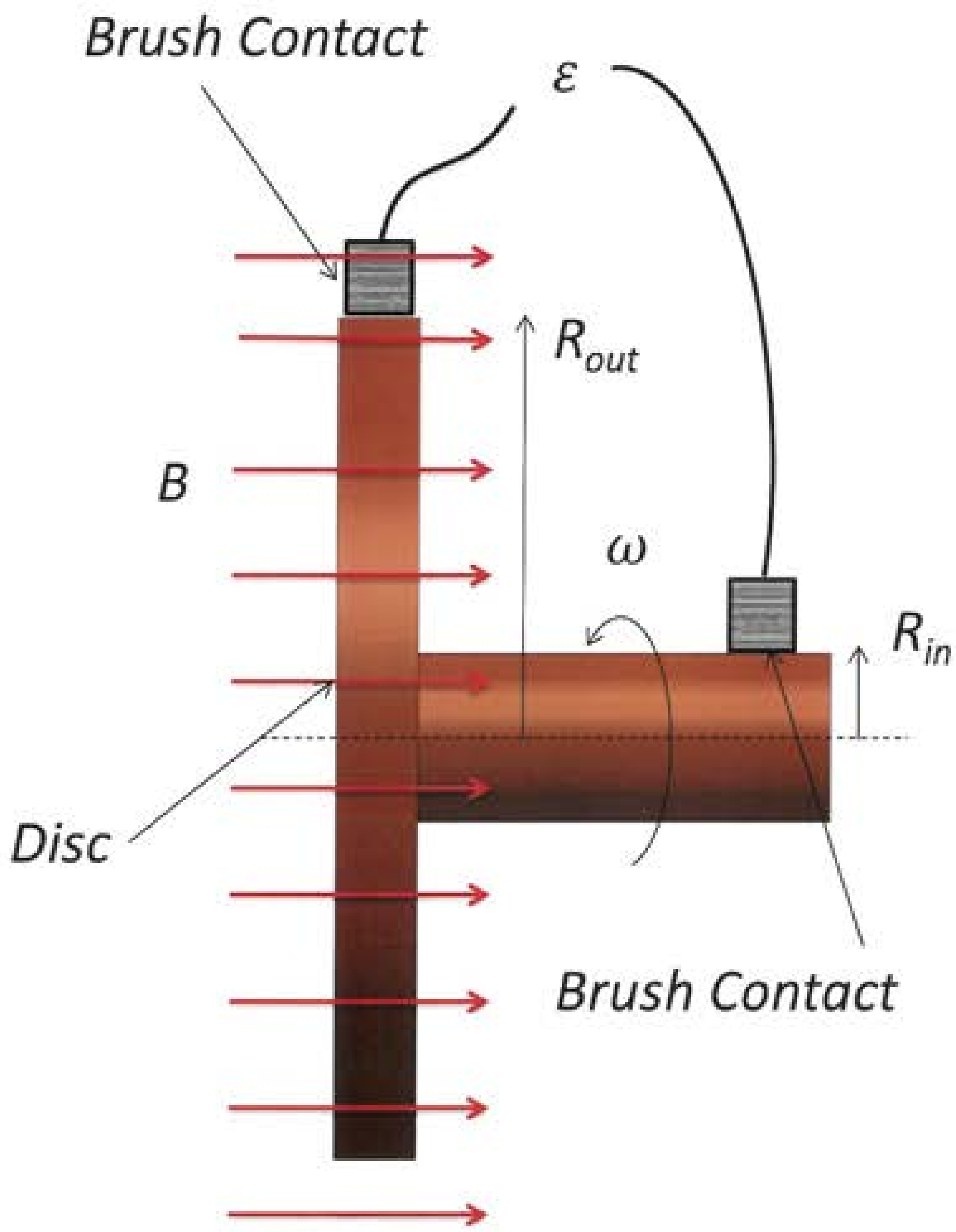
In the case of a uniform magnetic field:

$$\varepsilon = \omega \int_0^R B(r) r \, dr = \frac{R^2}{2} B\omega$$

As a motor the torque & power are given by:

$$T = I \int_0^R B(r) r \, dr$$

$$P = \frac{2I\pi N}{60} \int_0^R B(r) r \, dr$$



# HOMOPOLAR FUNDAMENTALS

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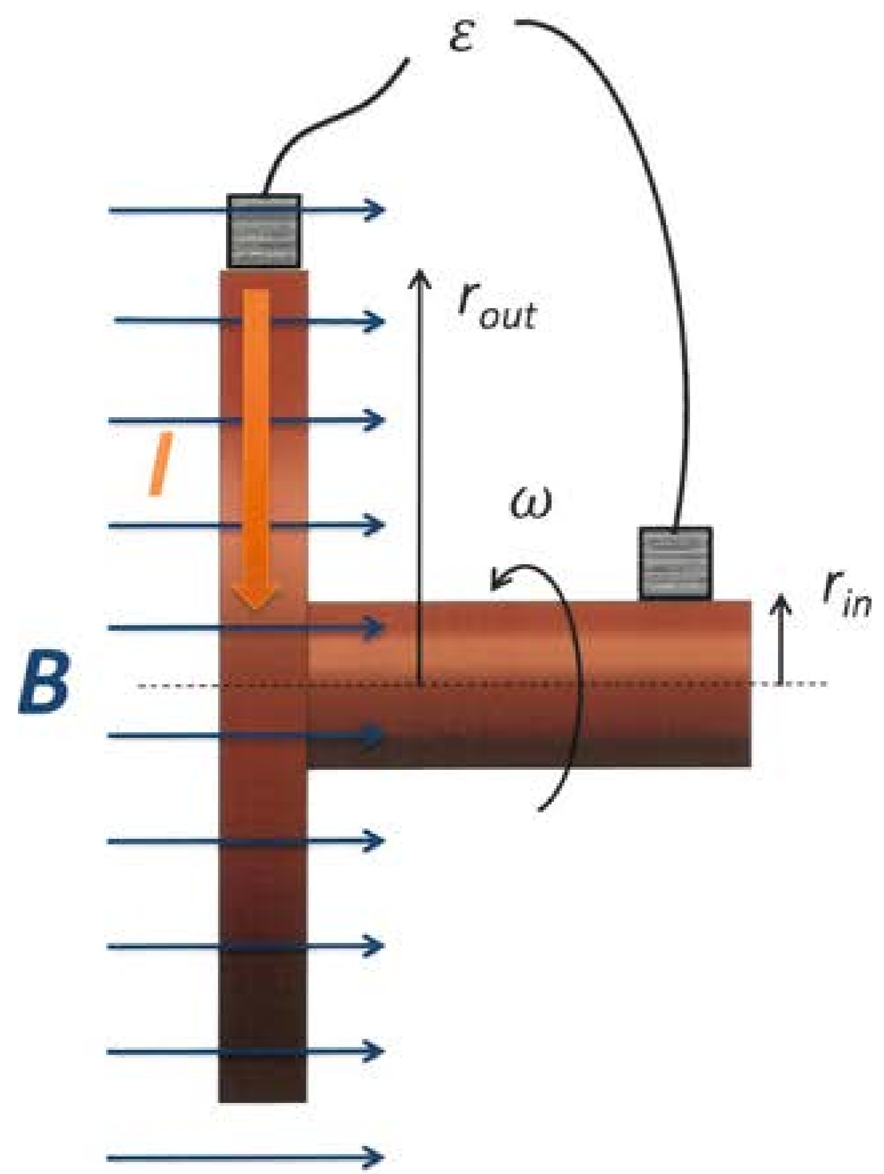
## How can we increase the performance of the machine?

$$P = \tau\omega = IB\left(\frac{{r_{out}}^2 - {r_{in}}^2}{2}\right)\omega$$




**Longer working length increases the voltage and torque**
**(size, surface speed)**

**Higher currents increase torque and decrease voltage**
**(electrical losses increase)**

**Higher rotational speeds increase voltage and power**
**(material limits, brushes)**

**Higher magnetic fields increase voltage and torque by same size (Superconductors)**

# PRINCIPLE OF OPERATION

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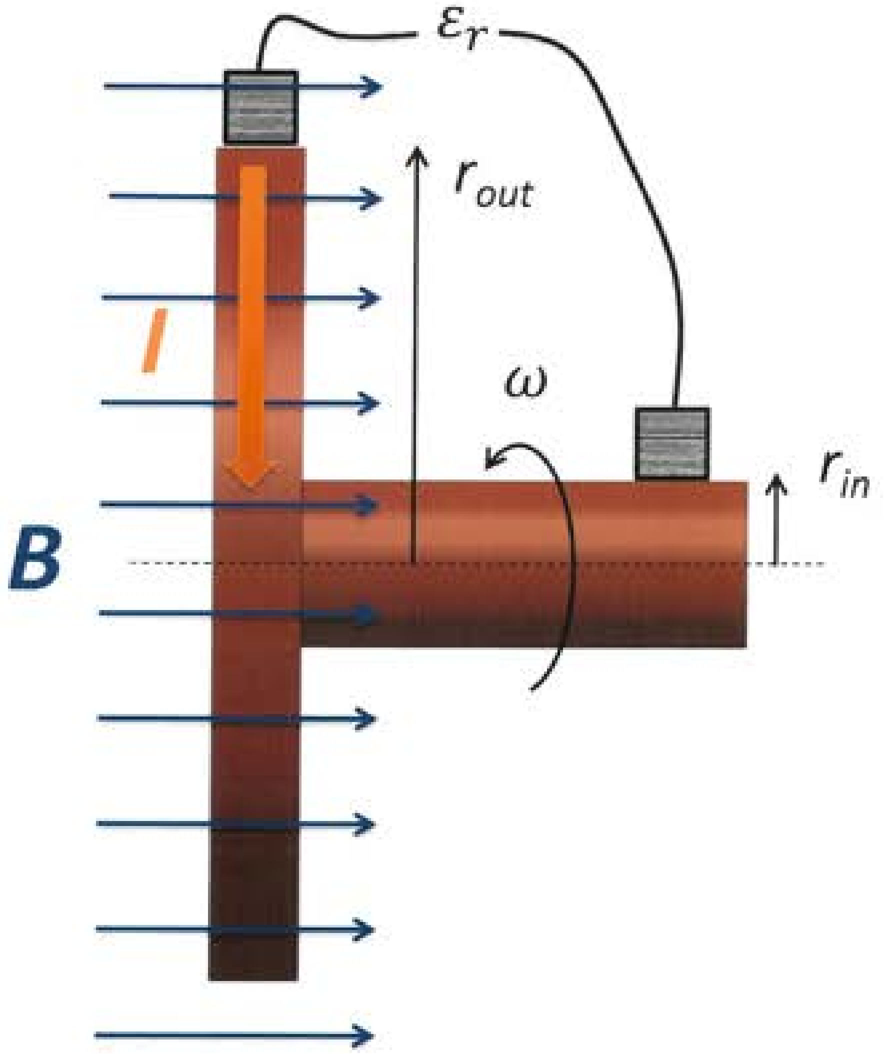
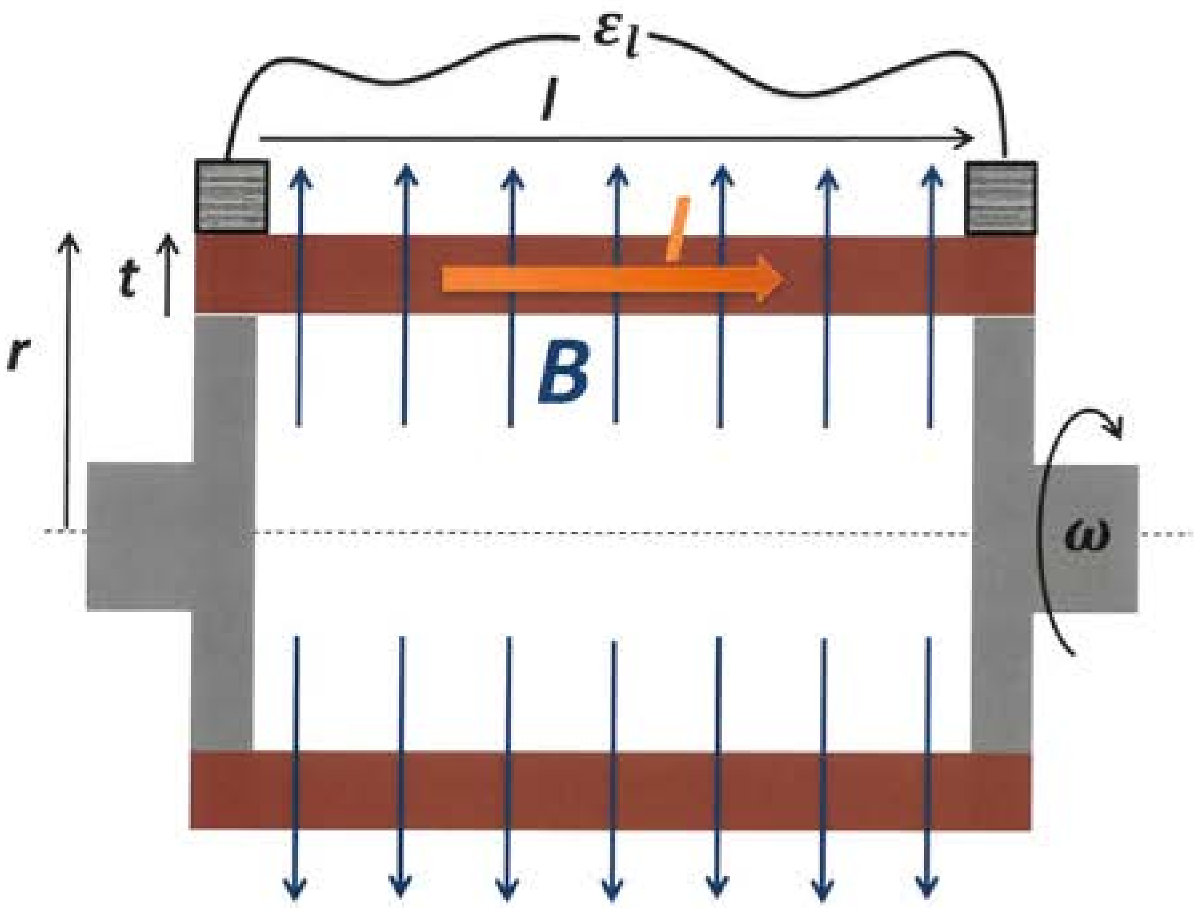
## Disc Type




## Drum Type




**Voltage:** $\varepsilon_r = \int_{r_{in}}^{r_{out}} \left( \frac{I}{2\pi r d\sigma} - \omega r B(r) \right) dr$

$$\varepsilon_l = \int_0^l \left( \frac{I}{2\pi \left( r - \frac{t}{2} \right) t\sigma} - \omega r B(l) \right) dl$$

**Torque:** $\tau_r = \int_{r_{in}}^{r_{out}} I\, B(r) r\, dr$

$$\tau_l = \int_0^l I\, B(l)\, r\, dl$$

# HOMOPOLAR FUNDAMENTALS

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## Advantages

- No AC fields => No AC losses — perfect for superconductors
- Constant homogenous torque => reduces stress on the mechanical parts
- Simplicity of operation => only DC electrical circuits are needed to control the device
- Magnet is separate from rotor and stator => no reaction forces on the magnet
- No power electronics needed

# HOMOPOLAR FUNDAMENTALS

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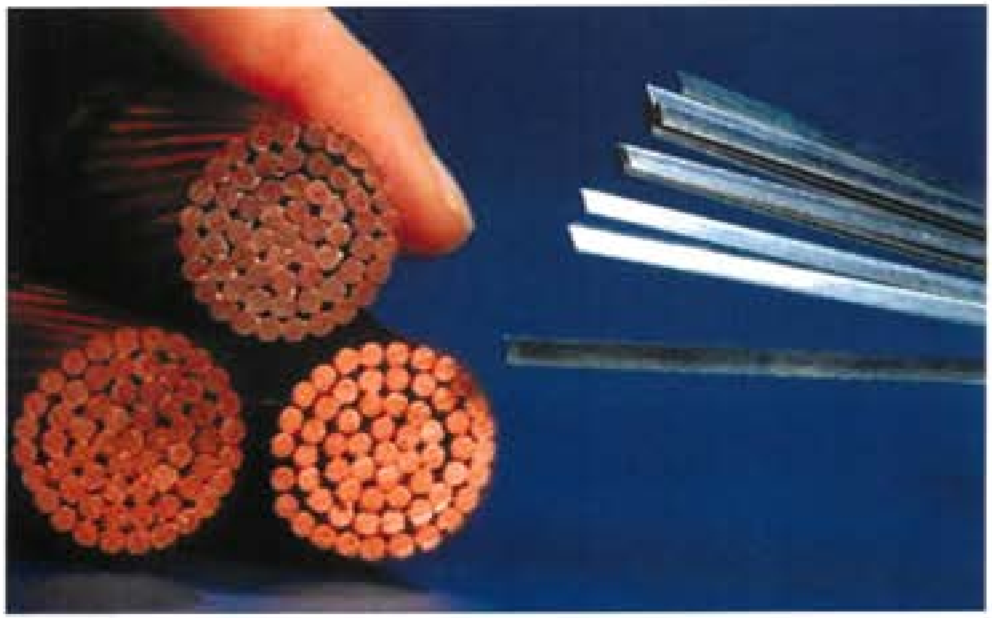
## Challenges that we have overcome

- Sliding contacts => operating in a high driving magnetic field
- Sliding contacts => Liquid Metal Current Collectors allow high speed and high currents
- Reliability and Safety => fully enclosed Liquid Metal Current Collectors
- High currents and low voltages => design for electrical losses
- Stray magnetic fields => active shielding required
- Eddy current losses in bearings => use of new materials
- Power electronics / Power Converters => Guina's Electromagnetic Power Converters

# WHAT IS A SUPERCONDUCTOR?

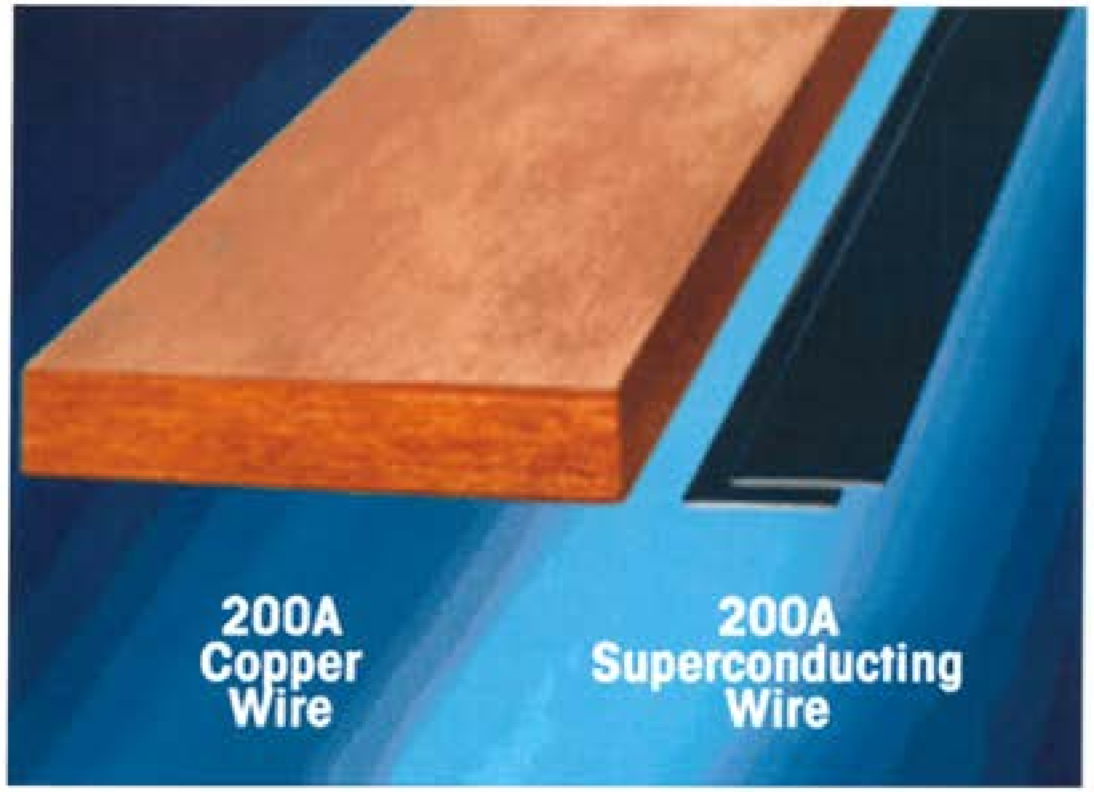
| | Resistivity (Ωm) | Conductivity (S/m) | Factor |
|---|---|---|---|
| Non-conductor | $>10^{10}$ | $<10^{-11}$ | 1 |
| Conductor | $10^{-7} — 10^{-8}$ | $10^{8} — 10^{6}$ | $10^{18}$ |
| Superconductor | $<10^{-24}$ | $>10^{23}$ | $>10^{36}$ |



Superconductivity appears in certain materials at very low temperatures, below -200°C. The phenomena is limited by a maximum current and magnetic field in the materials which can disable the superconductivity.

Current superconducting wires allow the transportation of 100 to 10,000 times the current of copper wires with the same cross-section. The picture above illustrates the amount of copper and superconducting wire required to transport the same current.

# WHAT IS A SUPERCONDUCTOR?

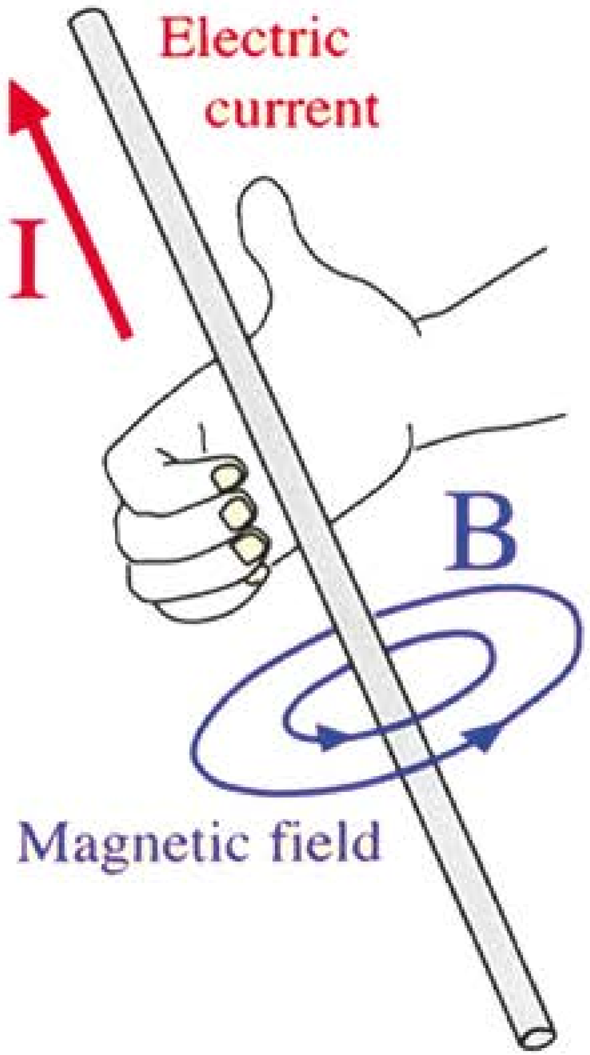




Superconductors allow very large currents to be transported in a small area with low losses. The magnetic field created by this current is used as the working or driving field in our Homopolar machines.

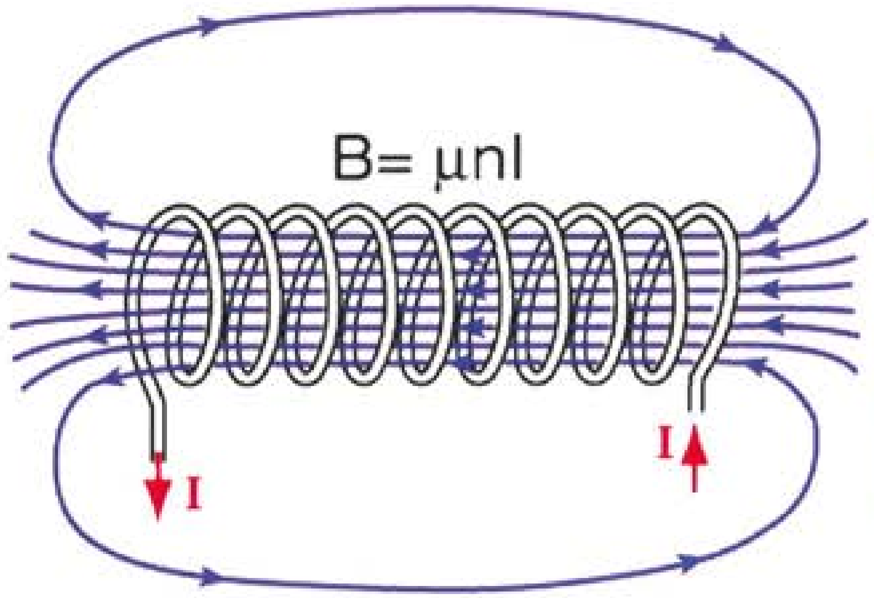
Superconductive wire must be maintained at cryogenic temperatures.

# WHAT IS A SUPERCONDUCTOR?

Field around a straight wire




Field around a coil of wire




Superconducting Coil

The superconductive wire is wound into coils to concentrate the magnetic field. The magnetic field created by these currents is used as the working or driving field in our homopolar machines.

# INTRODUCTION TO OUR TECHNOLOGY

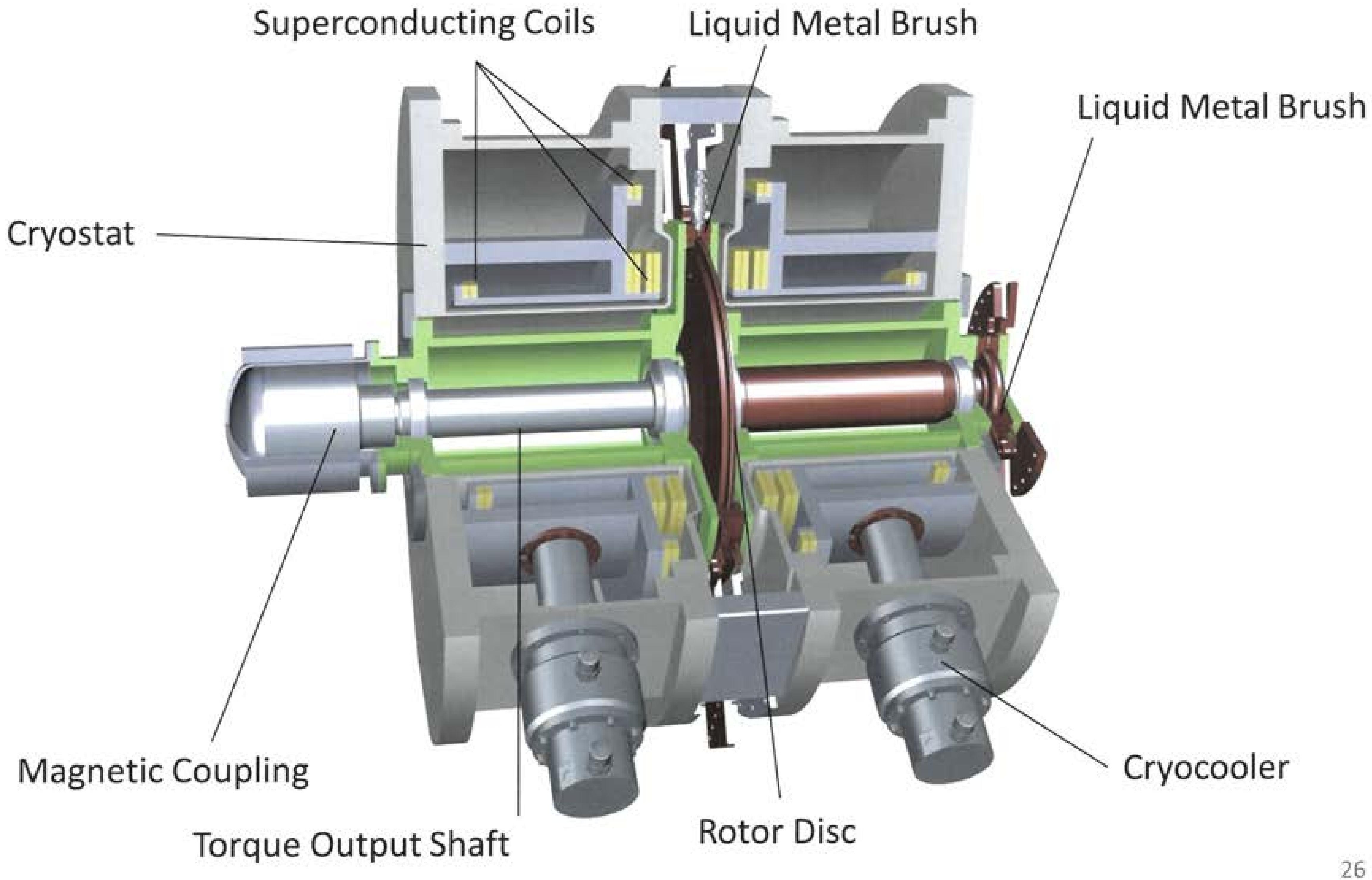
Guina's Homopolar Technology differs in three ways when compared with previous homopolar technology:

- Our technology uses our proprietary coil designs that exhibit Null Field Regions. These Null Field Regions allow the brush technology to effectively deliver very high amounts of current while surrounded by extremely high magnetic field densities.
- Our Stray Field Reduction Technology removes the need for heavy steel or iron flux guides.
- Our Electromagnetic Power Converters transform high voltage and low currents into low voltage and high currents needed for homopolar devices.

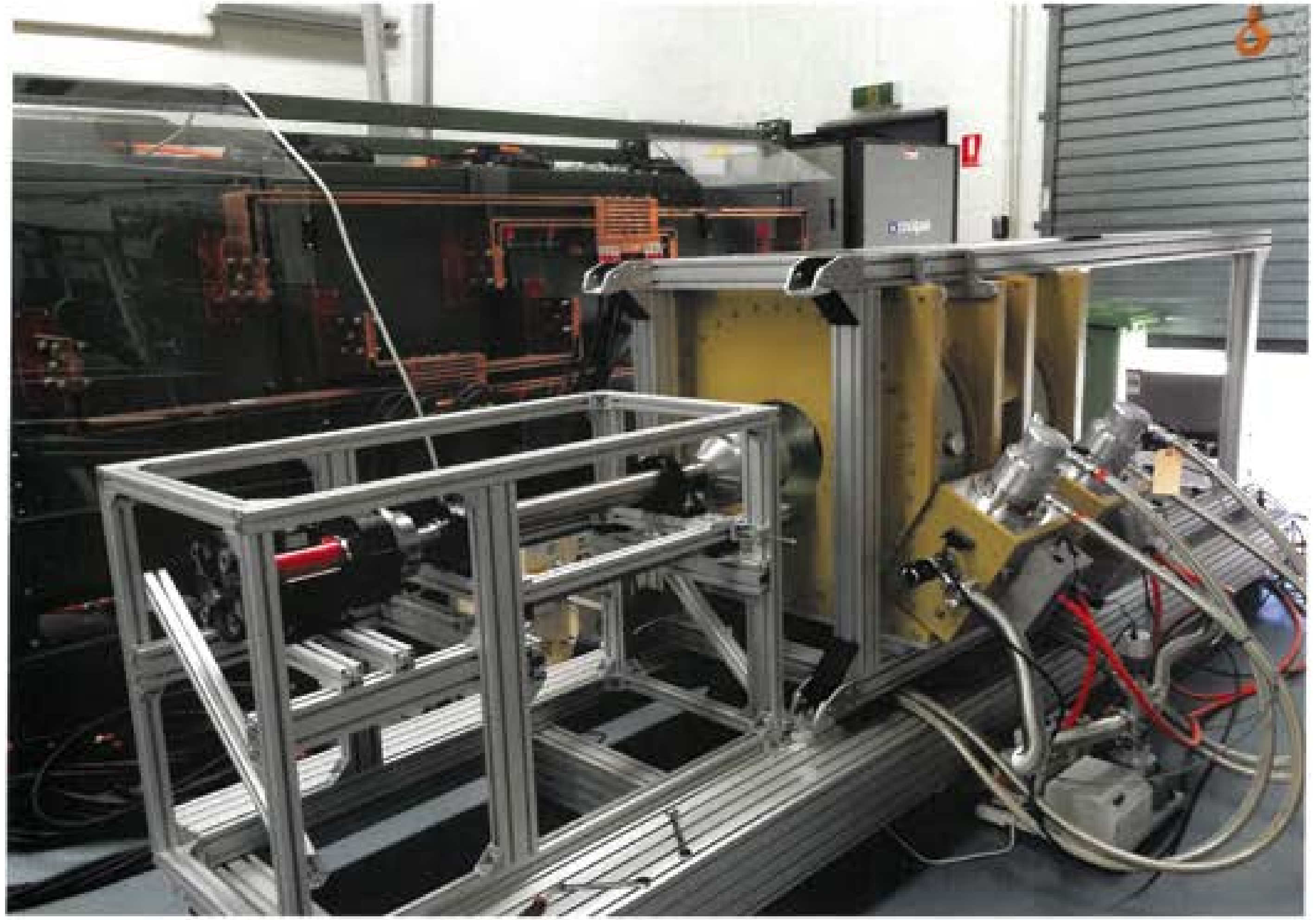
The technology shown has been extensively modelled and simulated using Vector Fields and Solidworks modelling software.

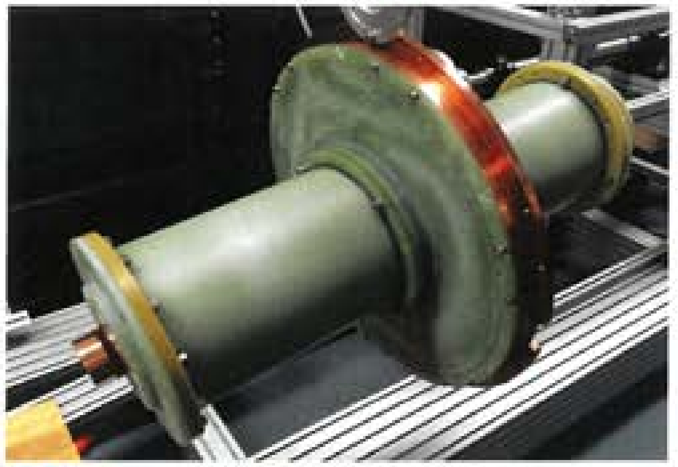
As a result of the above these devices exhibit extremely high power to weight ratios.

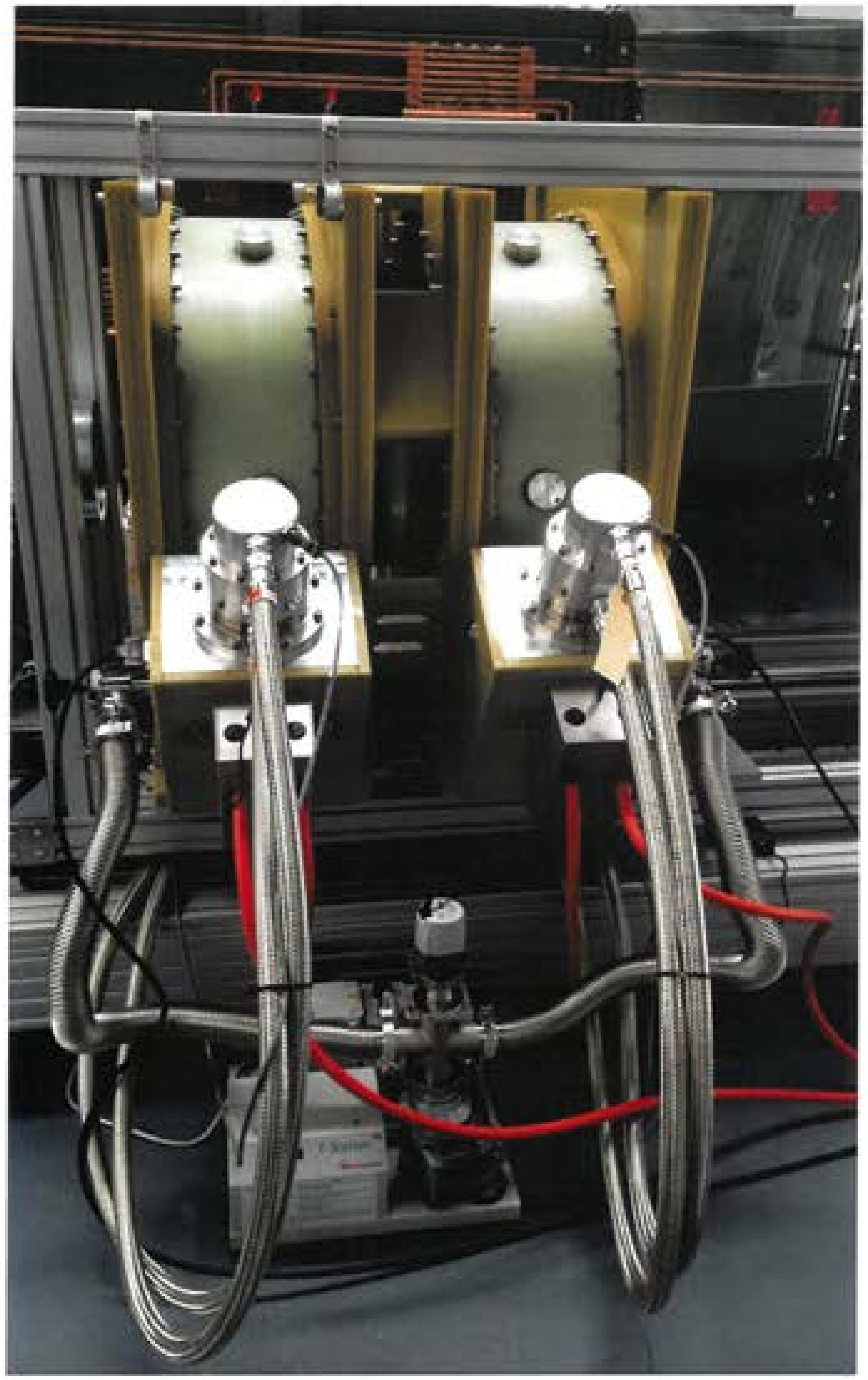
# GUINA'S PROTOTYPE HOMOPOLAR MACHINE LAYOUT



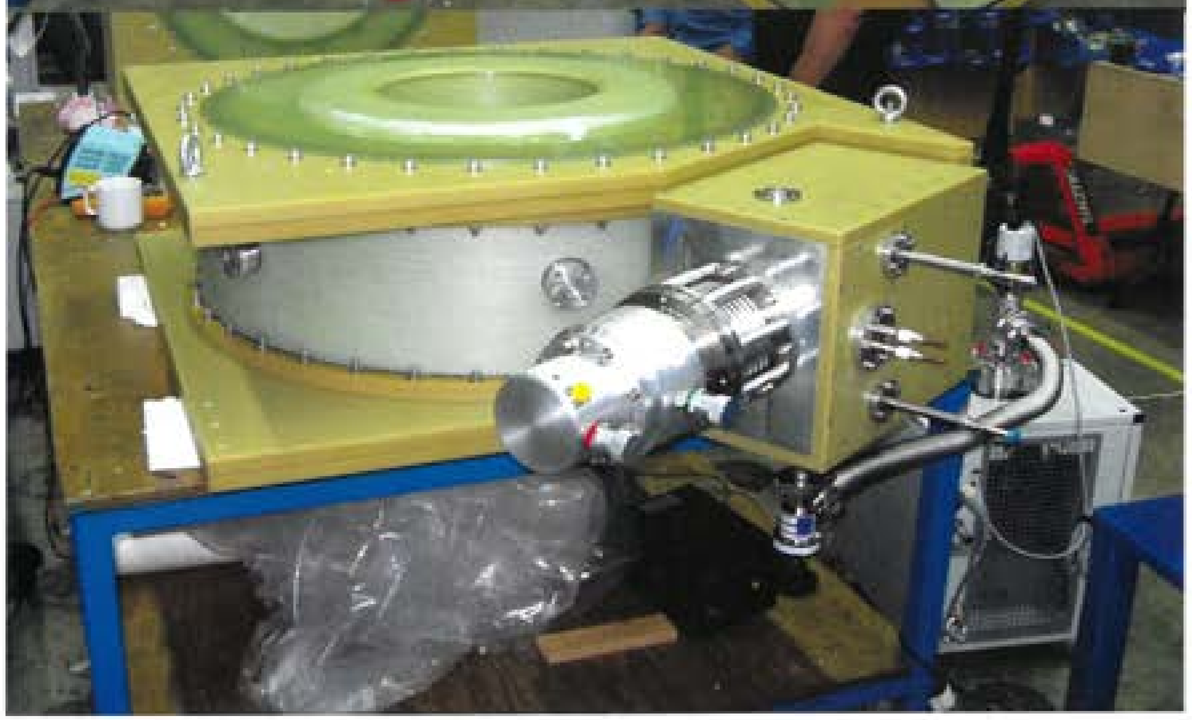
# 200kW MOTOR PROTOTYPE





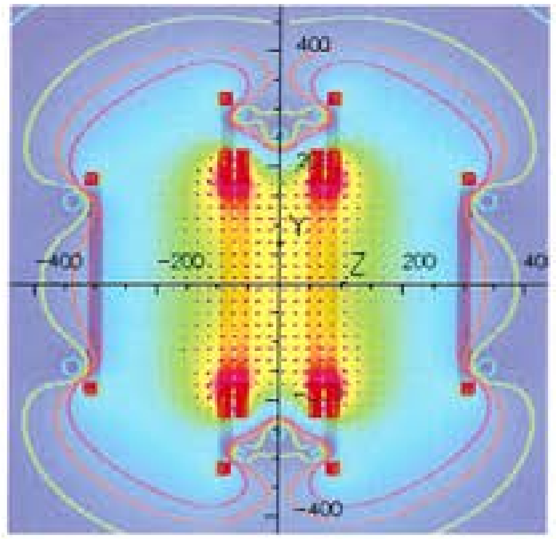


# SUPERCONDUCTING MAGNET ASSEMBLY



# GUINA ADVANTAGES

- Guina Energy's patented, unique coil arrangement produces a Null Field Region around the brush area to protect the brushes from strong magnetic fields.



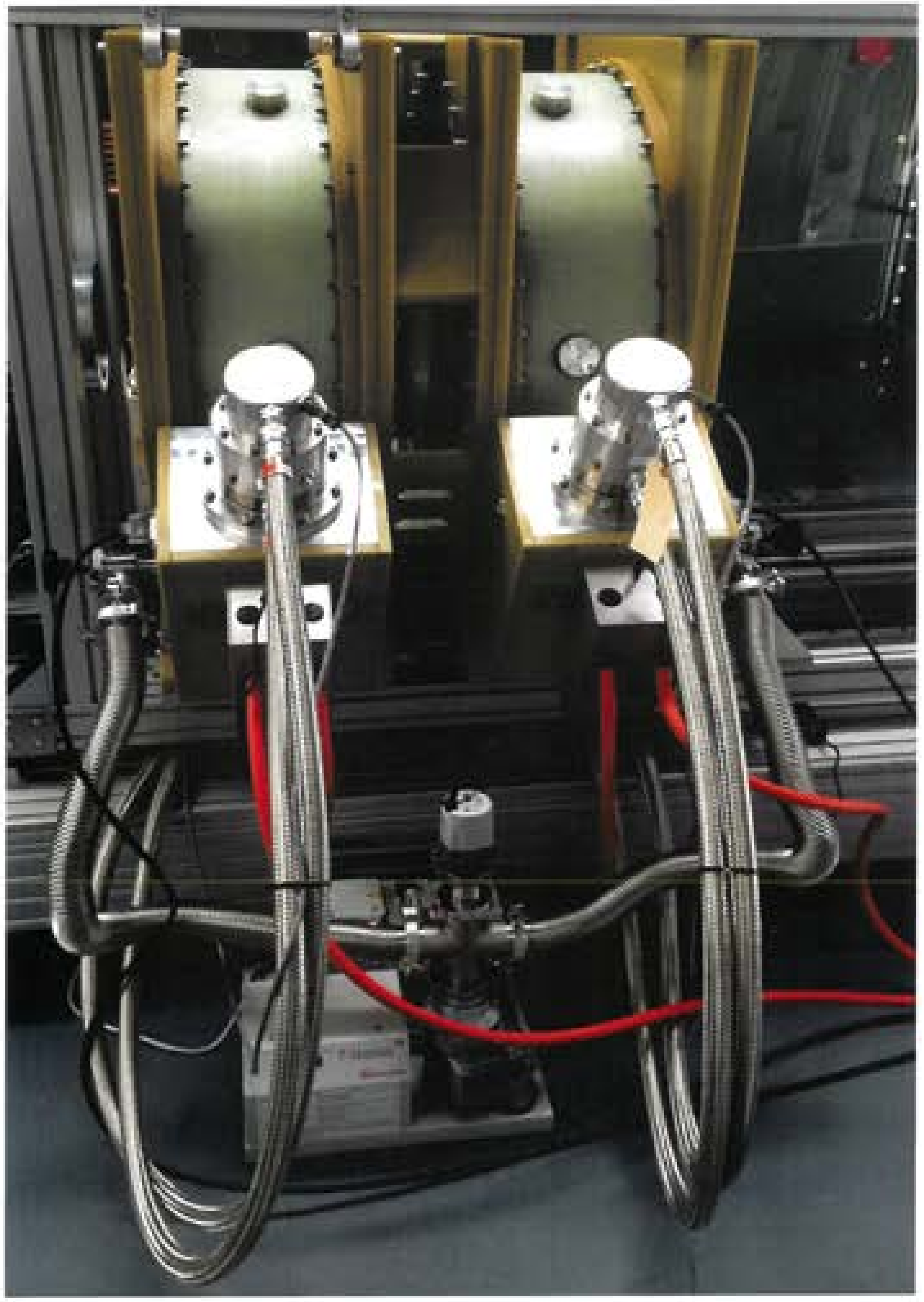

- Guina Energy has implemented Active Shielding in our generator and motor designs to reduce their total weight.

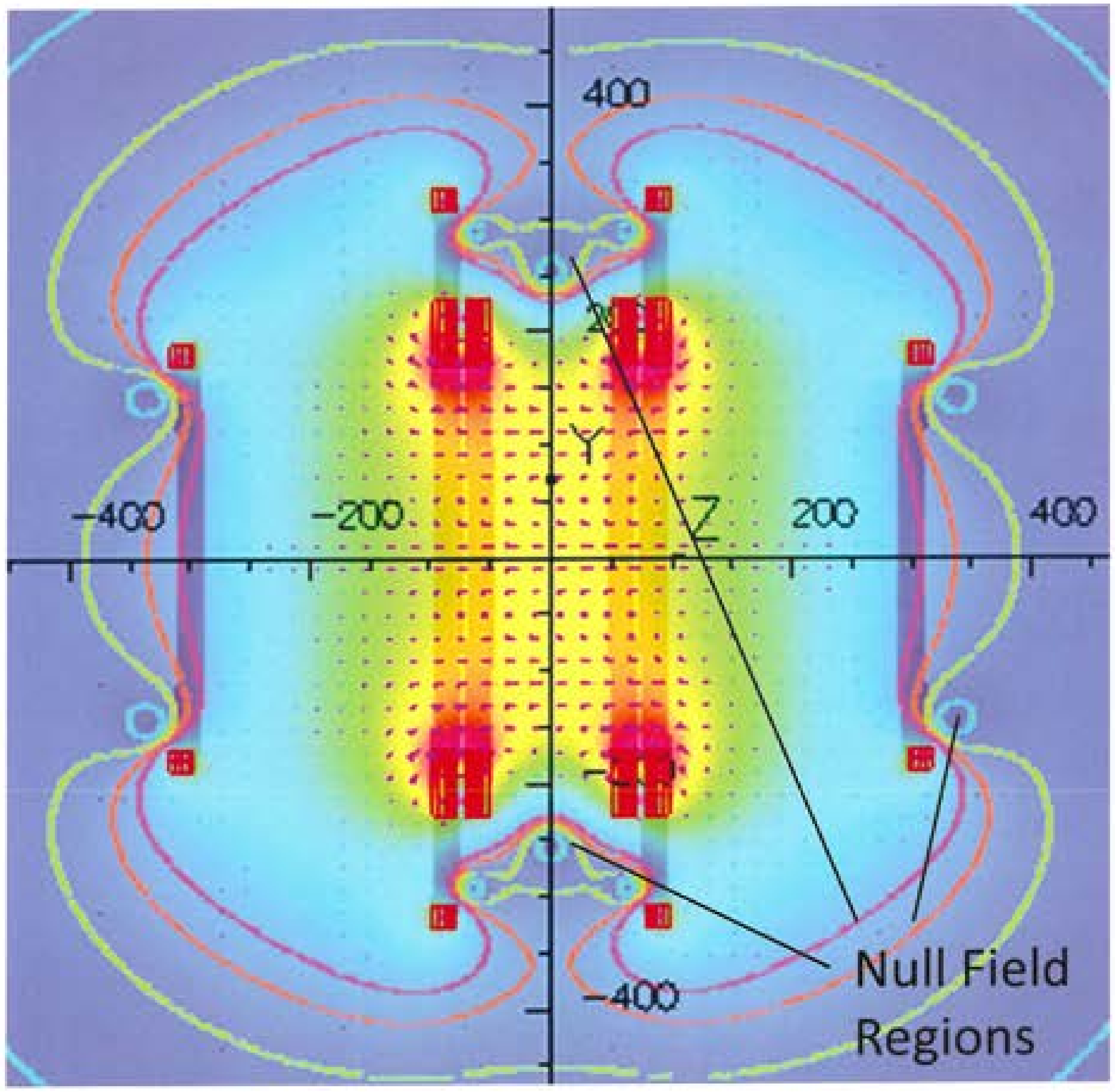
- Guina Energy has developed and tested Liquid Metal Current Collectors suitable for our motors and generators with Null Field Regions.

- Guina Energy has developed and tested DC Electromagnetic Power Converters for use with homopolar machines

# NULL FIELD REGION MAGNETIC FIELD PLOT

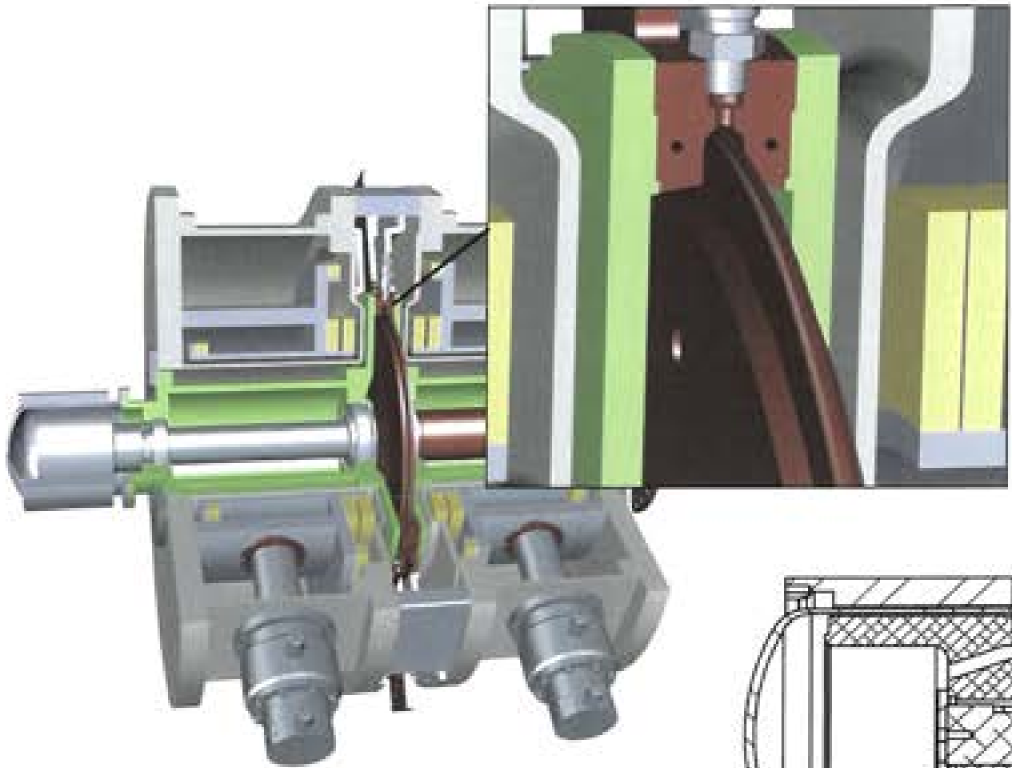
***Disc type machine with Null Field Regions and Liquid Metal Current Collectors.***

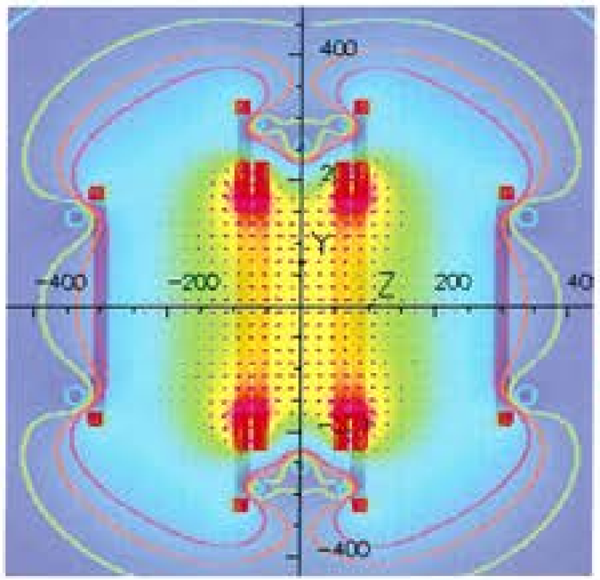


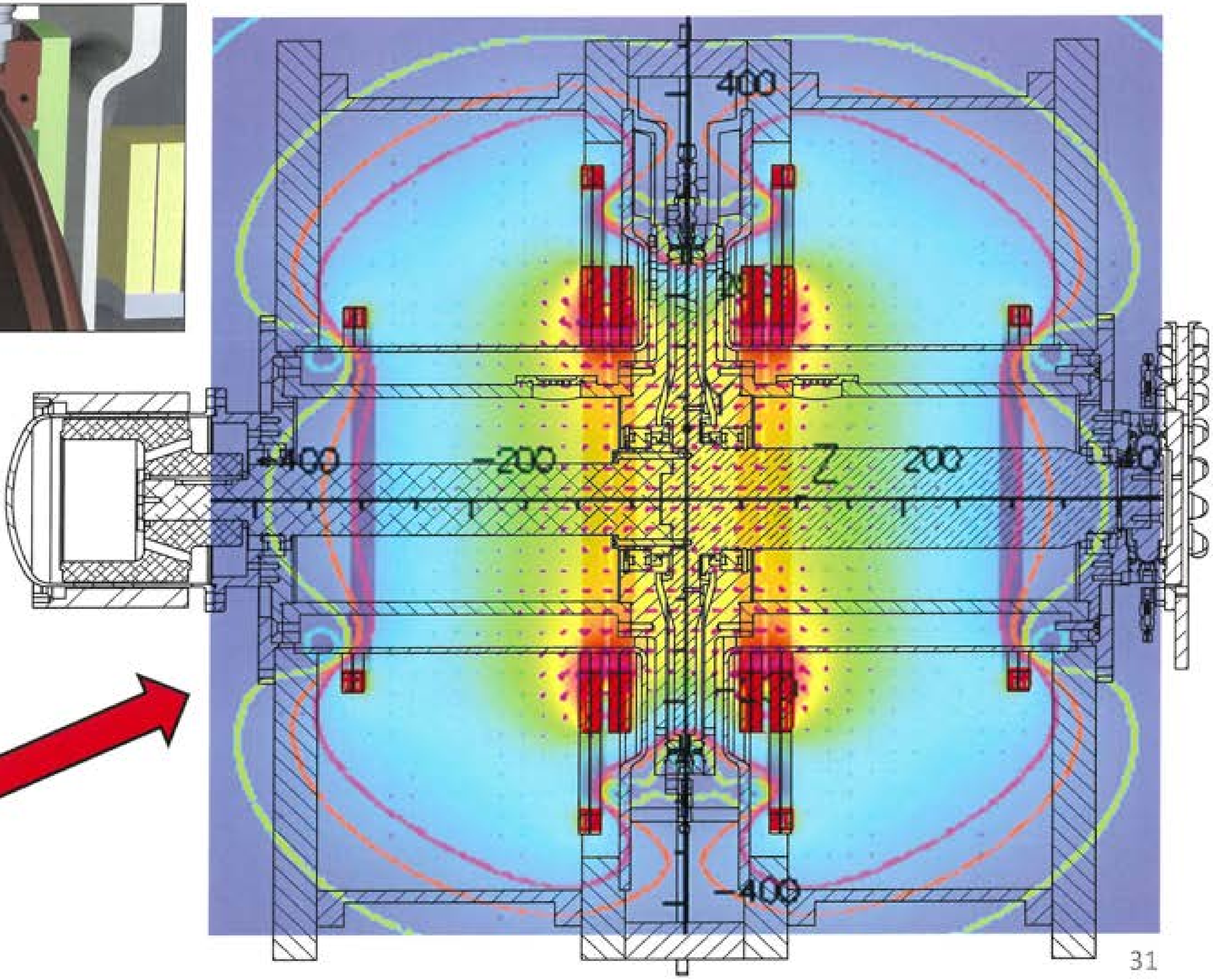


# MAGNETIC FIELD OVERLAY

***Disc type machine with Null Field Regions and Liquid Metal Current Collectors.***





# NULL FIELD REGIONS

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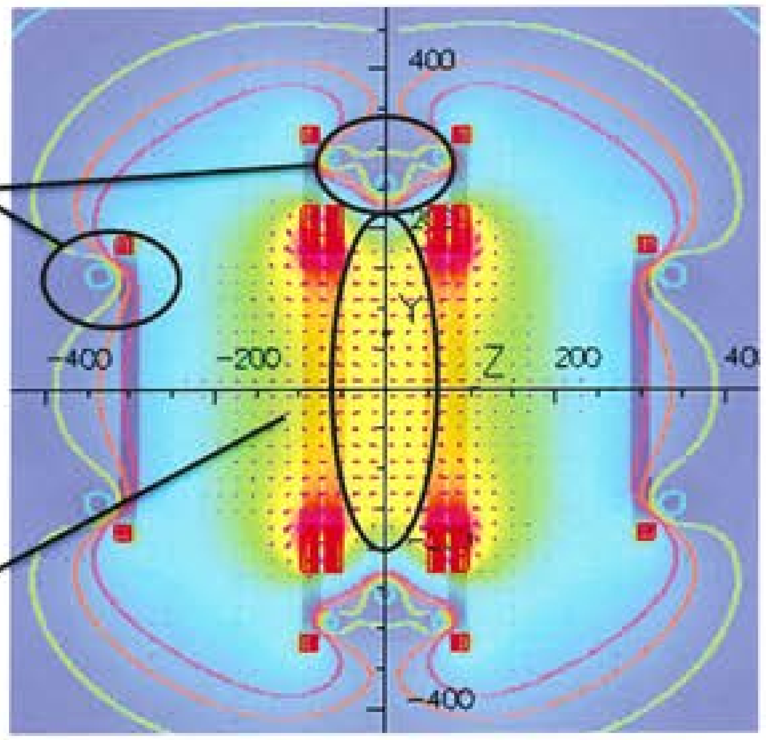
Our proprietary, unique coil arrangements produce maximum driving field with significantly reduced fields at the brush locations. This allows us the use of conducting liquids which results in:

- Longer lifetime of the brush system
- More stable operation
- Reduced frictional losses and wear

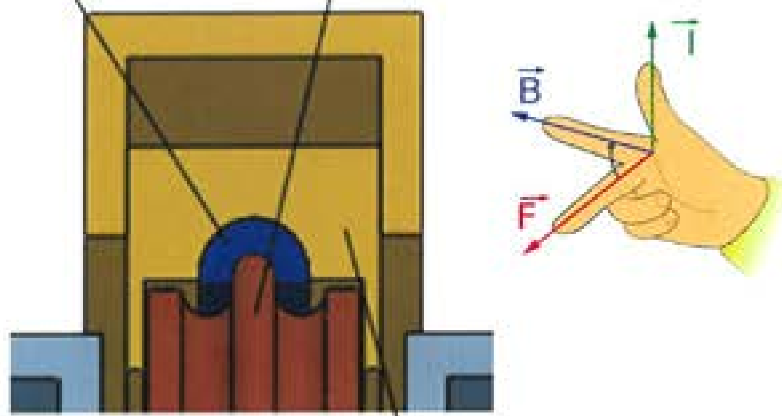
Magnetic Field levels under 150 mT

Drive fields of 6 Tesla and higher are possible




Forces on the brushes/liquids:

$$\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$$



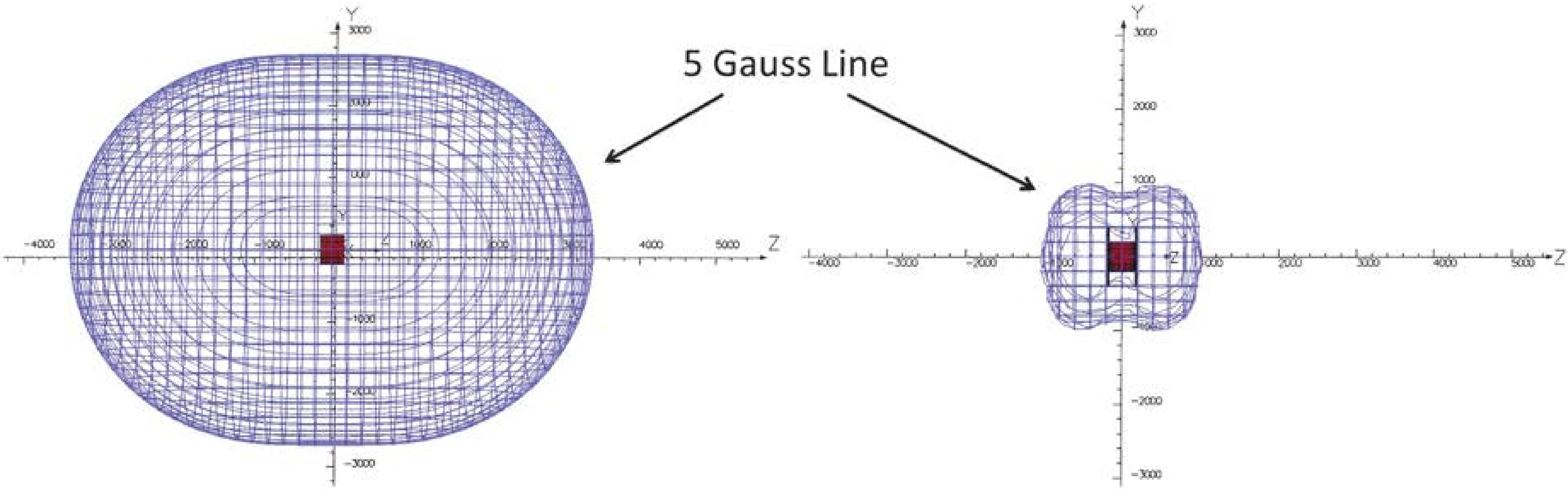
# ACTIVE SHIELDING

## Steel flux guides

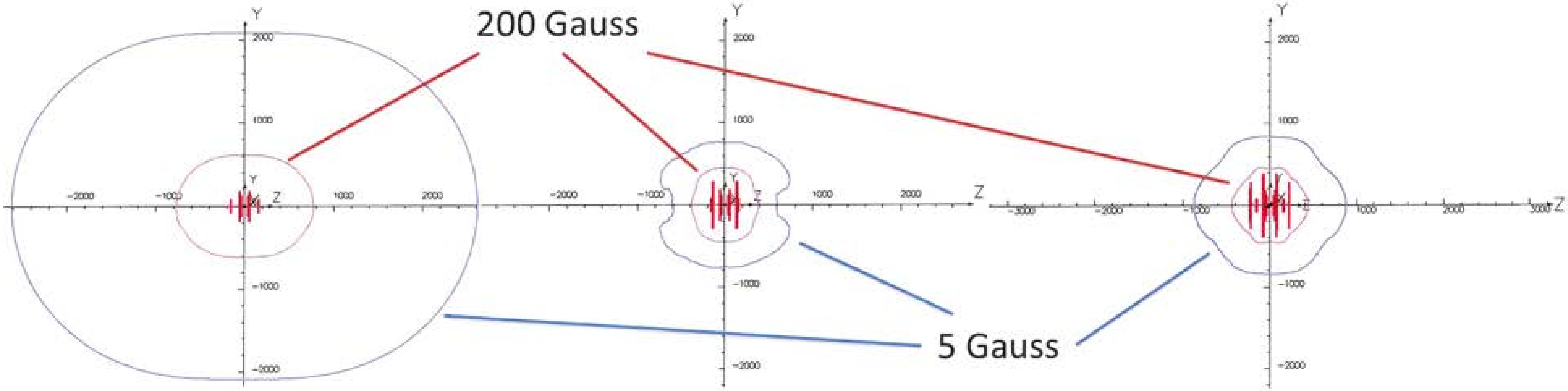
- are very heavy
- saturation of the material limits the maximum magnetic field
- have design and manufacturing limits

## Active shielding

- is lighter and uses less material
- has no upper field limits
- allows a more flexible design
- the overall dimensions are slightly larger



## Typical reduction of the stray field in disc type motor/generator




No Shielding | 2 Coil Shielding | 4 Coil Shielding

Guina Energy has developed active shielding systems with two, four and five coil arrangements, similar to those used in MRI magnets. Depending on the environmental requirements the 200 gauss line can be brought right on the surface of the machines, even for high field magnets.

# LIQUID METAL CURRENT COLLECTOR

- **Silver graphite solid brushes**, for low speed industrial applications where the surface brush speed is around 15m/s.

- **Metal fibre brush technology** for higher speed and/or noise sensitive applications. These brushes have an operating surface speed of up to 60m/s. They presently represent the state of the art in brush technology and allow for a great reduction in both brush noise, frictional losses (approximately 1/5th conventional brush losses) and are self lubricating.

- **Liquid metal current collectors** are suitable for high performance applications at low and high speeds. Current is transferred between the rotating and non-rotating parts, which are separated by a narrow gap that is filled with a liquid metal.

# LIQUID METAL CURRENT COLLECTOR

Liquid metal current collectors are known for their capacity to efficiently transfer high currents between moving and stationary parts. Our team has developed a safe and economical liquid metal current collector system for various applications.

Advantages include:

- Higher current densities than conventional brush systems
- Higher surface speeds
- Low frictional and electrical losses
- Wear free and low maintenance

## Materials under consideration:

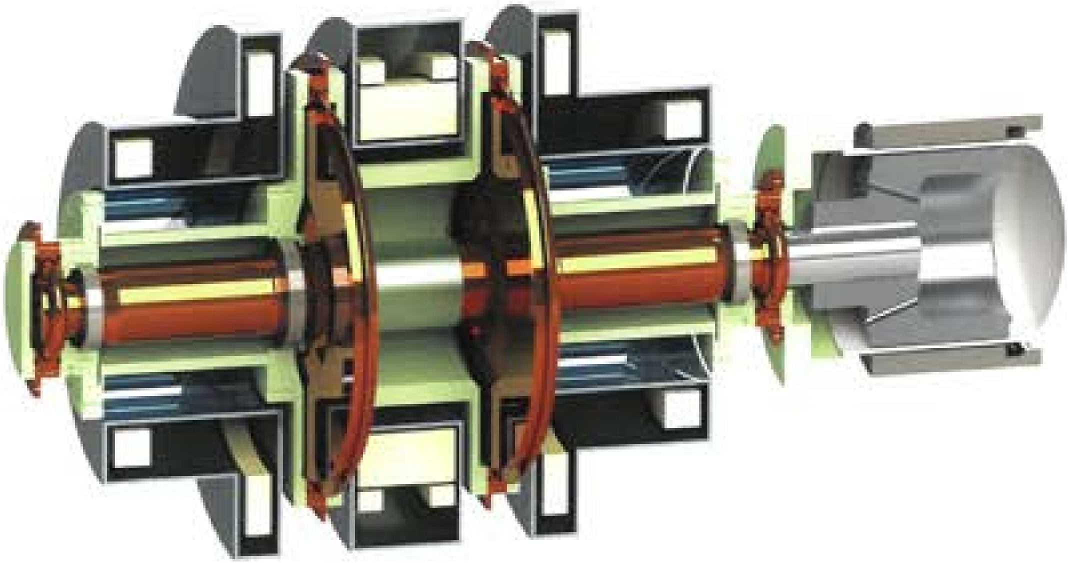
**Liquid Sodium-Potassium 78 Eutectic Alloy**
Melting point: -12.6 °C
Density (ρ): 0.866 g/cm$^3$
Viscosity: 0.000546 Pa · s
Resistivity at 20 °C: 41 · 10$^{-8}$ Ohm · m

**Gallium-Indium-Tin Eutectic Alloy**
Melting point: -19 °C
Density (ρ): 6.44 g/cm$^3$
Viscosity: 0.0024 Pa · s
Resistivity at 20 °C: 29 · 10$^{-8}$ Ohm · m

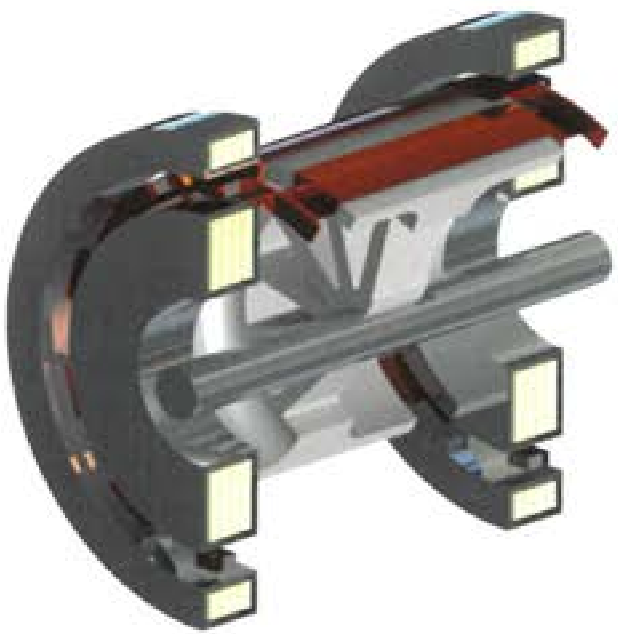
# ALTERNATIVE DESIGNS

## 1st Generation G1 Design

## 2nd Generation G2 Design



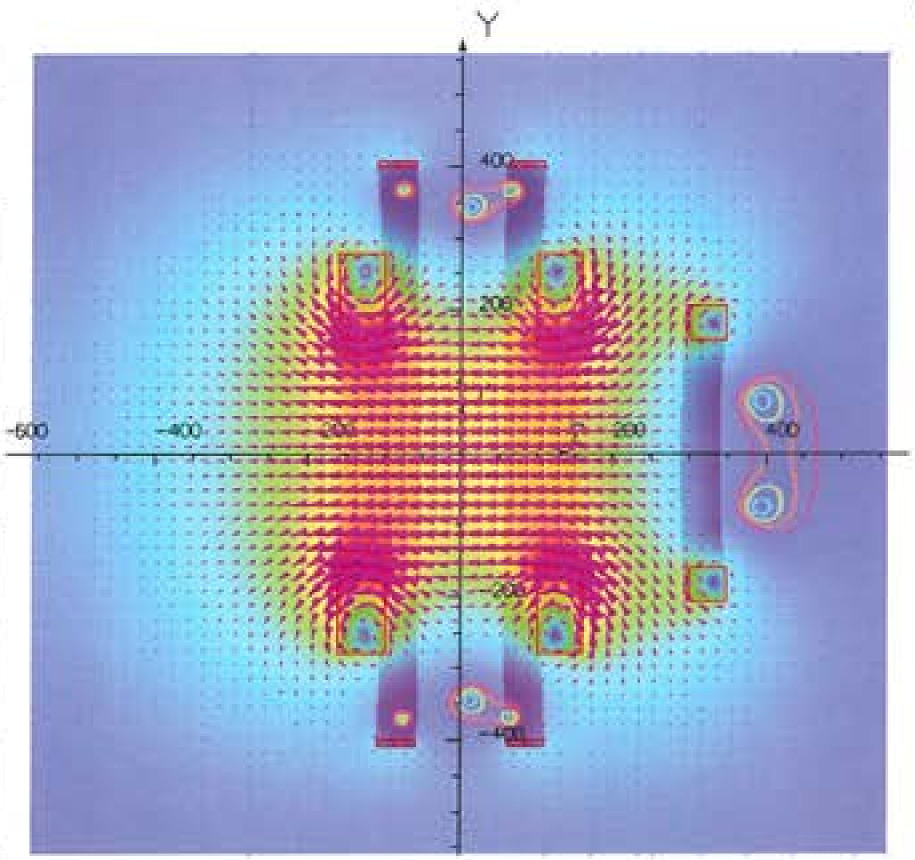
## Gamma-Tron Drum Type

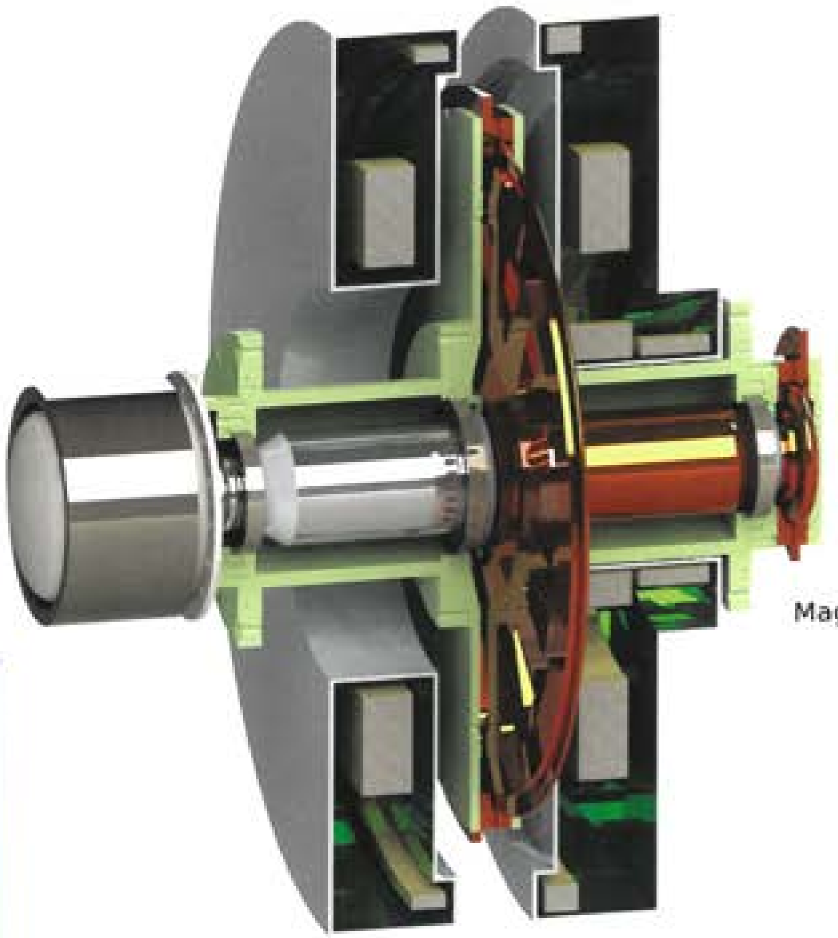


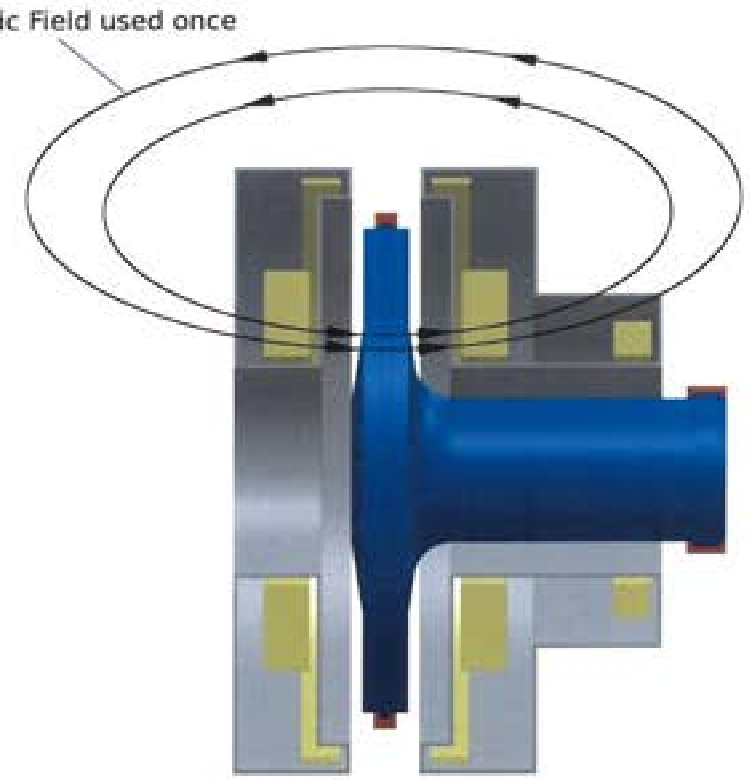
# HIGH SPEED G1 SUPER-TRON

## 1st Generation
## G1 Super-Tron

***Single disc type machine with Null Field Regions and Liquid Metal Current Collectors.***






First Generation - G1 Super-Tron

# HIGH SPEED G2 SUPER-TRON

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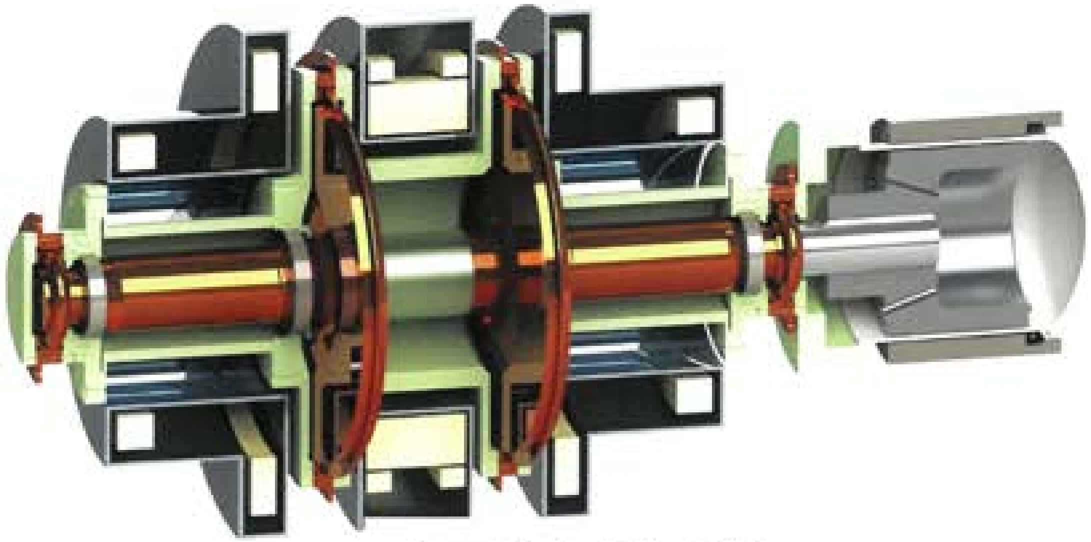
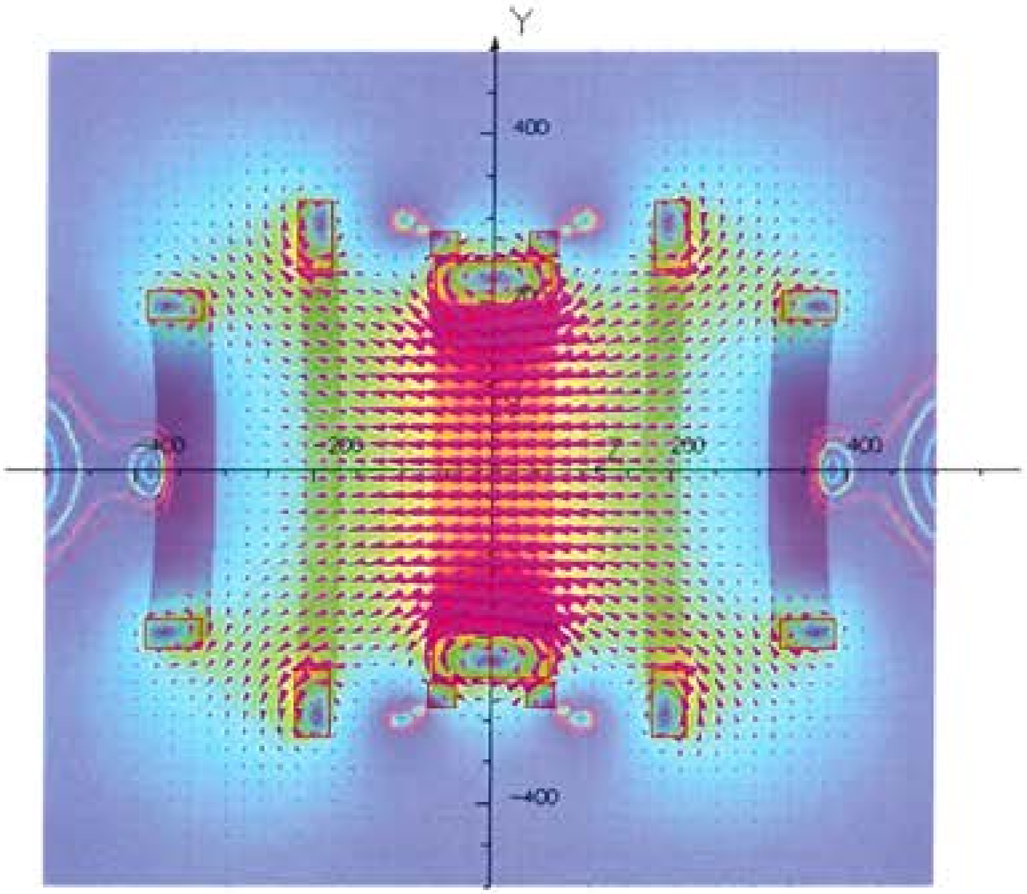
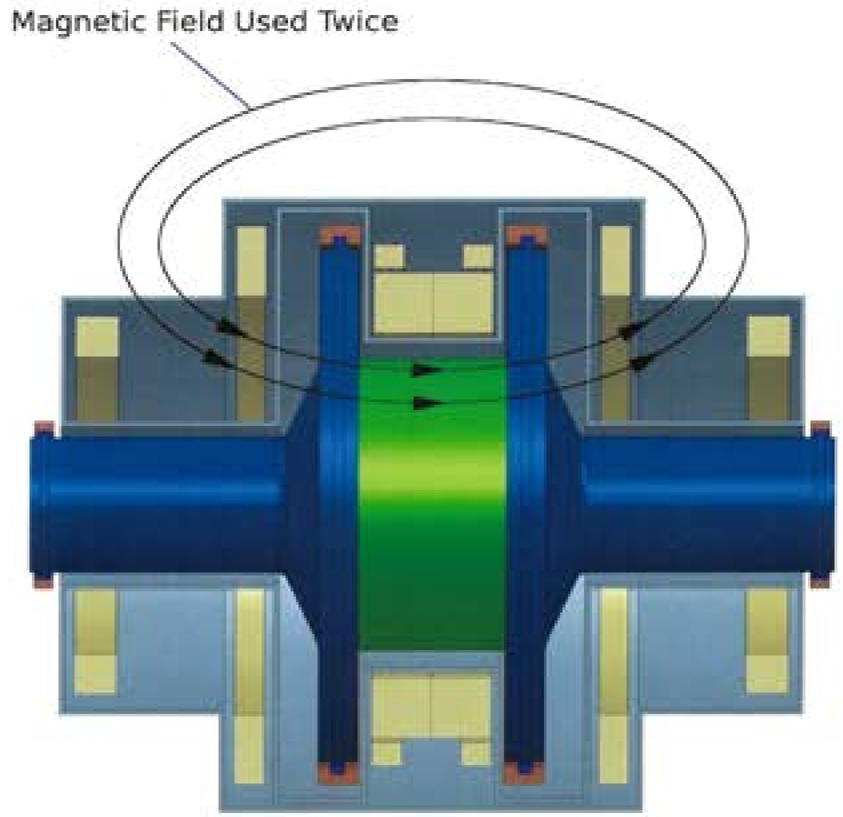
## *2nd Generation G2 Super-Tron*

***Dual disc type machine with Null Field Regions and Liquid Metal Current Collectors.***





# G2 SOLENOID STYLE HIGH SPEED SUPER-TRON

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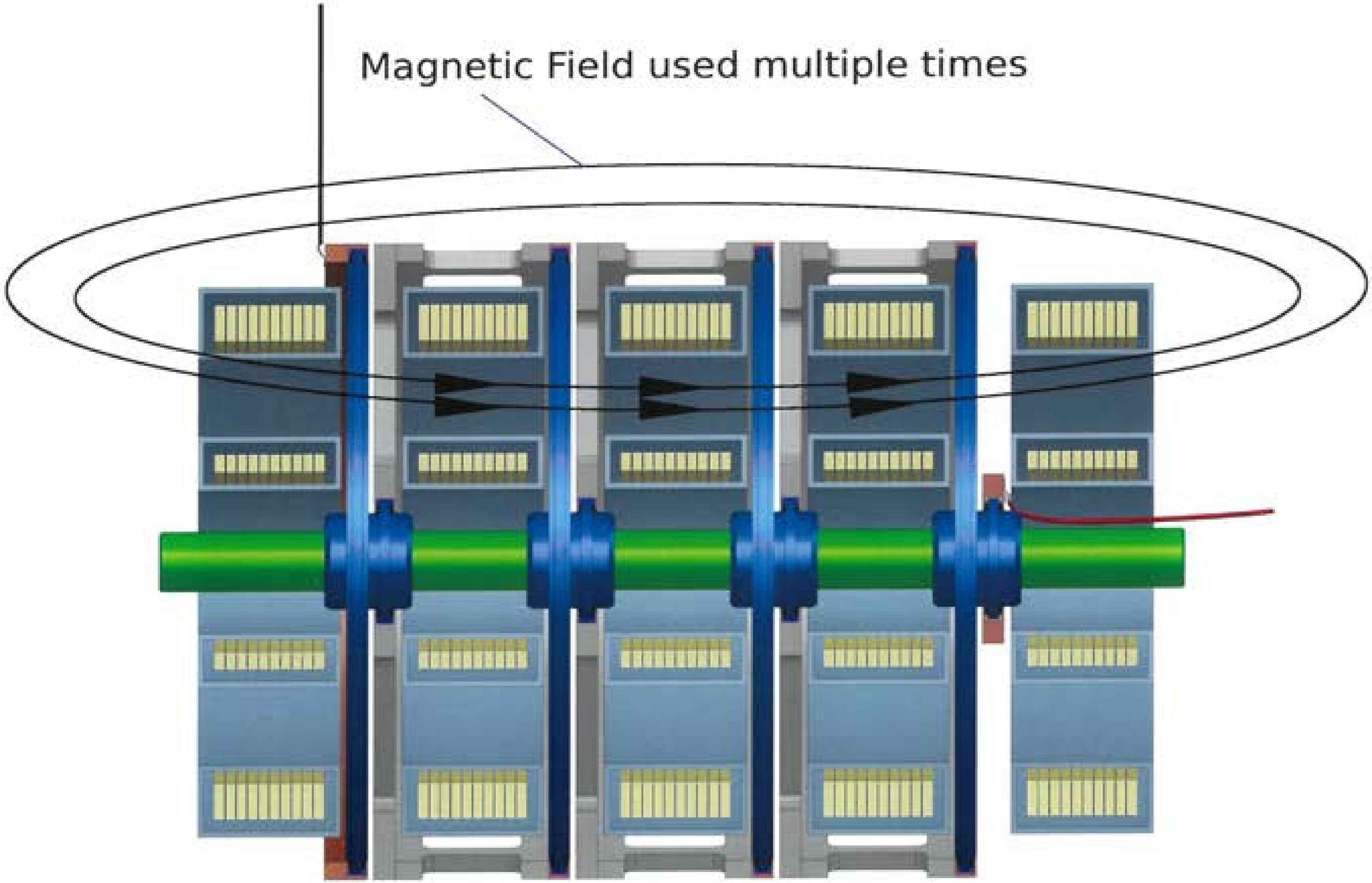
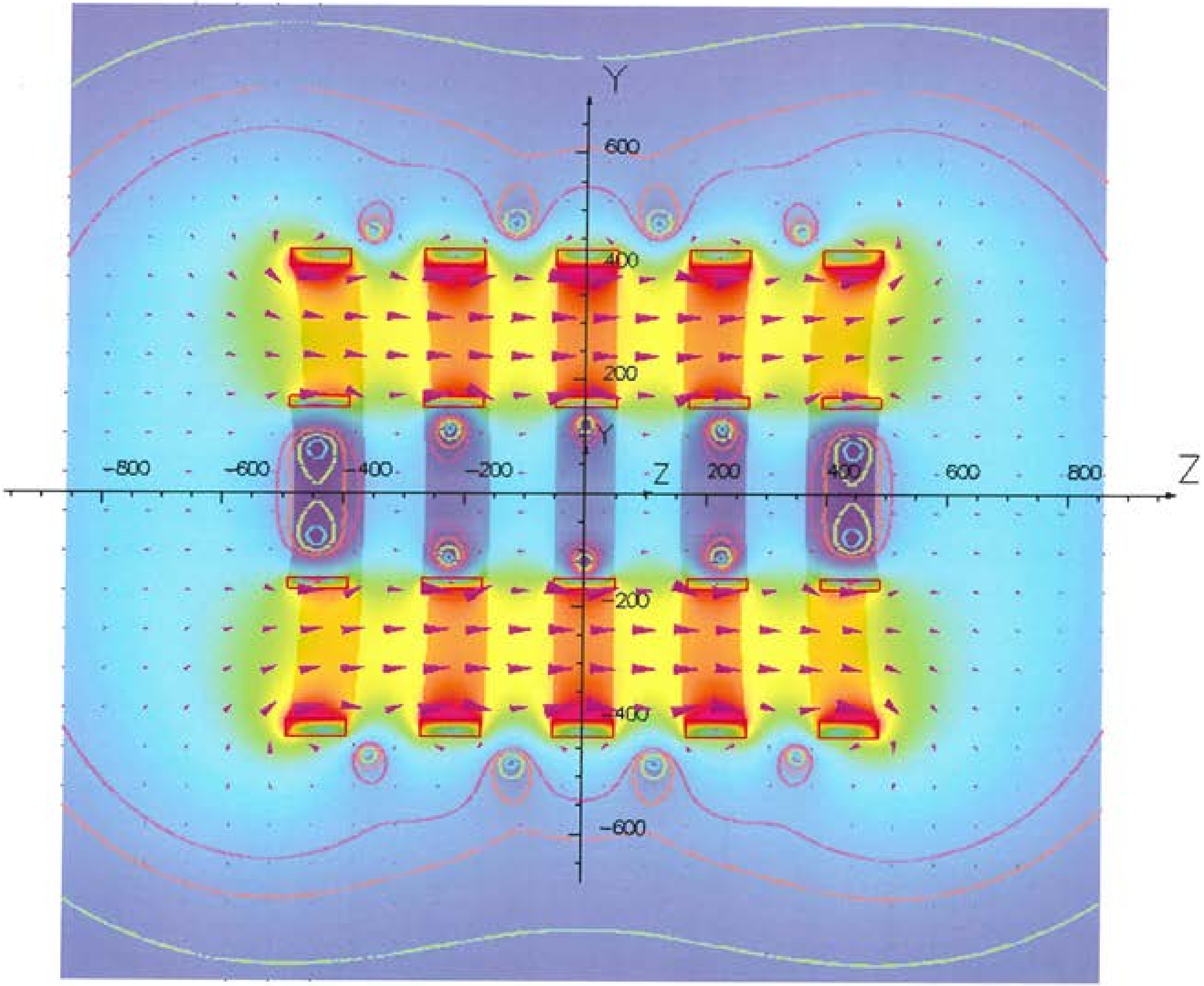



Multi-rotor solenoid style Tron Electromagnetic Turbine

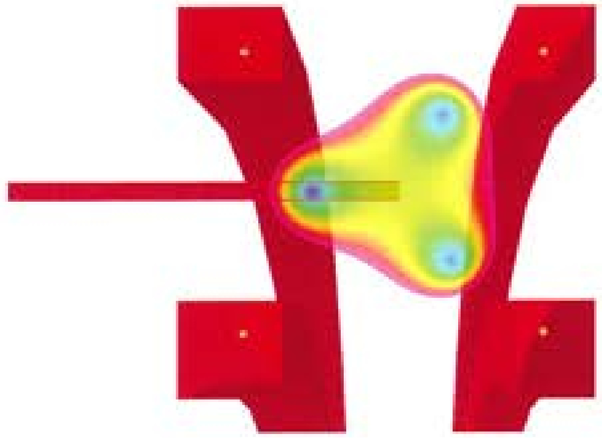
# G2 SOLENOID STYLE HIGH SPEED SUPER-TRON

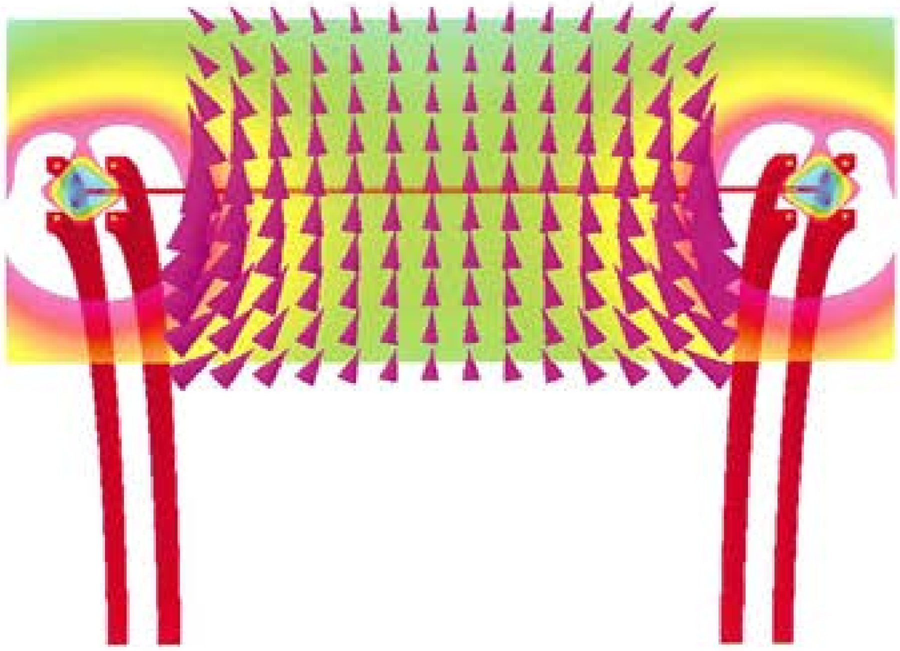


# GAMMA-TRON DRUM TYPE

***Drum type machine with Null Field Regions and Liquid Metal Current Collectors.***

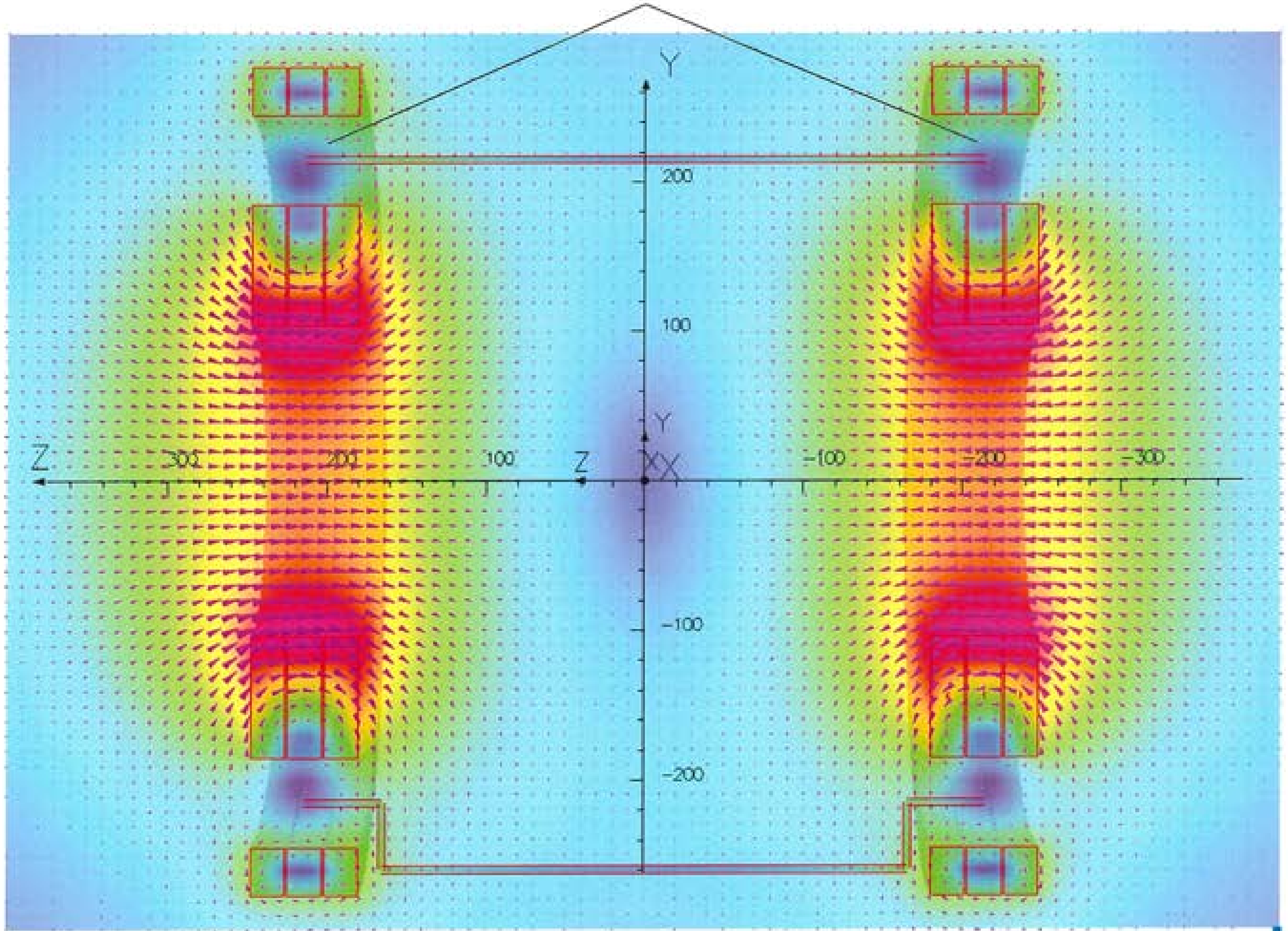
***Drum Type Gamma-Tron***





# GAMMA-TRON DRUM TYPE

Null Field Regions



# LIQUID METAL CURRENT COLLECTOR (LMCC) DEVICES FOR HOMOPOLAR MOTORS AND GENERATORS

# BACKGROUND

- **Why liquid metal current collectors for homopolar machines?**
  - High current carrying capacity with low resistance
  - High to extreme surface speeds with low friction
  - Excellent cooling ability, comparable with water
  - No mechanical wear and long service life
  - Low running costs

- **Conventional solid brushes and even advanced metal fibre brushes cannot compete with LMCC. For many applications LMCC are the only choice.**

# CONDUCTIVE LIQUIDS FOR LMCC

## NACK

**(NaK 78) Sodium-Potassium Eutectic Alloy**

Melting point: -12.6 °C
Density: 0.866 g/cm$^3$
Viscosity: 0.000546 Pa·s
Resistivity at 20 °C: 41 $\cdot 10^{-8}$ Ohm·m

## GALINSTAN

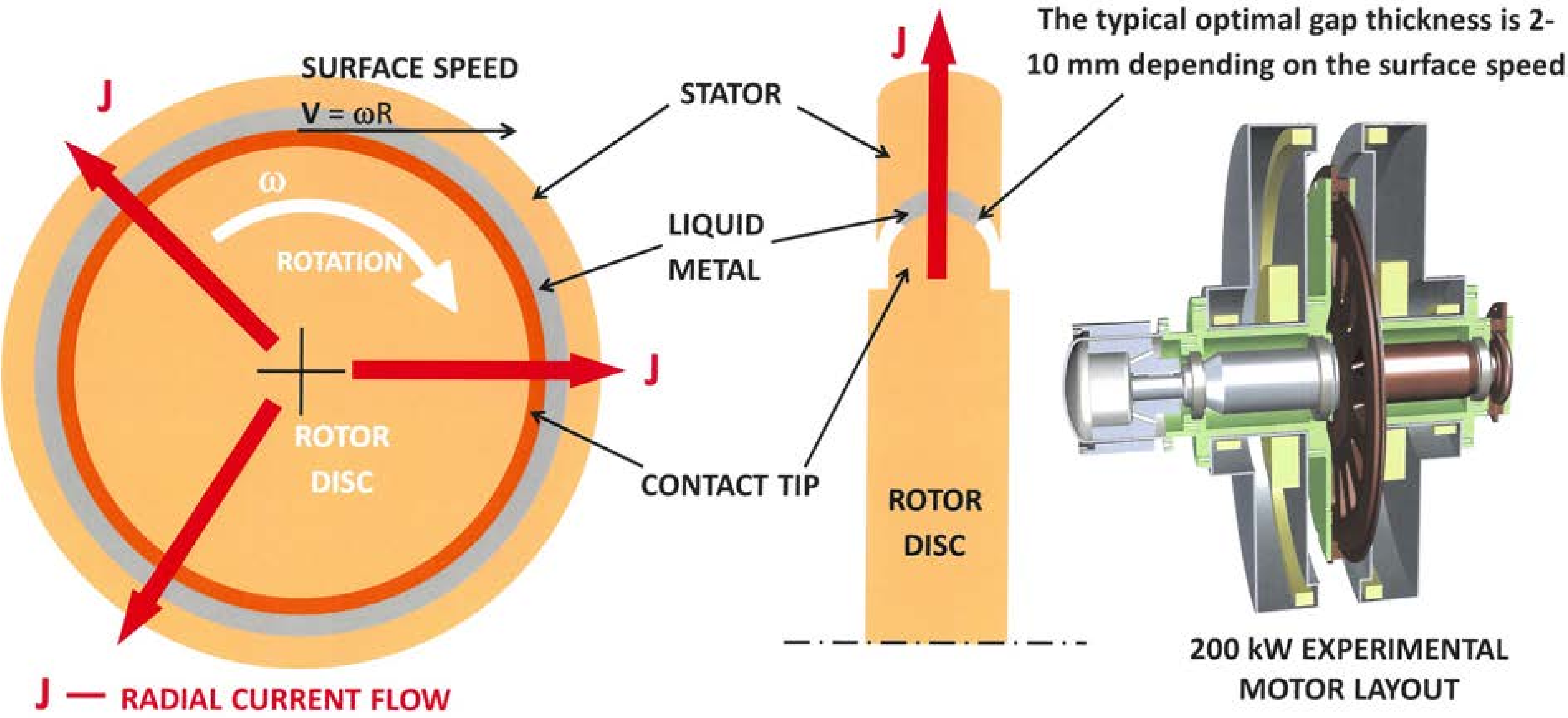
**Gallium-Indium-Tin Eutectic Alloy**

Melting point: -19 °C
Density: 6.44 g/cm$^3$
Viscosity: 0.0024 Pa·s
Resistivity at 20 °C: 29 $\cdot 10^{-8}$ Ohm·m

## MERCURY

Melting point: -38.8 °C
Density: 13.53 g/cm$^3$
Viscosity: 0.00155 Pa·s
Resistivity at 20 °C: 98 $\cdot 10^{-8}$ Ohm·m

# RING CHANNEL LIQUID METAL CURRENT COLLECTOR


The liquid metal is distributed uniformly around the disc circumference and maintained in position by centrifugal force

## SIMPLE LIQUID METAL CURRENT COLLECTOR DESIGN

# LOSSES IN A LIQUID METAL CURRENT COLLECTOR

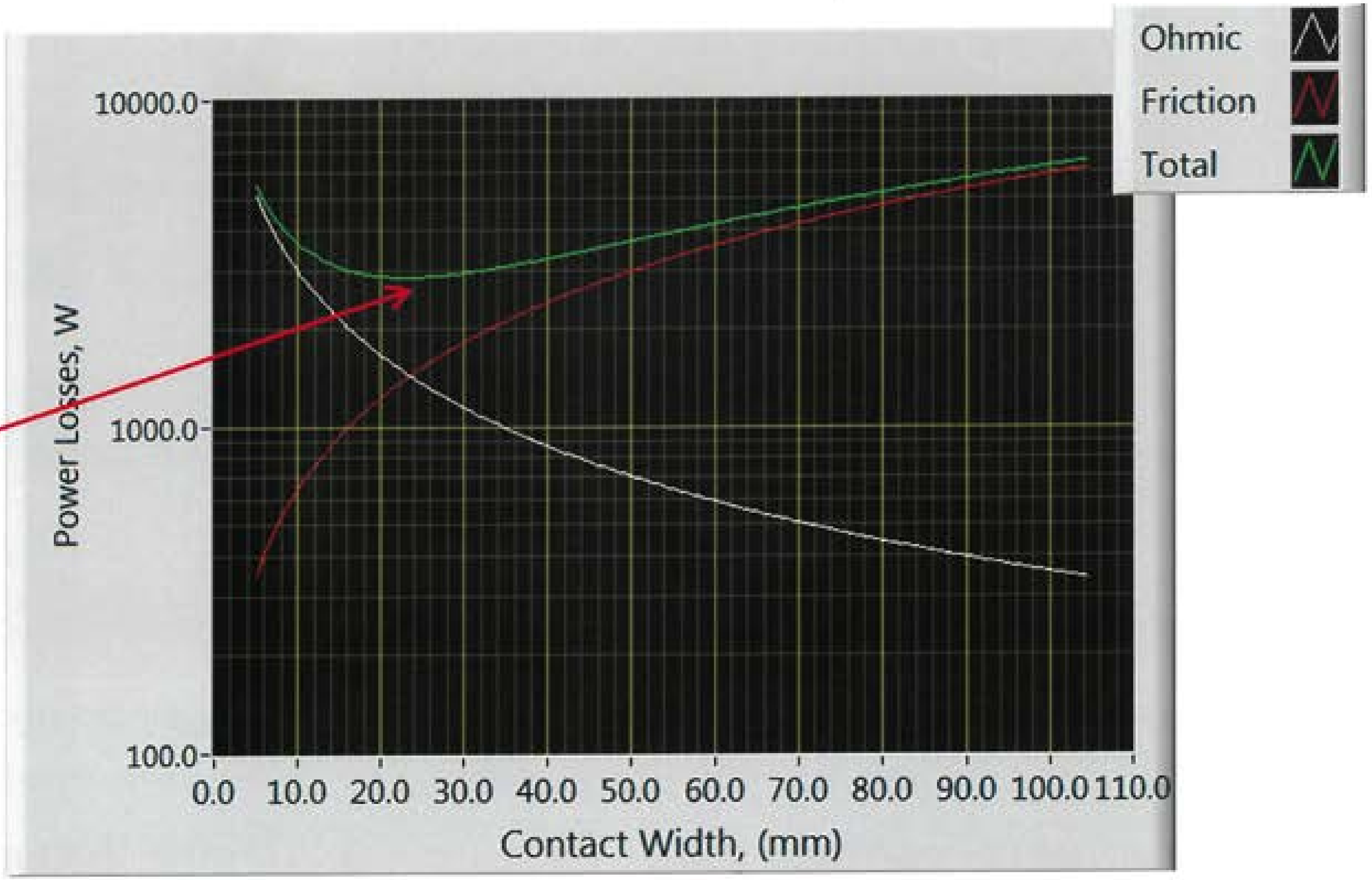
Frictional losses are proportional to the liquid density and the third power of the surface speed:

$$P_{loss} \sim v^3\rho$$

Optimal gap thickness: $\Delta \sim D/Re^{0.182}$, where D — rotor diameter;

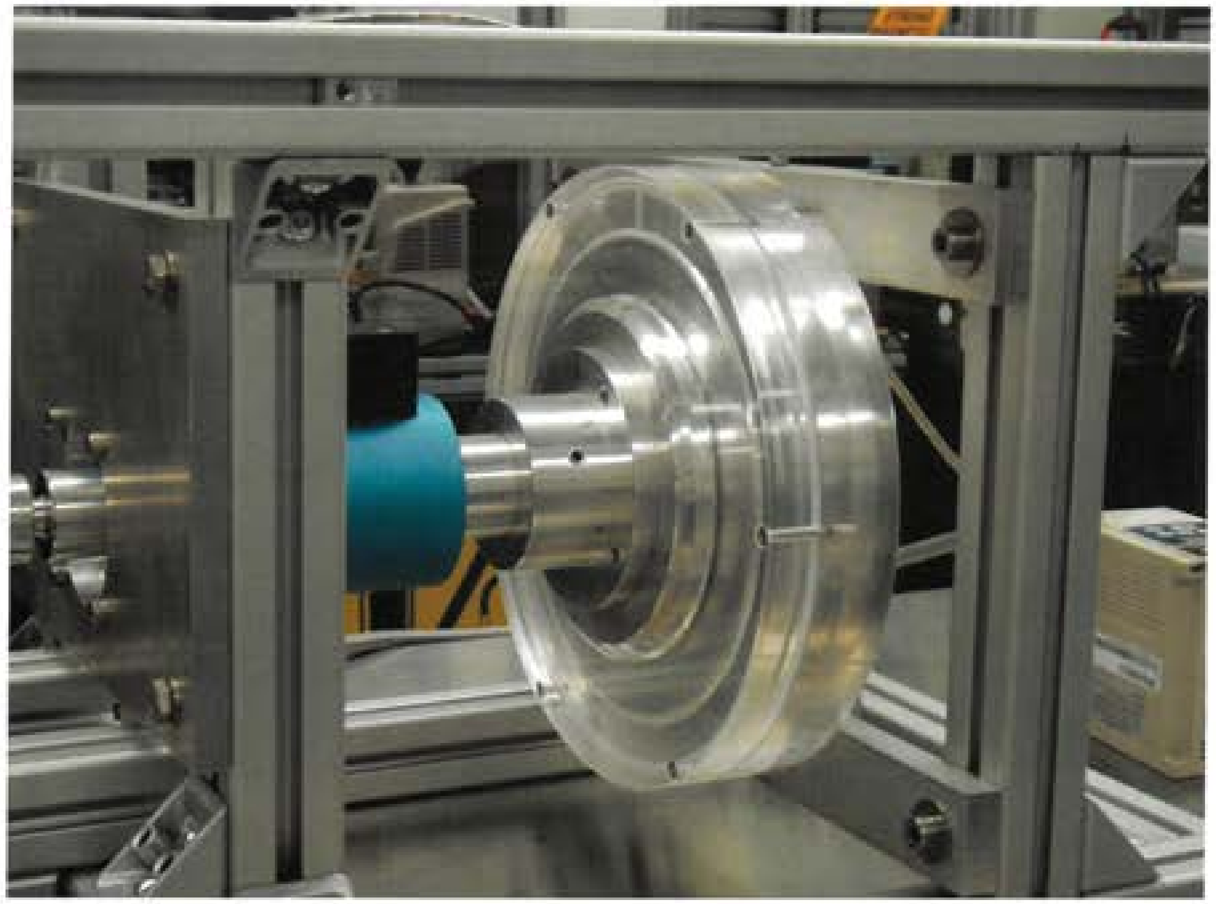
**$Re = D^2\omega/\nu$**— Reynolds number, where $\omega$ — **angular velocity, $\nu$ — kinematic viscosity**

A large contact area (wide contact tip) increases the frictional losses, but reduces resistance of the liquid metal link. The contact is optimized for each application in terms of best overall performance.

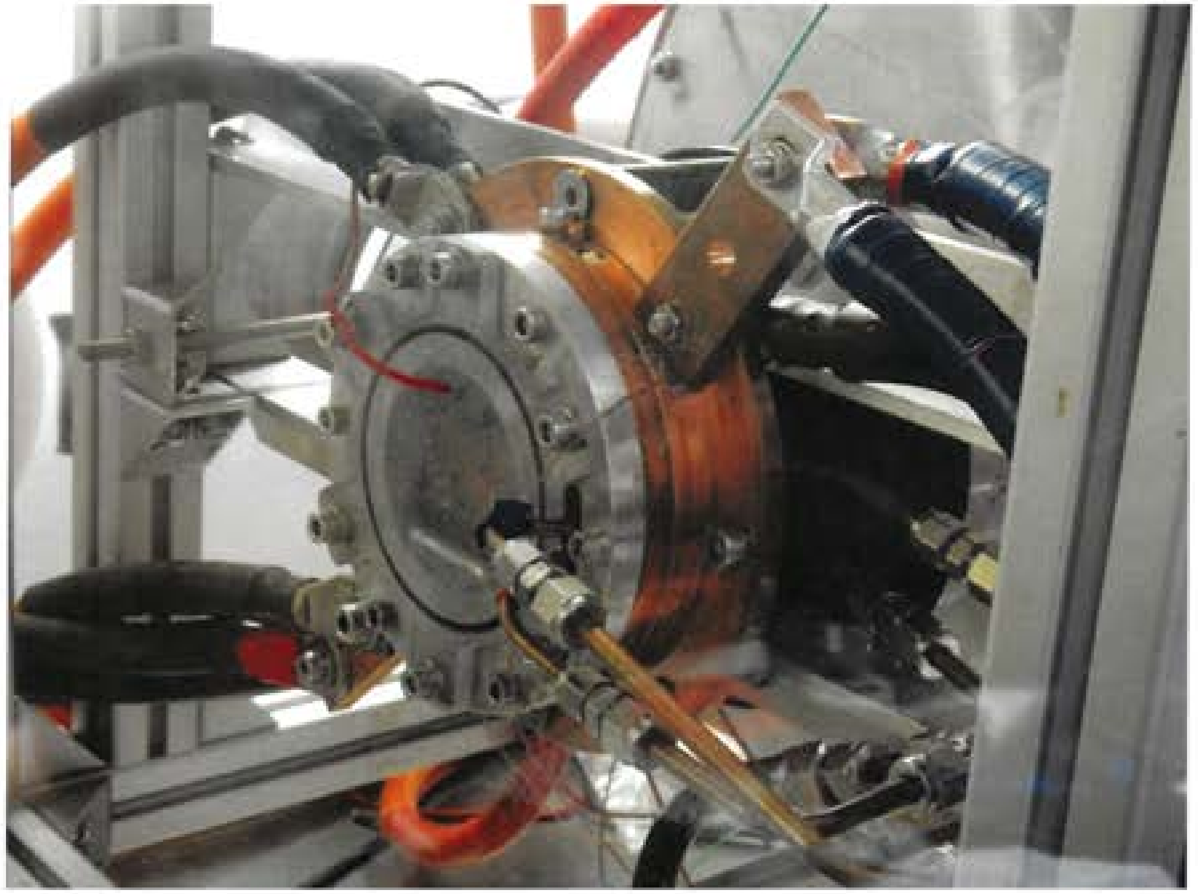



Typical dependence of the total power loss on the contact tip width (theoretical calculation)

# LIQUID METAL CURRENT COLLECTOR DEVELOPMENT

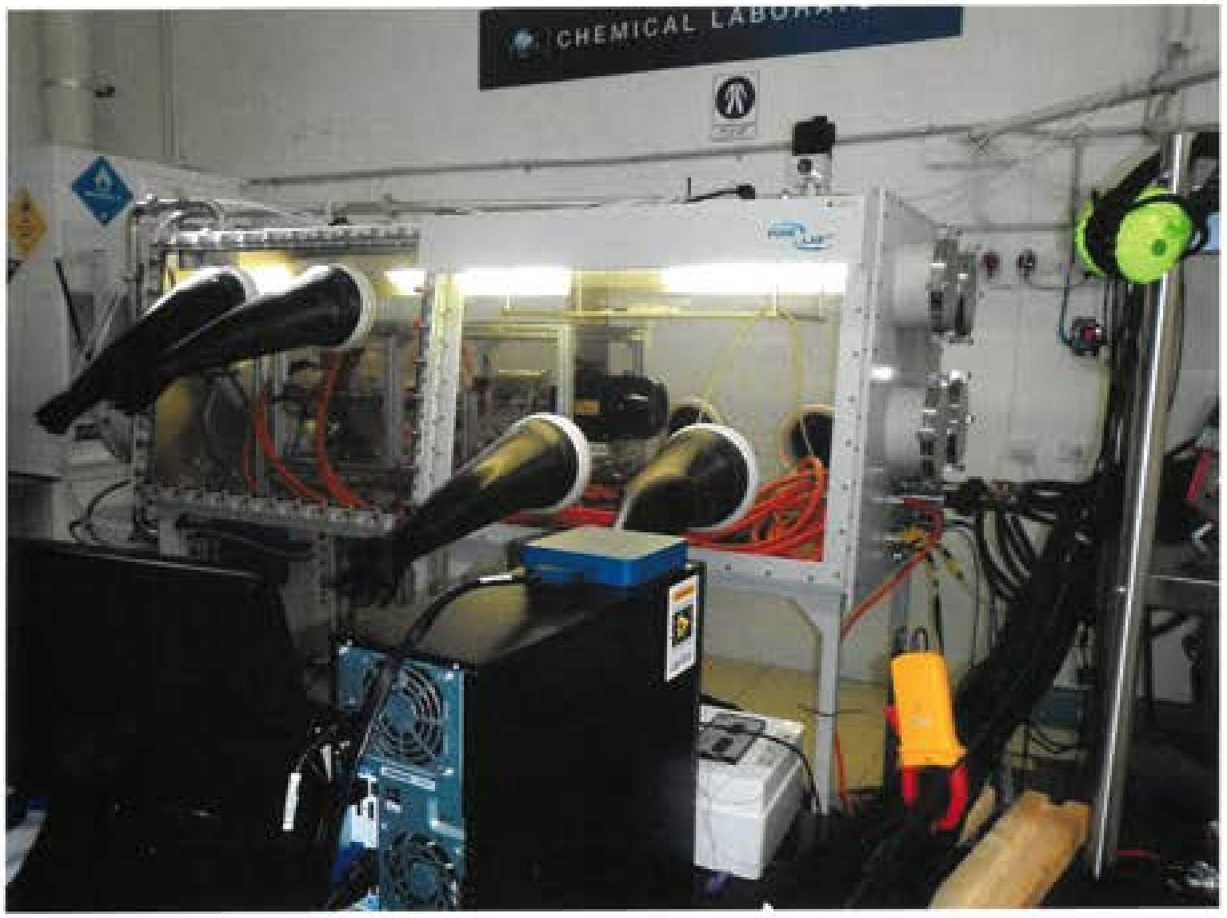


Water Model with plastic stator allowing fluid flow visualization with different rotor geometry



NaK liquid metal current collector (20 kA, 3600 RPM) in a glove box. Small (inner) disk 100 mm diameter.

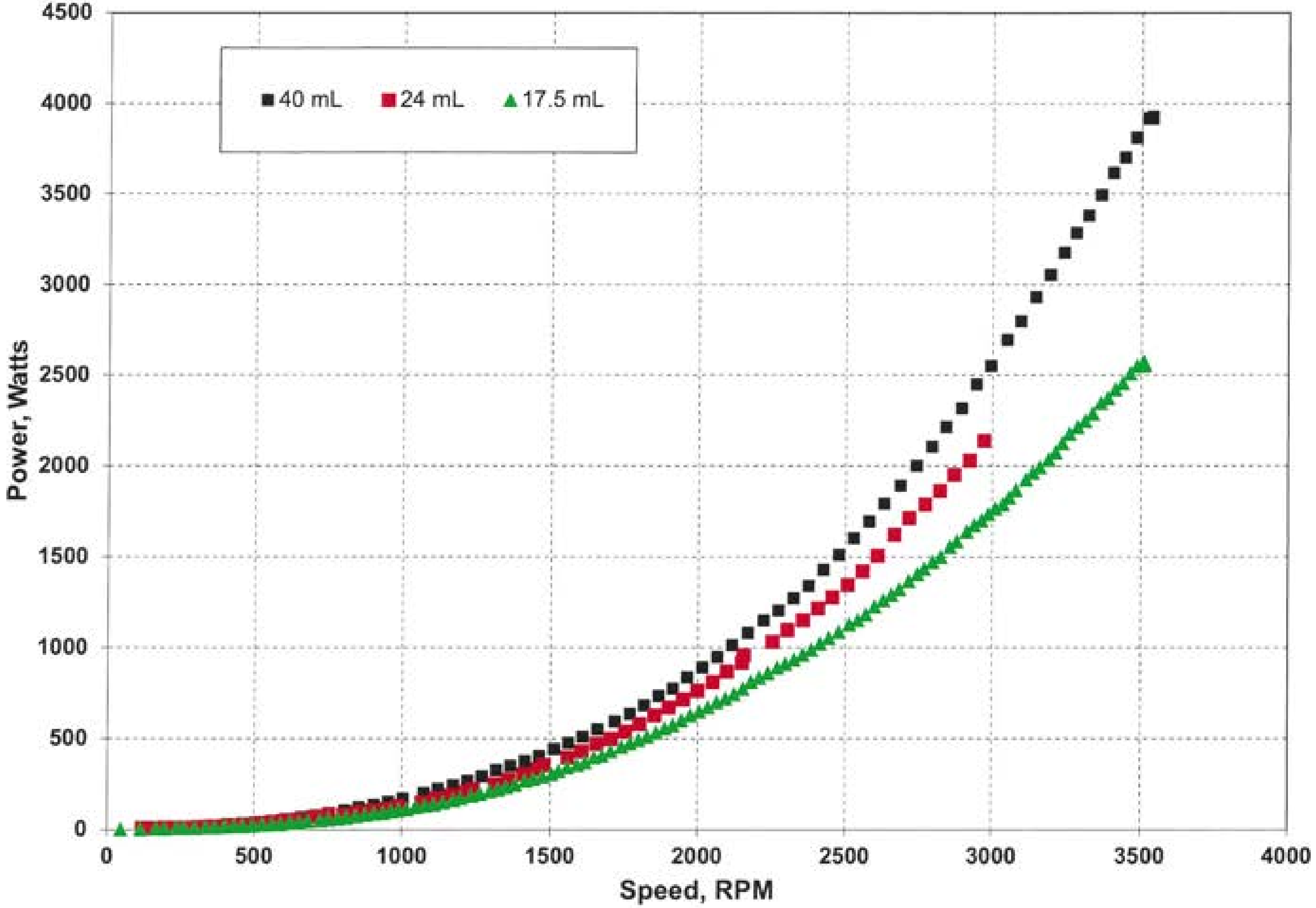
# LIQUID METAL CURRENT COLLECTOR DEVELOPMENT




Argon gas glove-box for experimentation with LMCC

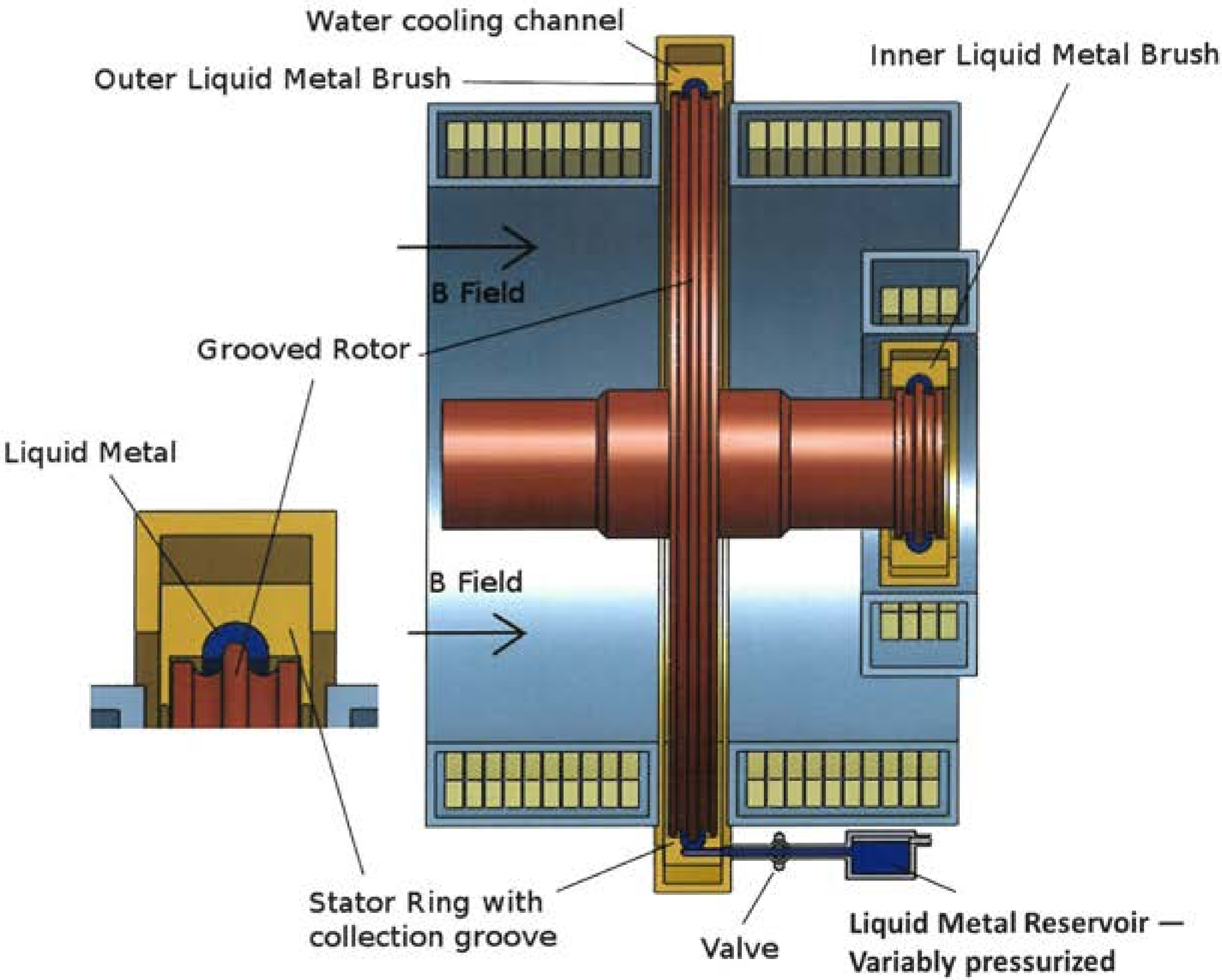
Large 400 mm outer disk (rotor of homopolar motor).

# FRICTIONAL LOSSES: TESTING UP TO 3600 RPM



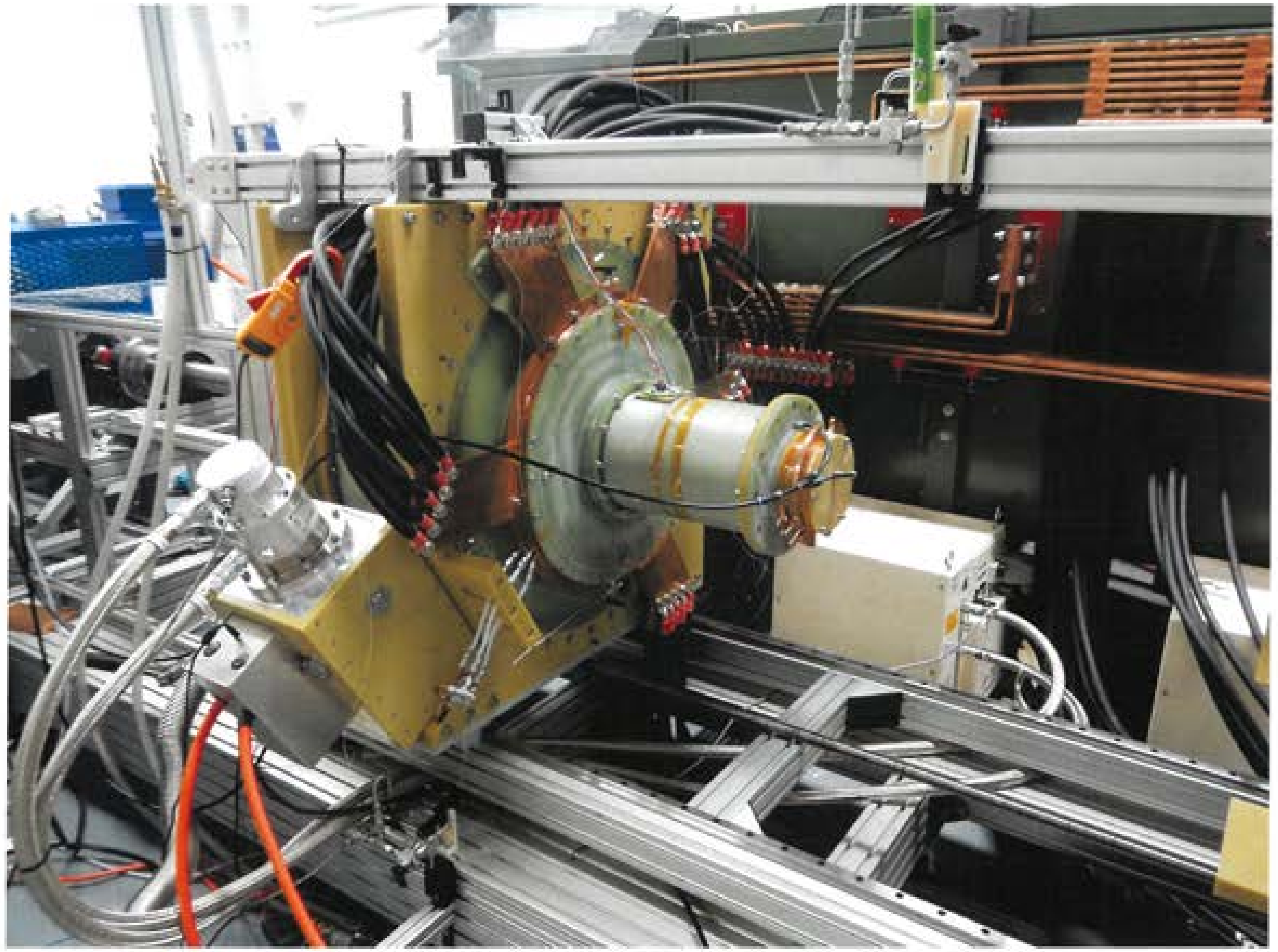

FRICTIONAL LOSSES MEASURED FOR VARIOUS NACK QUANTITIES

# 200 kW TEST HOMOPOLAR GENERATOR CONCEPT



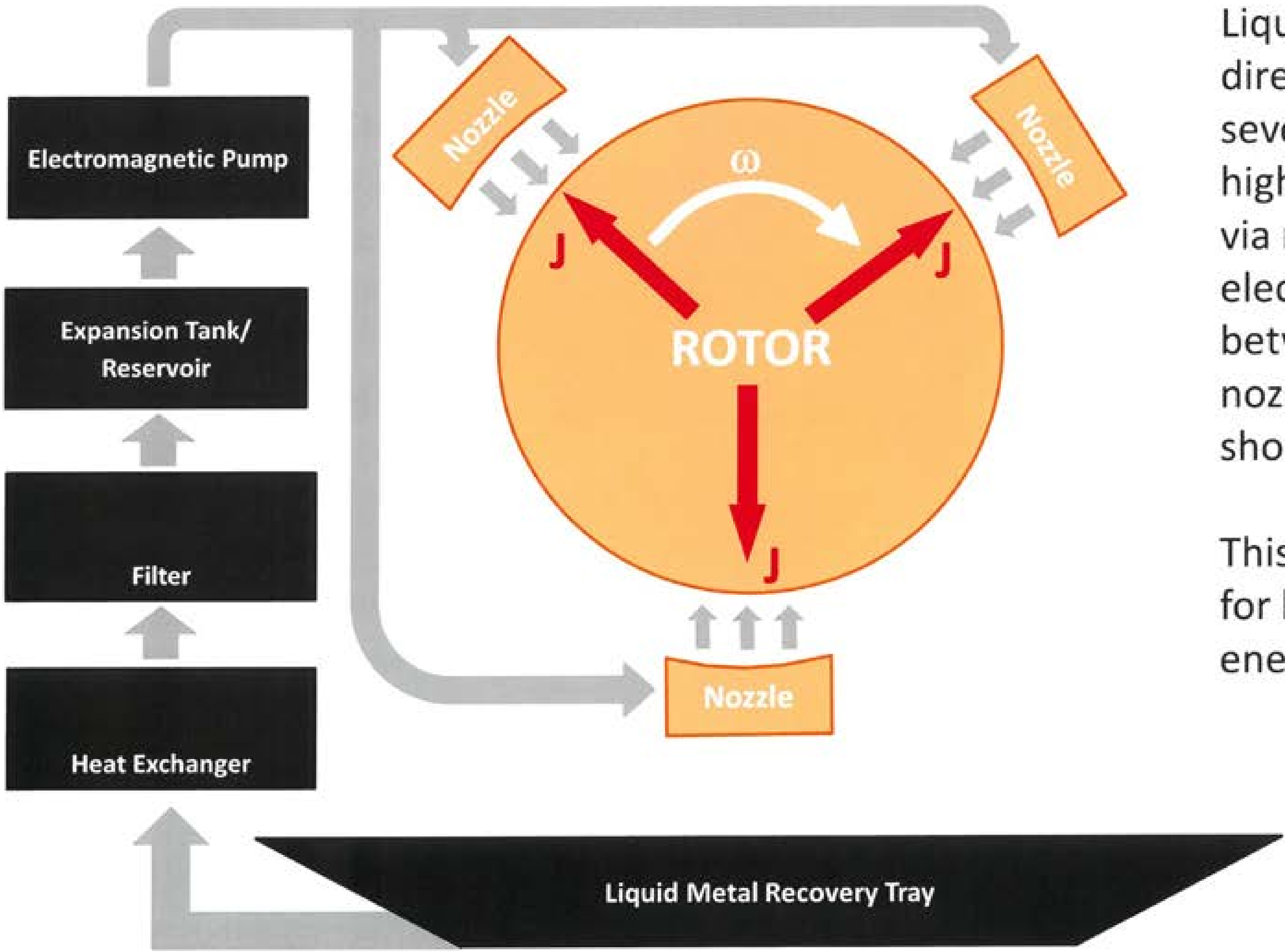
# 200 kW TEST HOMOPOLAR GENERATOR EXPERIMENT

Liquid metal current collector allows motor operation at 20 kA and 95 m/s surface speed.



Electrical and mechanical losses are expected not to exceed 4000 W, thus efficiency excluding cryogenic and water cooling systems is expected to be >98% for a 200 kW test motor.

# JET-SPRAY LIQUID METAL CURRENT COLLECTOR




Liquid metal jets are directed to a rotor at several locations and at high pressure and flow-rate via nozzles creating an electrical connection between the conductive nozzle and rotor during a short period of time.

This approach is necessary for high-current, high-energy pulse discharge.

# RECIRCULATING LIQUID METAL CURRENT COLLECTOR

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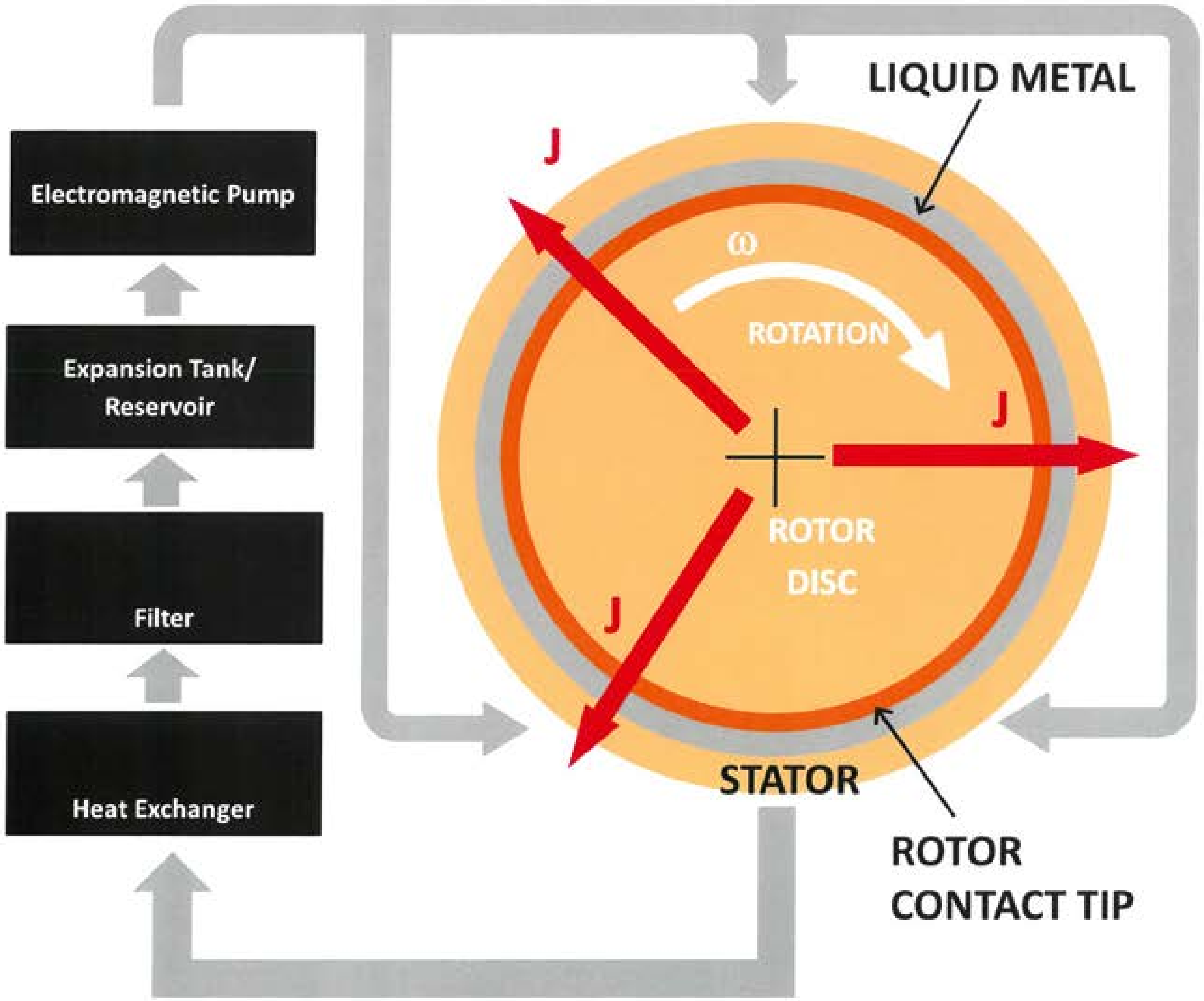
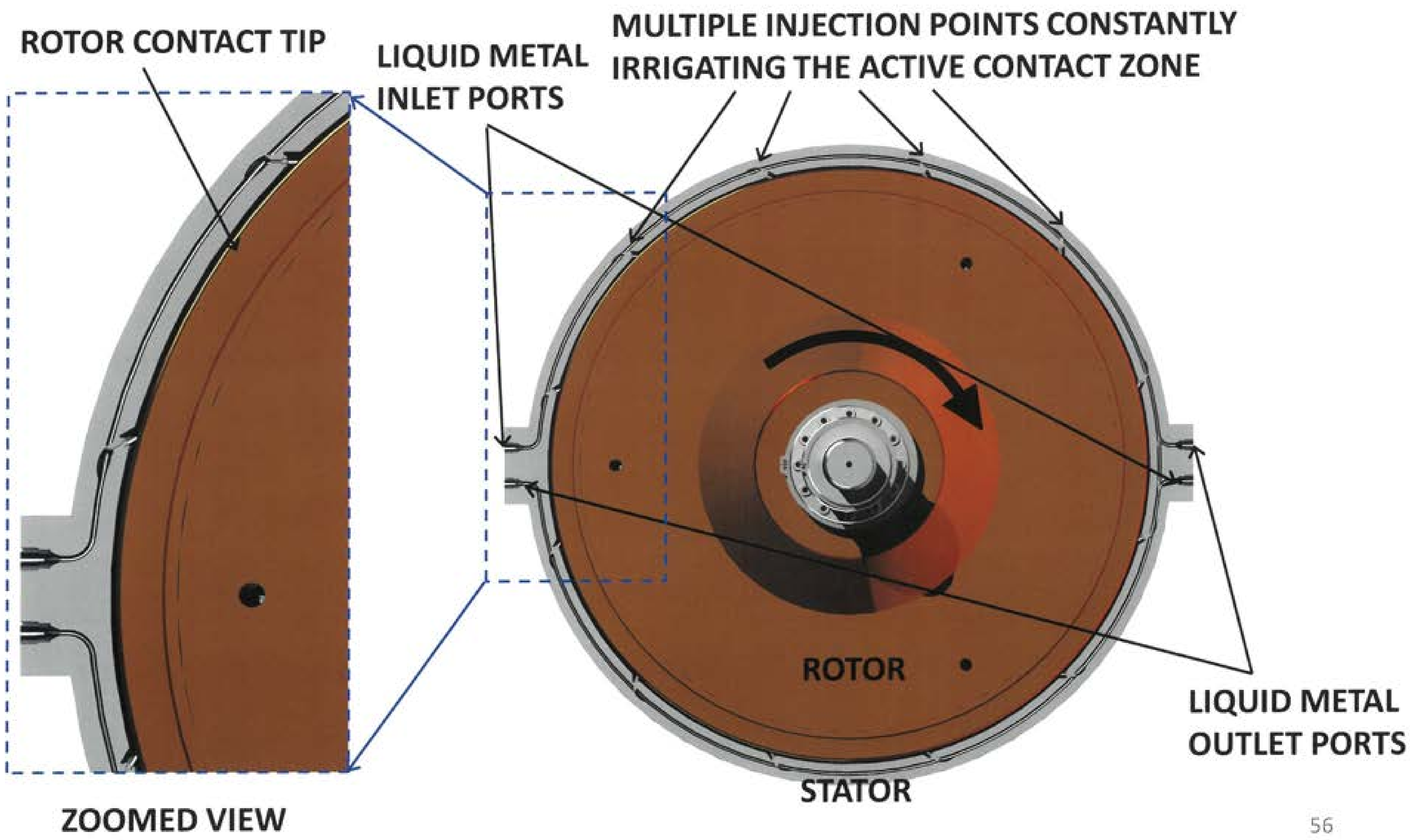



Liquid metal is supplied to stator continuously at relatively low flow rate through multiple inlets to maintain stable contact operation.

This approach is especially critical for slow speed and large (> 2 m) diameter rotors where hydrodynamic stability of the flow becomes an issue.

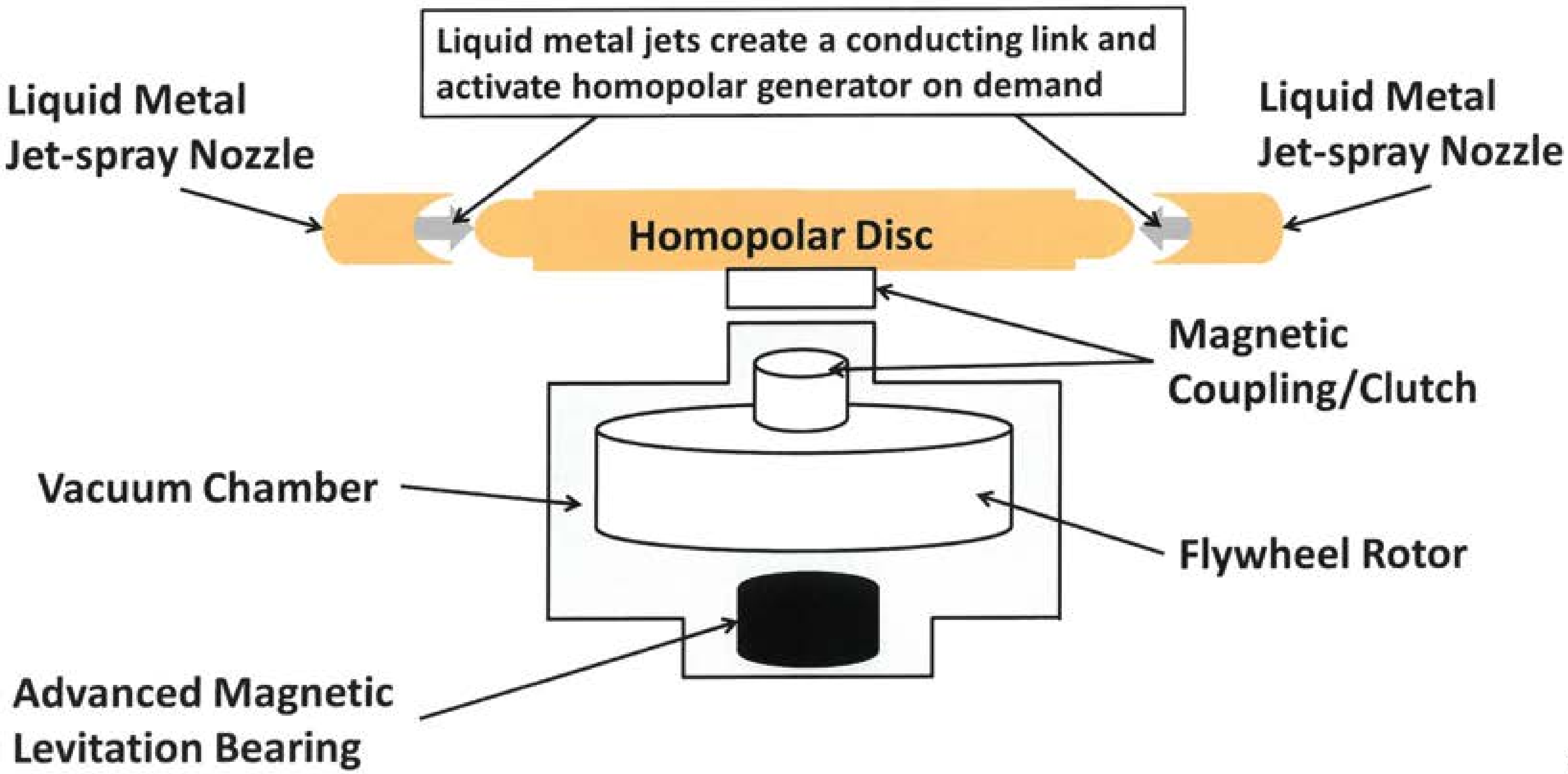
Liquid is removed from contact zone and returned to circulation loop via single or multiple extraction ports.

# RECIRCULATING LIQUID METAL CURRENT COLLECTOR



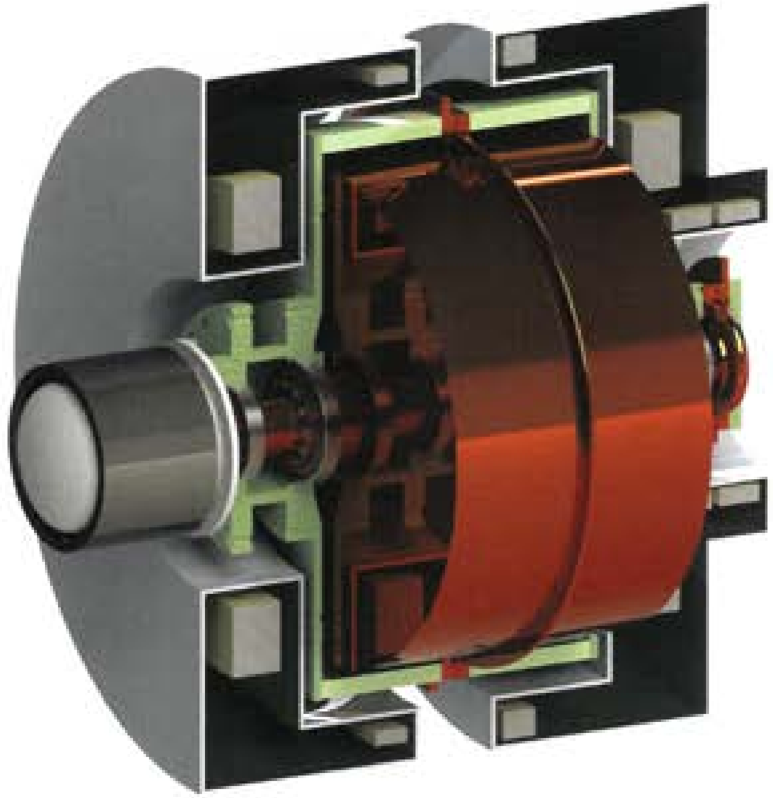
# HOMOPOLAR GENRATOR-BASED ENERGY STORAGE

- A Flywheel energy storage system can be coupled with a homopolar generator equipped with liquid metal jet-spray current collector system as a means of energy storage



# GUINA PULSE HOMOPOLAR GENERATOR

Applications include Slug Launch Systems and Particle Accelerators.

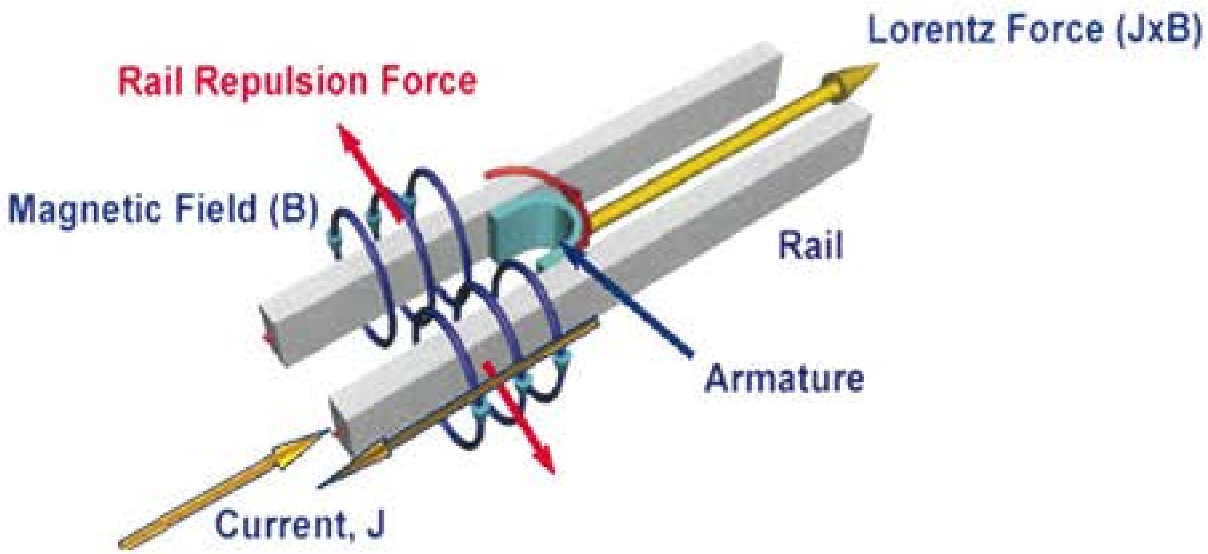


Mechanical Parameters:

- E = 30.5 MJ (stored energy)
- n = 4720 RPM (rotation speed)
- v = 247 m/s (surface speed)
- M = 2000 kg (disc weight)
- **r = 0.5 m (disk radius)**
- d = 285 mm (disk thickness if made out of copper)

Electromagnetic Parameters:

- 1 second discharge time




Option A (higher initial voltage and lower current):
- B = 1 T
- V = 54 V
- I = 565 kA

Option B (lower initial voltage and higher current):
- B = 280 mT
- V = 15 V
- I = 2033 kA = 2.03 MA

# GUINA PULSE HOMOPOLAR GENERATOR

Applications include Aircraft Catapult Systems.

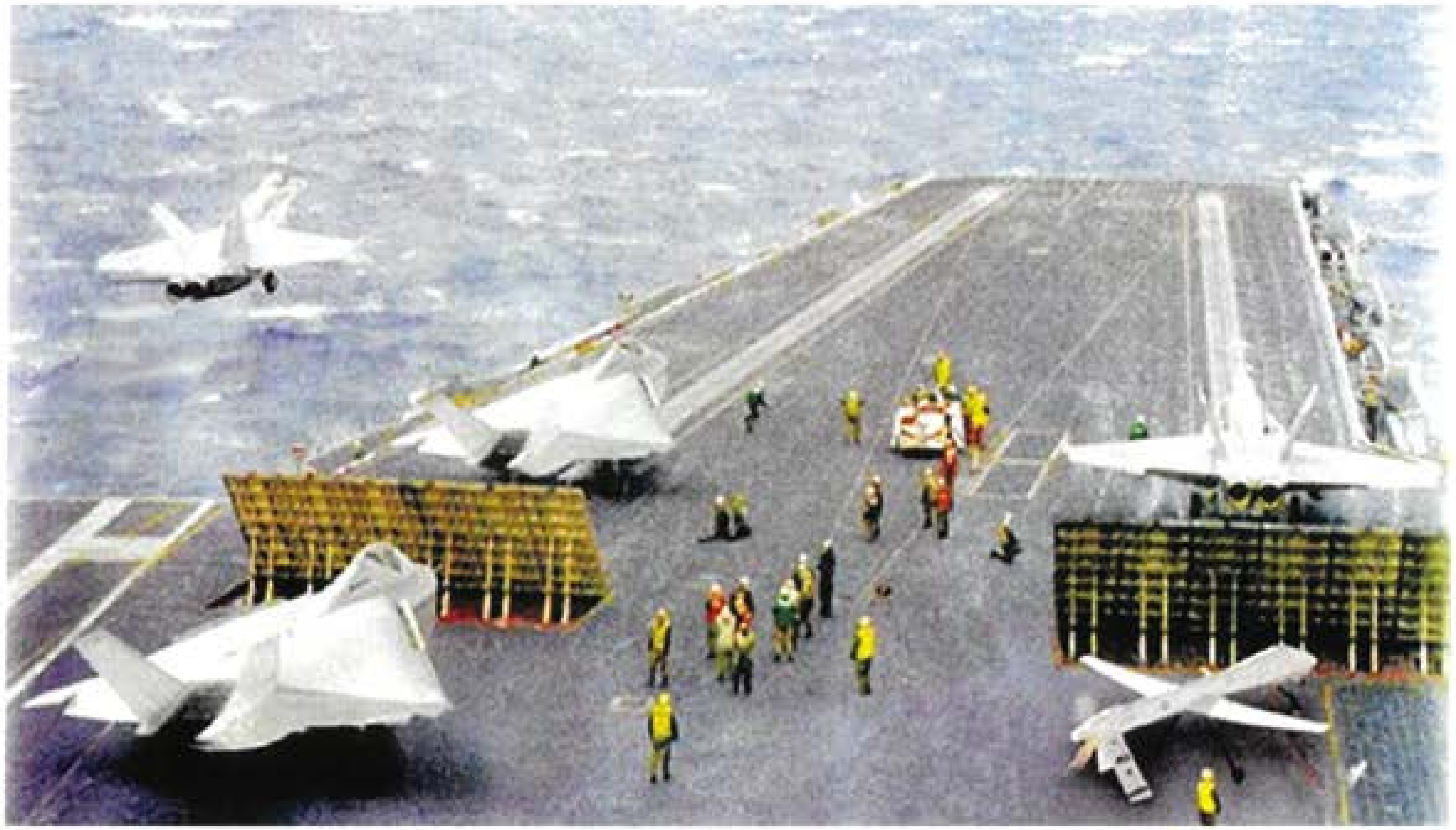
Mechanical Parameters:

E = 130 MJ (full stored energy)
n1 = 1500 RPM (max rotation speed)
n2 = 240 RPM (min rotation speed)
v = 236 m/s (max surface speed)
M = 9400 kg (disk weight)
**r = 1.5 m (disk radius)**
d = 149 mm

Electromagnetic Parameters:

Option A:
B = 3.2 T
V = 565 V
I = 75 kA

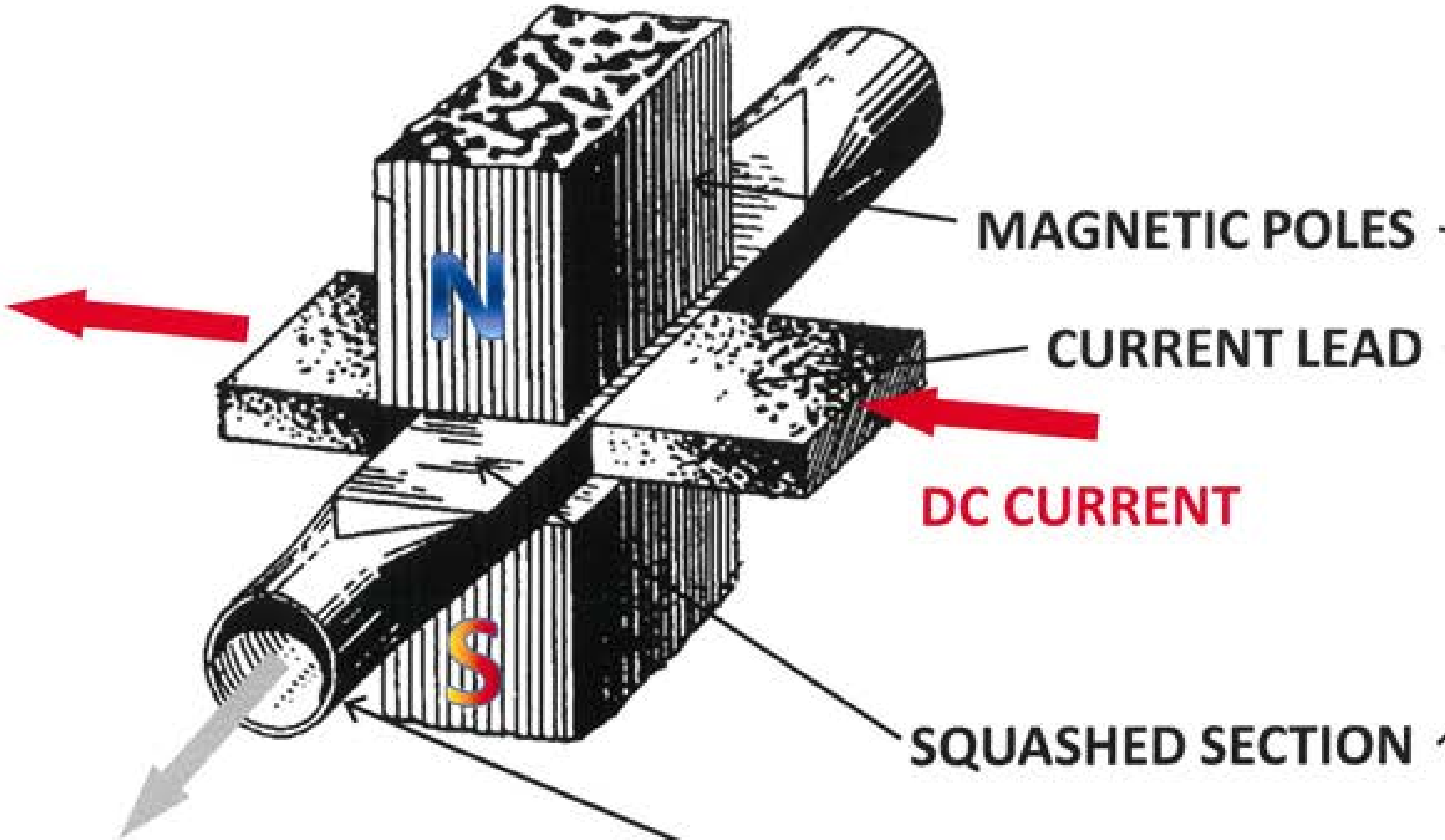
Option B:
B = 240 mT
V = 42.2 V
I = 1000 kA = 1MA

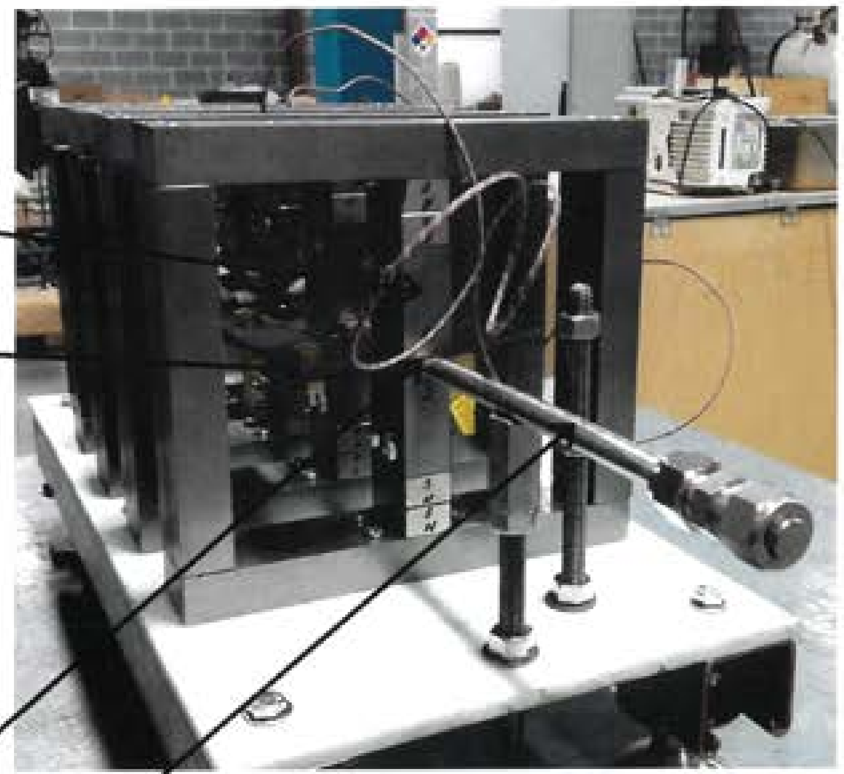


**Discharge time 3 sec, released energy 126.7 MJ**
**The 45 tonne aircraft is accelerated from 0 to 240 km/hr in this 3 seconds**

# DC ELECTROMAGENTIC PUMP FOR LIQUID METALS

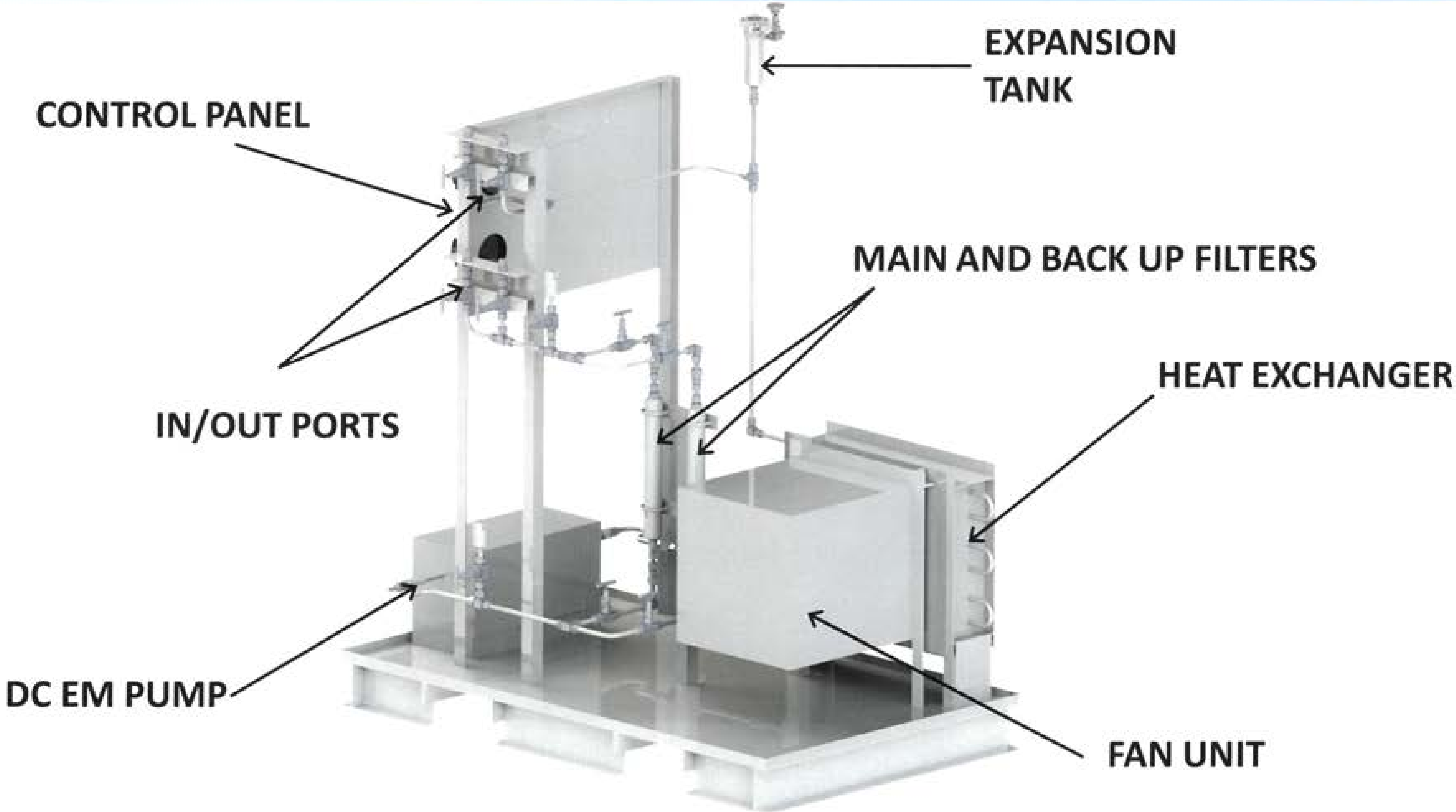
A DC EM Pump, in conjunction with a fine sintered filter, is a core element of any type of liquid metal current collector system. This system supplies liquid metal to the contact, maintains the liquid metal purity and provides liquid metal circulation for cooling purposes.



**MAXIMUM PRESSURE: 48 psi (3.2 bar)  MAXIMUM FLOW RATE 10 L/min at 850 A**

# LIQUID METAL RECIRCULATION SKID SYSTEM




**Our recently built purification and cooling loop allows removal of up to 5 kW of heat from the active zone of the LMCC and maintain liquid metal purity by utilizing fine sintered filters.**

# LIQUID METAL CURRENT COLLECTOR APPLICATIONS

- LMCC can be used in conventional rotating machines as a low wear and low friction replacement of solid brushes

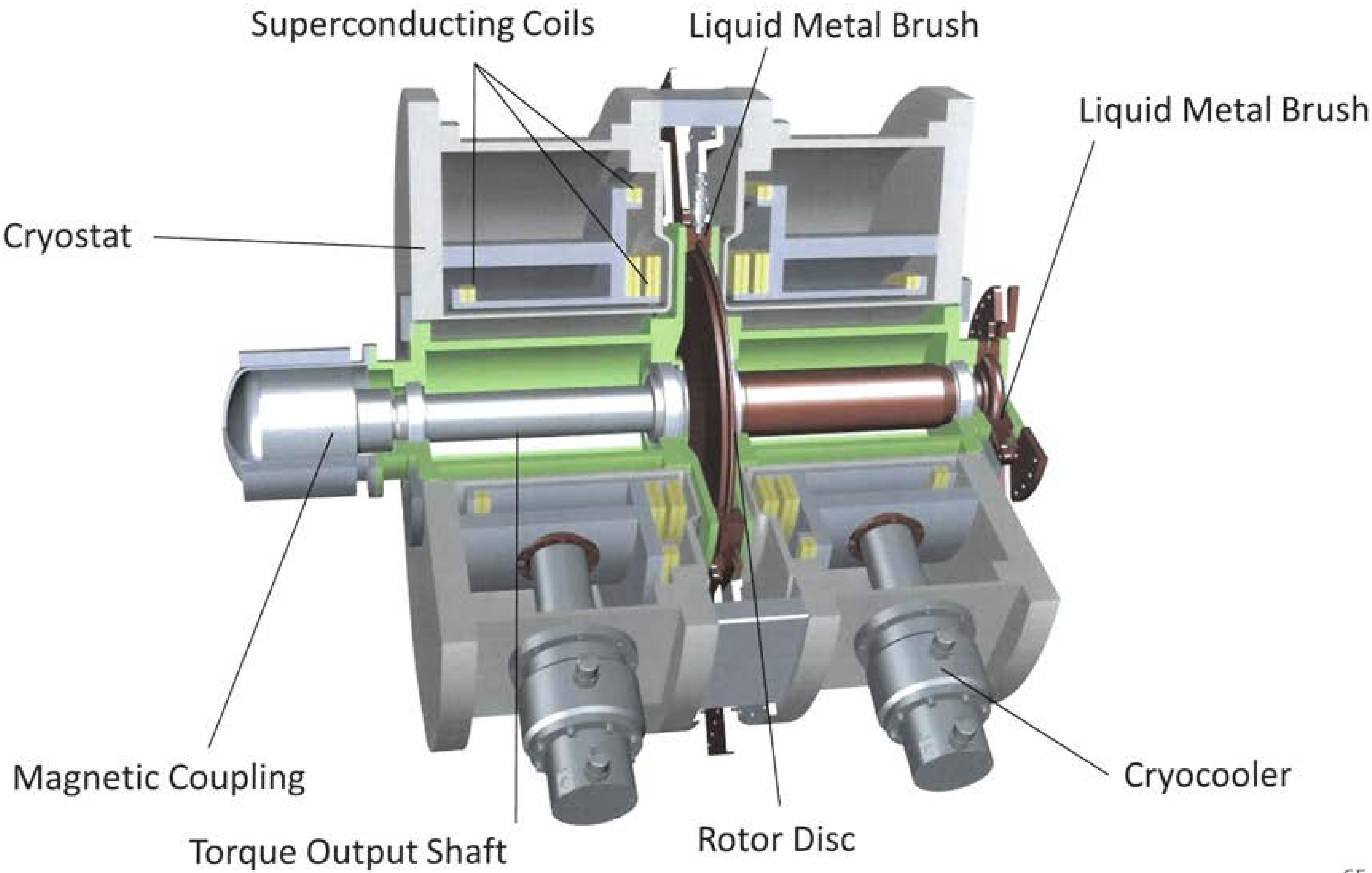
- Other than electrical rotating machines LMCCs can be used for low-noise long-life data transmission in rotary feed-throughs:
  - Robotic arms with unlimited rotation allowing for power transfer to manipulators and obtaining feed-back data
  - Signals from thermocouples and other sensors installed on rotors, wheels, propellers and other pieces of rotating machinery
  - Various research applications requiring low-noise electric signal transmission from stationary to rotating parts

# PRESENTING:
# PROTOTYPE HOMOPOLAR MACHINE AND HIGH SPEED SUPER-TRON TECHNOLOGY

# SECTION OUTLINE

- 200 kW Prototype Development
  - HTS Magnet System
  - Liquid Metal Current Collector Testing
  - Integrated testing
- Homopolar Test Facilities
- High Speed Turbines

# PROTOTYPE HOMOPOLAR MACHINE LAYOUT



# 200 kW MOTOR PROTOTYPE

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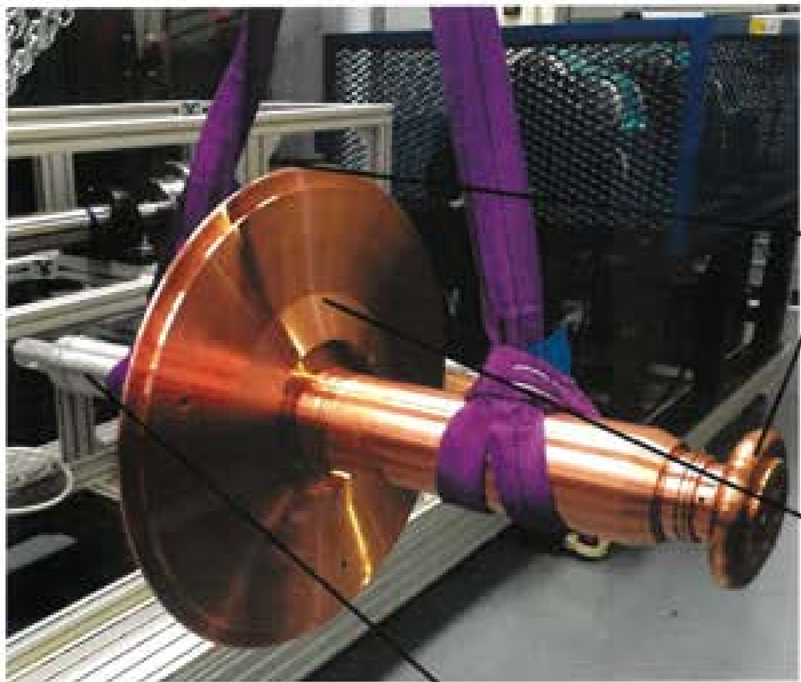
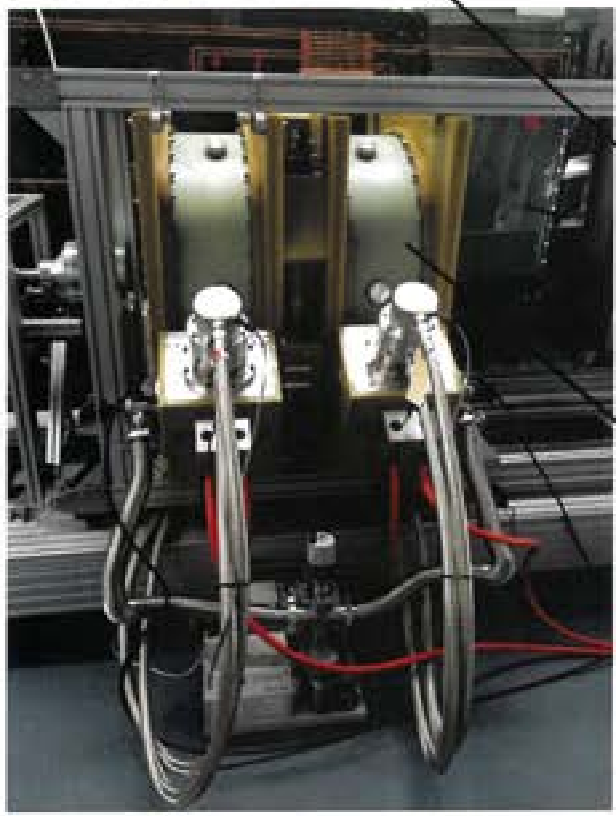




Liquid Metal Contact Region

Rotor Disc

Torque Output Shaft

Superconducting Magnet

Motor Power is given by:

$$P = \frac{2I\pi N}{60} \int_0^R B(r)rdr$$

$$\int_0^R B(r)r\,dr = 0.0267\ Tm^2$$

$$I = 20{,}000\ A$$

$$N = 3{,}600\ RPM$$

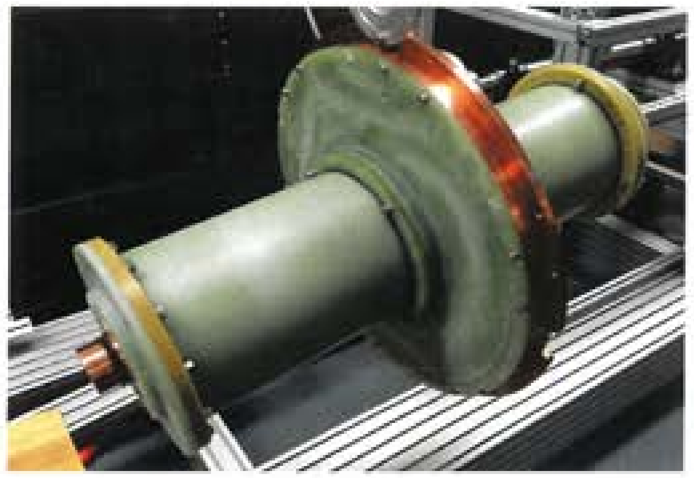
$$P = 201\ kW$$

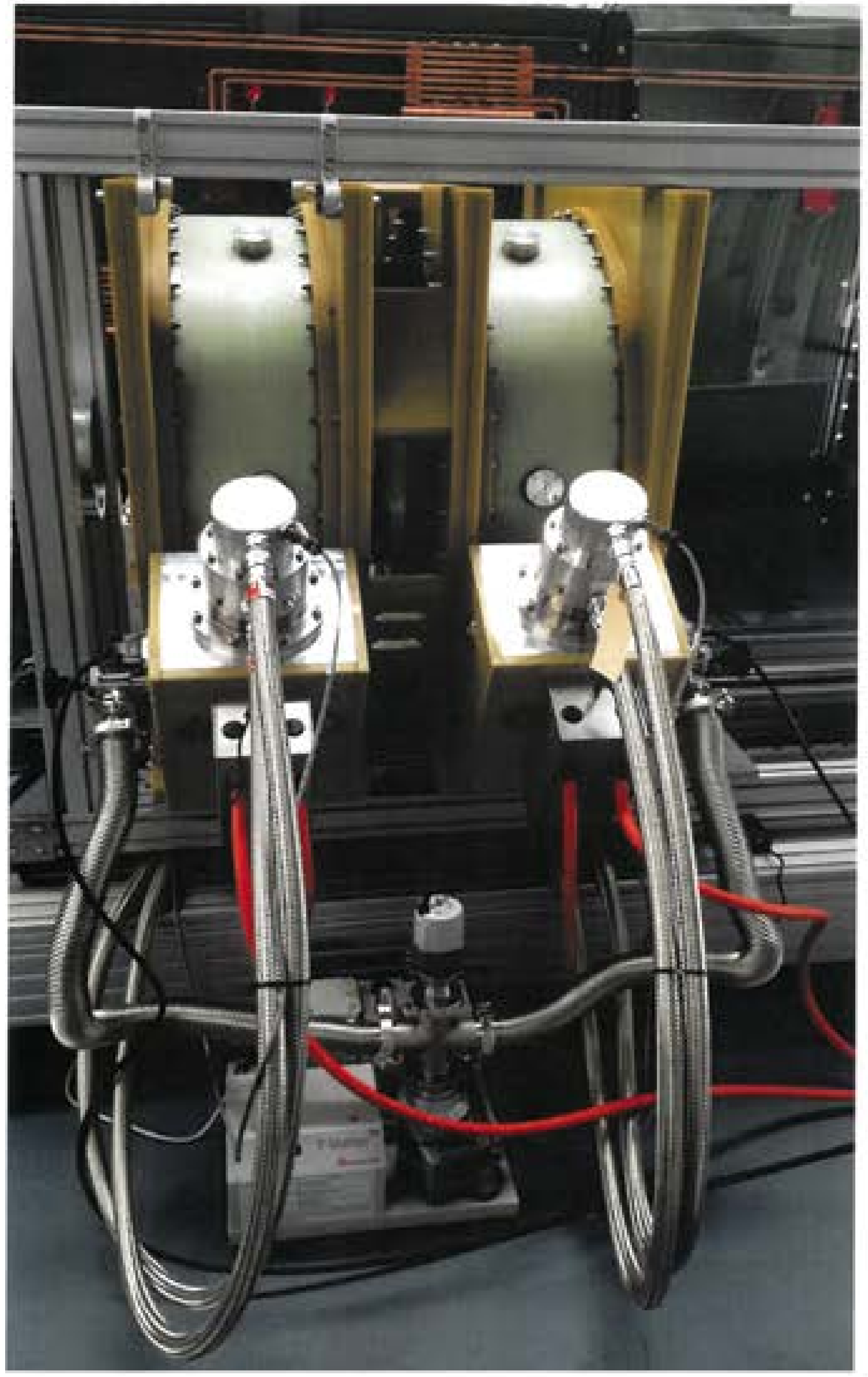
Disc Diameter= $500mm$

$$V = 10\,V$$

# 200kW MOTOR PROTOTYPE

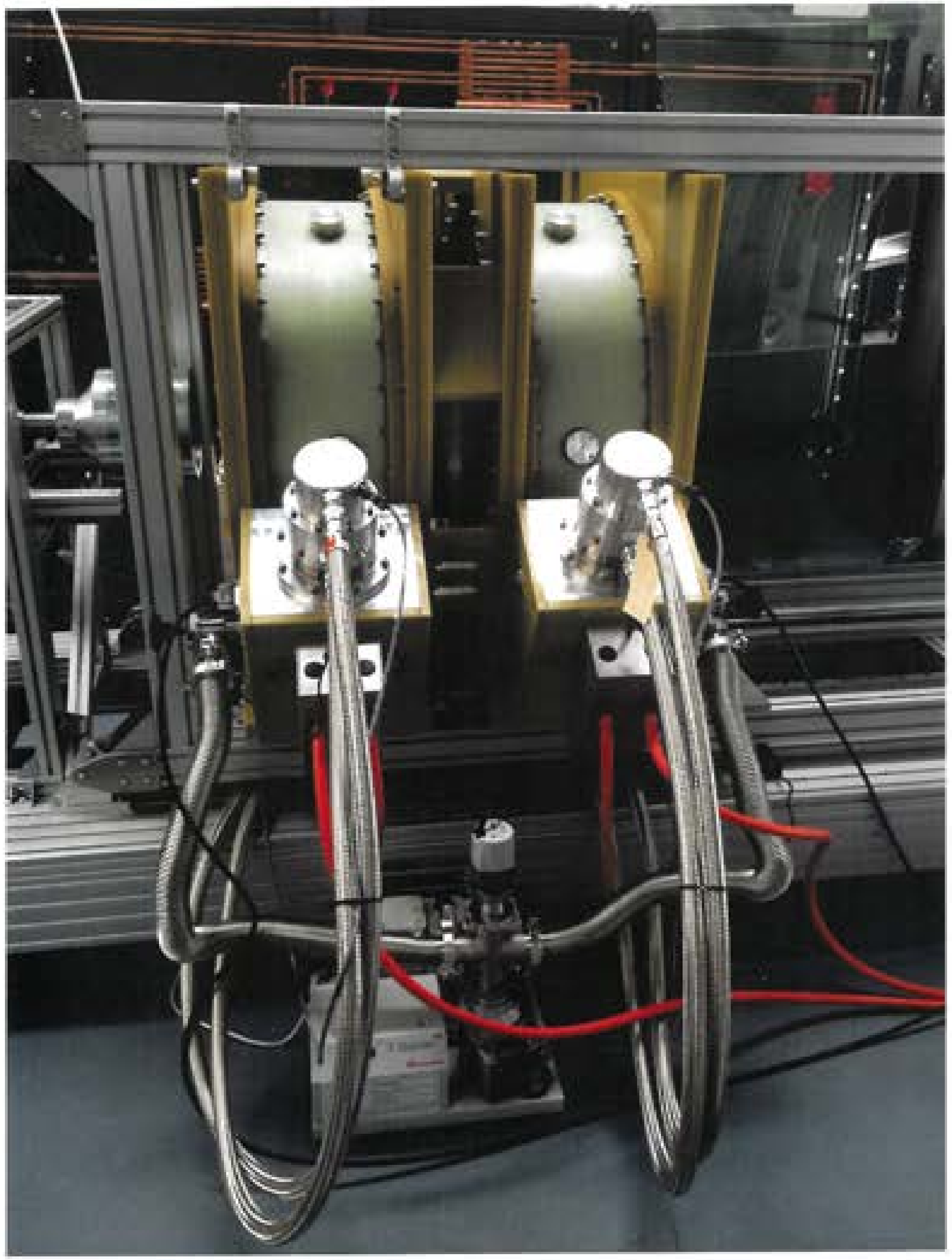
GUINA ENERGY GROUP





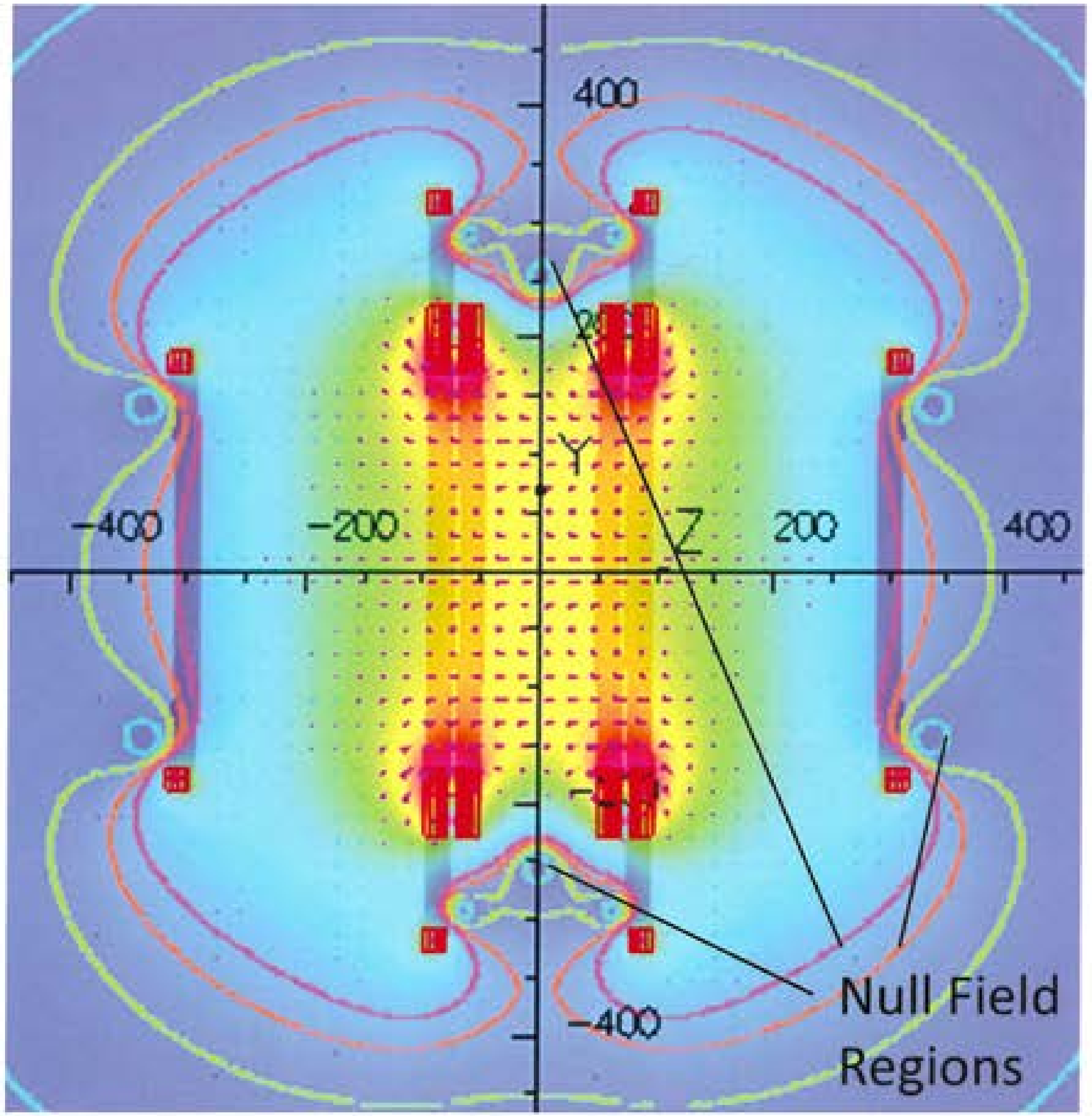
# HTS MAGNET SPECIFICATIONS

- Split Pair Design
- 1G HTS Tape
- 1.3 Tesla Central Field
- Composite Cryostat
- Null Field Cancelling Coils
- 30 K Operating Temp
- 160 A operating current
- 900 mm x 900 mm x 760 mm overall size
- ∅290 mm Warm Bore

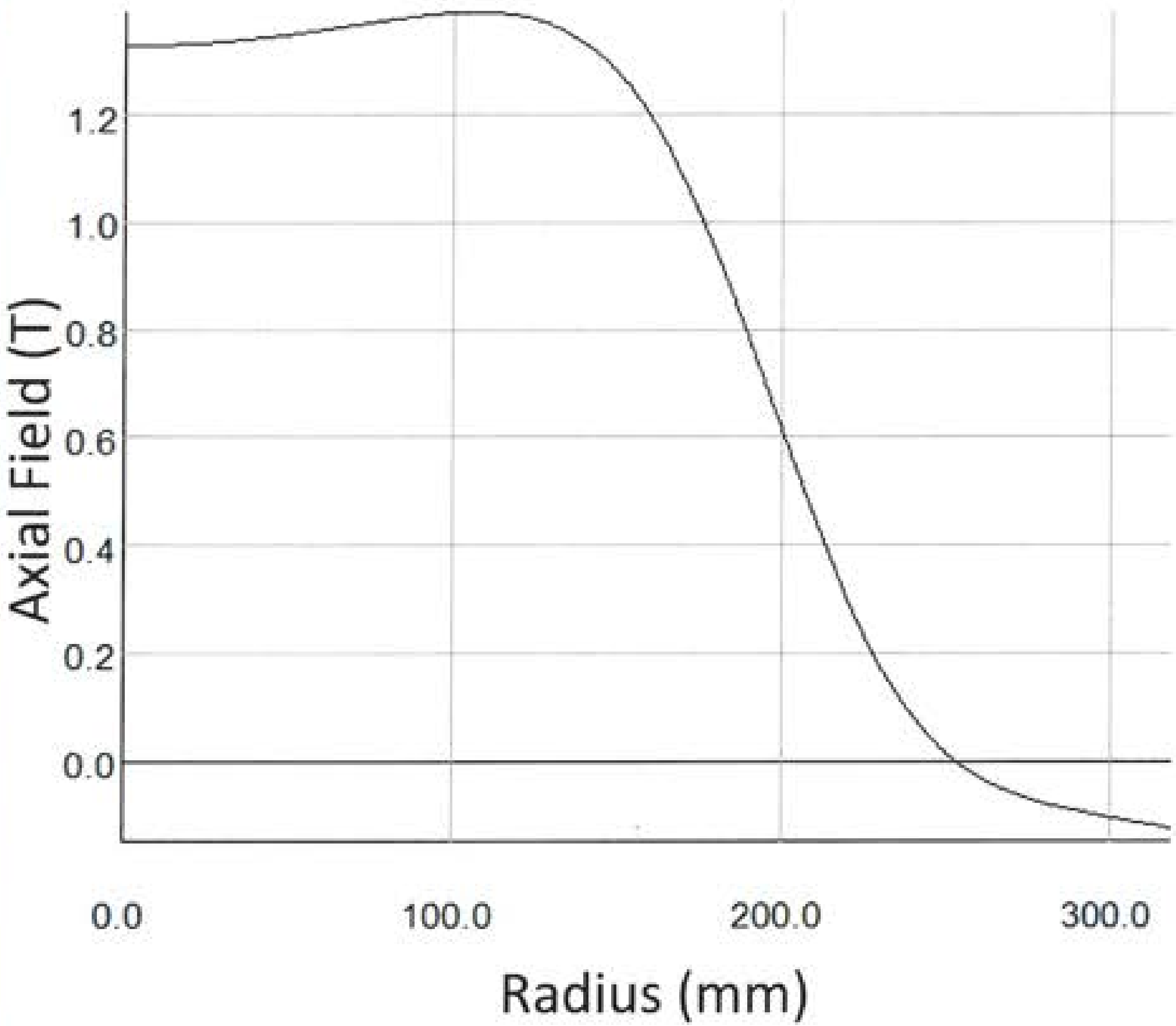


# MAGNETIC FIELD PLOTS

## NULL FIELD REGIONS



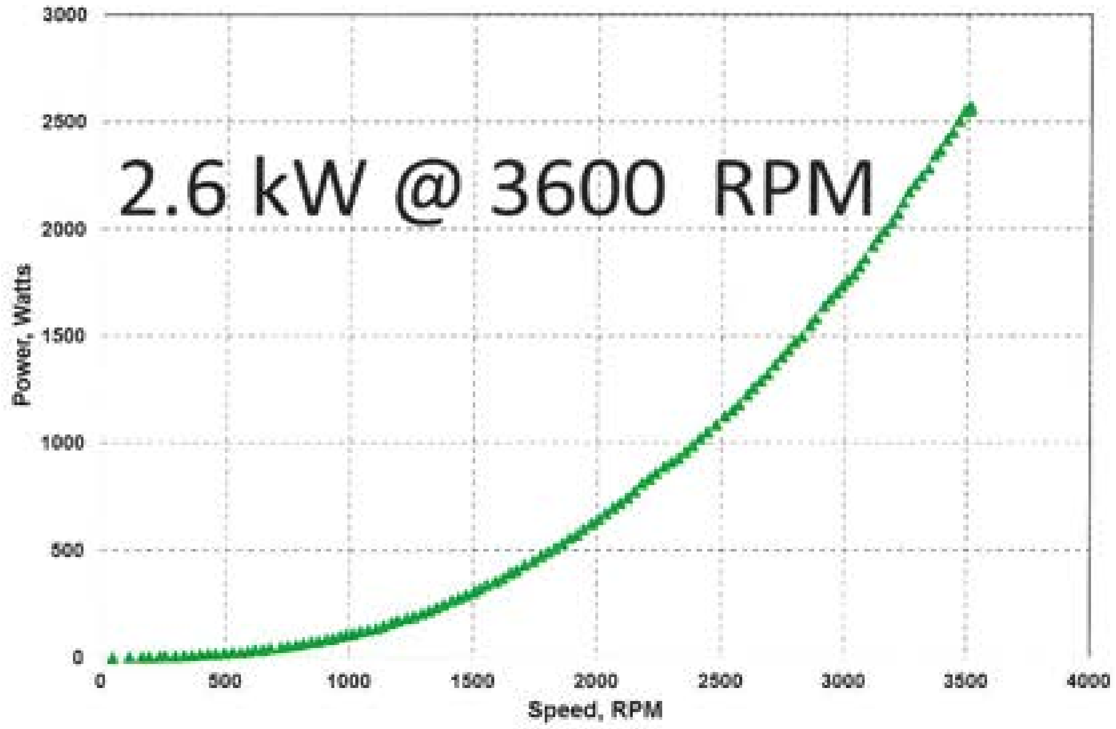

## MAGNETIC FIELD AT CENTRELINE

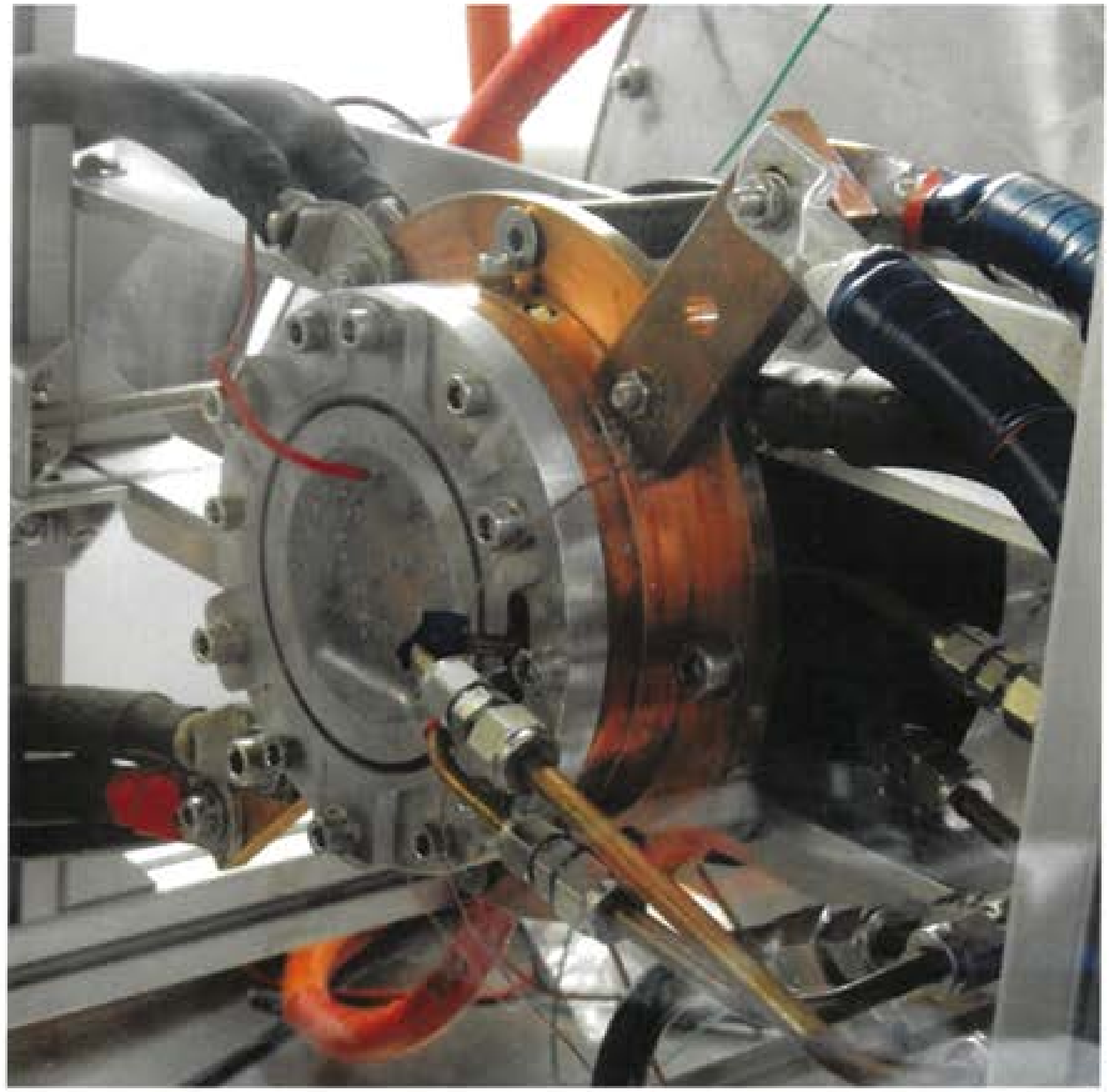


# LIQUID METAL CURRENT COLLECTOR SYSTEM

- NaK liquid metal current collector successfully tested 10,000 A @ 3600 RPM (75m/s surface speed)
- Water cooling system for heat removal.

## MECHANICAL POWER LOSS



## ELECTRICAL POWER LOSS

- Liquid Metal Link Resistance: ~1 μΩ
- Liquid Link Power loss @ 10000 A : 100 W
- Rotor Estimated Resistance: <5 μΩ
- Estimated Total Electrical Power loss at full 20,000 A working current: <2.4 kW

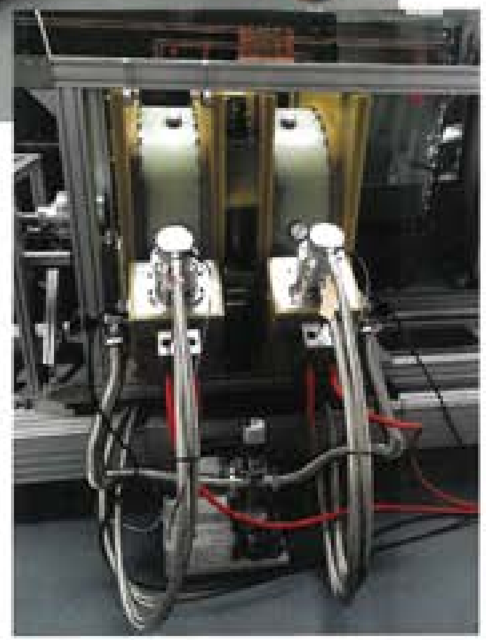
# PROTOTYPE TEST RESULTS

## Purpose:

- Integration of Magnet and Rotor assemblies
- In field testing of the liquid metal current collector system

## Proven:

- Liquid Metal Current Collector system works in conjunction with low field regions
- Tested up to 16,000A @ 2500 RPM



# EFFICIENCY ESTIMATES

**10 X MAGNETIC FIELD**

*Current Prototype*

$B \sim 1\ T\ Nominal$

$I = 20{,}000\ A$

$N = 3{,}600\ RPM$

$P = 200\ kW$

Mechanical Loss: 5kW

Electrical Loss: 2.5kW

Water Cooling System: 1.5kW

Cryogenic Cooling: 14 kW (2x7 kW)

Compressor Cooling: 6kW

Vacuum Pump: 1kW

Total: **30kW**

**Efficiency ~ 86 %**

*10 Tesla Prototype*

$B \sim 10\ T\ Nominal$

$I = 20{,}000\ A$

$N = 3{,}600\ RPM$

$P = 2000\ kW$

Mechanical Loss: 5kW

Electrical Loss: 2.5kW

Water Cooling System: 1.5kW

Cryogenic Cooling: 14 kW (2x7 kW)

Compressor Cooling: 6kW

Vacuum Pump: 1kW

Total: **30kW**

**Efficiency ~ 98 %**

# EFFICIENCY ESTIMATES

GUINA ENERGY GROUP

<u>*Current Prototype – 4x Current - 80,000 A*</u>

$B \sim 1\,T\ Nominal$

$I = 80{,}000\ A$

$N = 3{,}600\ RPM$

$P = 800\ kW$

Mechanical Loss: 5kW

Electrical Loss: 40kW

Water Cooling System: 14kW

Cryogenic Cooling: 14 kW (2x7 kW)

Compressor Cooling: 6kW

Vacuum Pump: 1kW

Total: **80kW**

**Efficiency ~ 91 %**

**10 X MAGNETIC FIELD**

<u>*10 Tesla Prototype*</u>

$B \sim 10\,T\ Nominal$

$I = 80{,}000\ A$

$N = 3{,}600\ RPM$

$P = 8000\ kW$

Mechanical Loss: 5kW

Electrical Loss: 40kW

Water Cooling System: 14kW

Cryogenic Cooling: 14 kW (2x7 kW)

Compressor Cooling: 6kW

Vacuum Pump: 1kW

Total: **80kW**

**Efficiency ~ 99 %**

# HOMOPOLAR TEST FACILITES

- 500 $m^2$ Laboratory facility to be able to test homopolar machines up to 240kW power level
- Key equipment and in-house test capabilities include…

# DIESEL GENERATOR

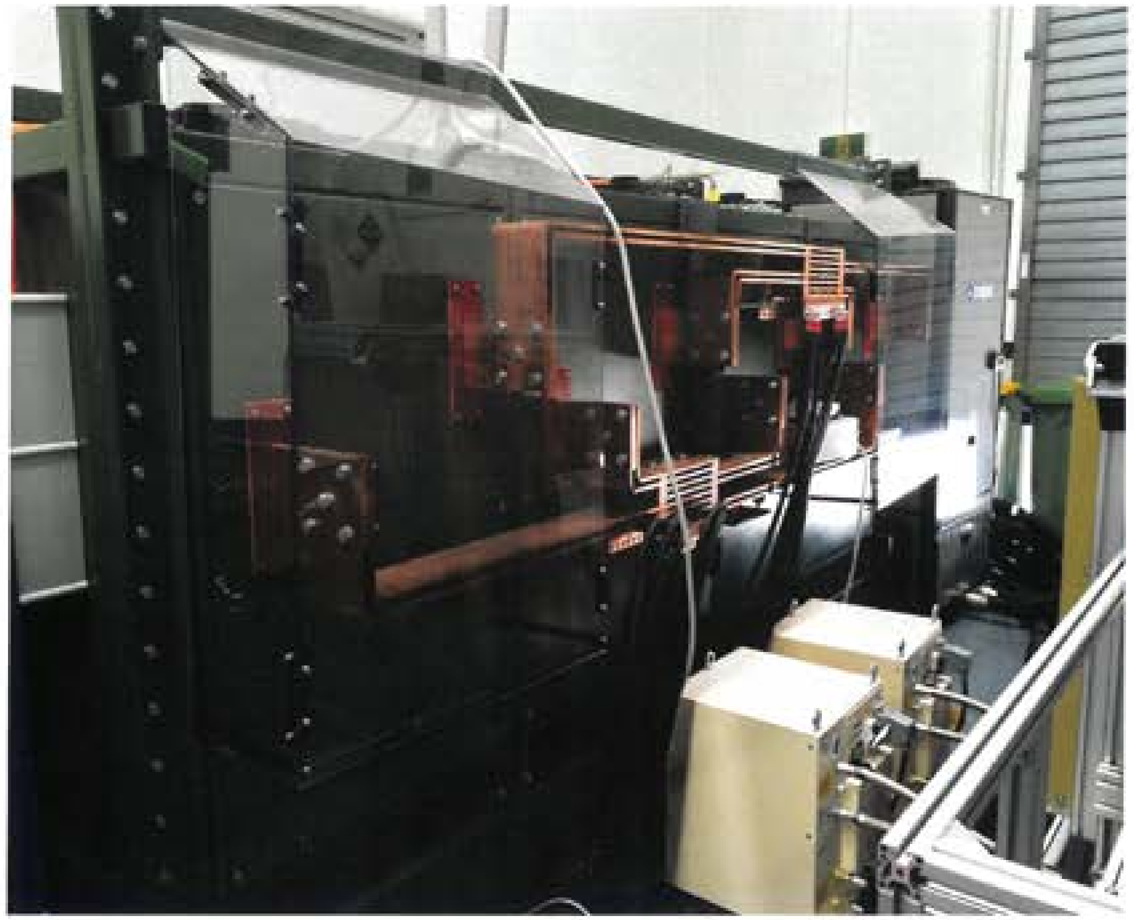
- 300 kW Diesel Generator to power all equipment required for full load testing



# HIGH CURRENT DC POWER SUPPLY & DYNAMOMETER

240 kW DC Power Supply that delivers 20,000A @ 12V

300 kW, 3600 RPM Eddy Current Dynamometer



# ARGON GLOVE BOX

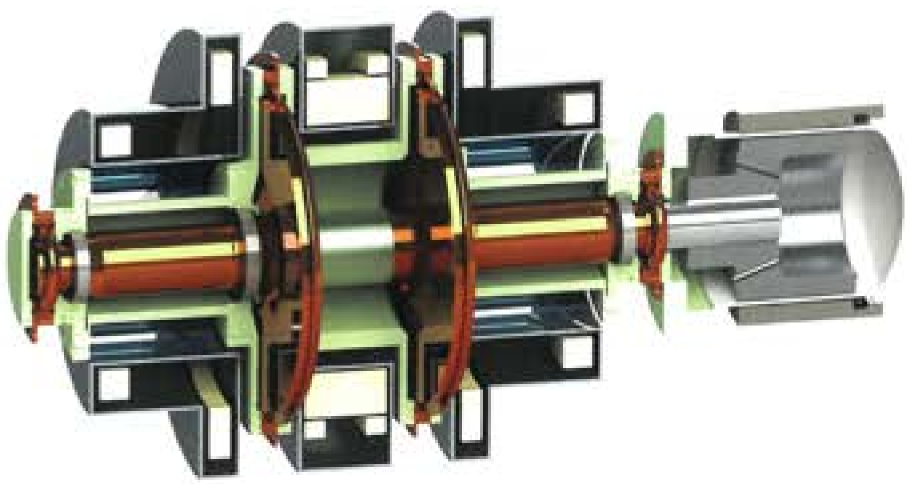
8 glove unit used for the development of our NaK liquid metal current collector system.


# HIGH SPEED TURBINES

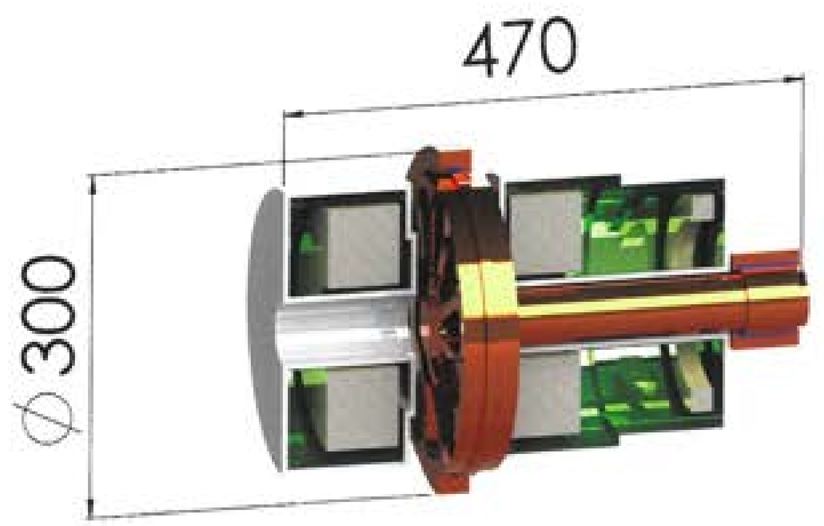
The High Speed Super-Tron Electromagnetic Turbine generators and motors, designed by Guina Energy, represent the simplest design implementations that encompass all of our unique technology.

These Electromagnetic Turbines have the highest power to weight of all the Guina Tron series of Electromagnetic Turbines due to their high speed of operation.

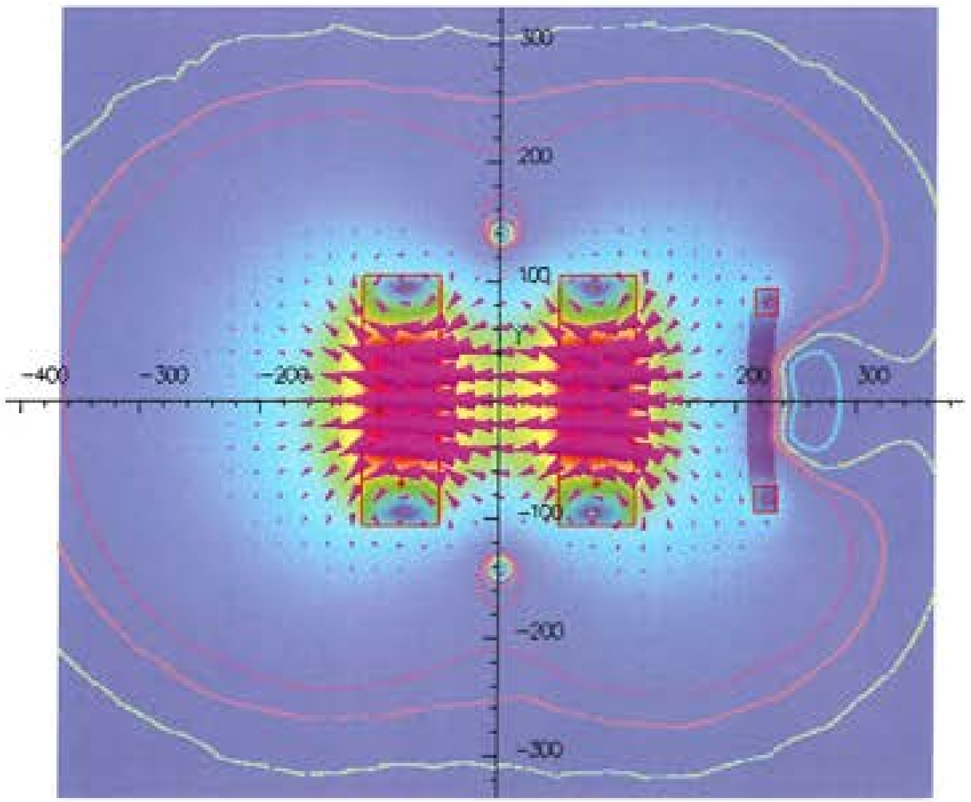
Our latest development program has resulted in the second generation of our High Speed Super-Tron Electromagnetic Turbine motors & generators which use the same magnetic drive field more than once in order to increase power density. These designs incorporate improvements in power to weight, a reduction of inter-coil forces and reduced superconducting wire length and cost.



# 1 MW G1 SUPER-TRON ELECTROMAGNETIC TURBINE

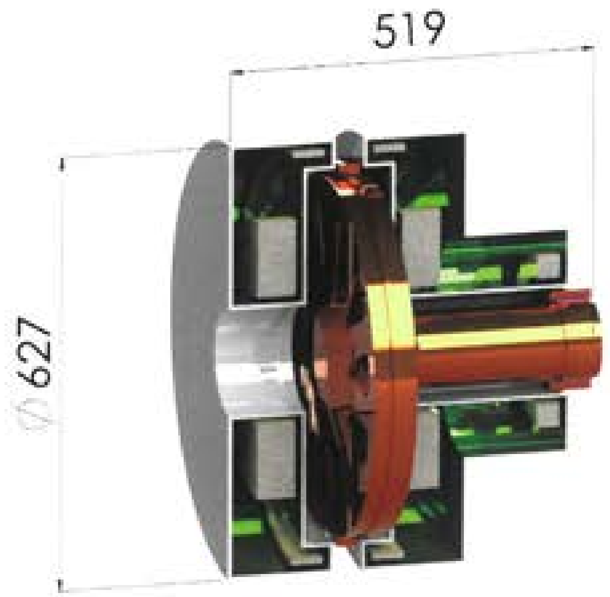



Overall Dimensions without Stray Field Cancelling Coils

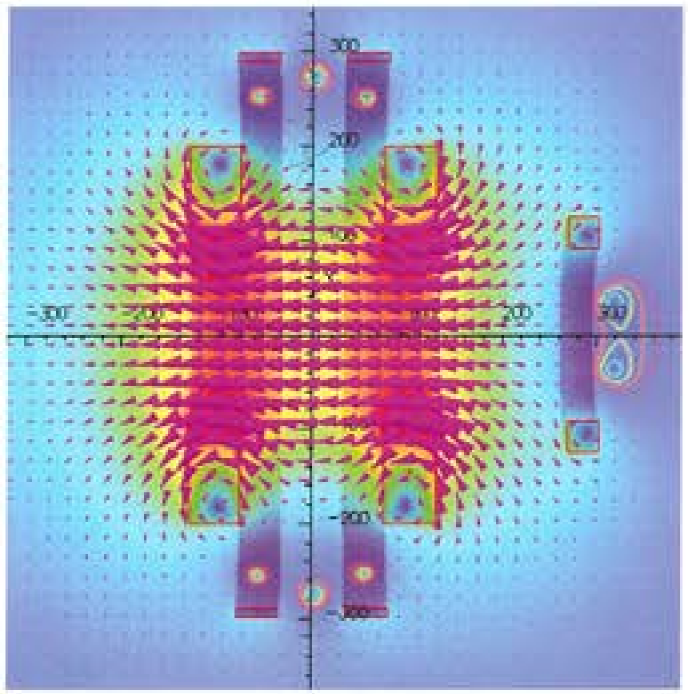



| | |
|---|---|
| Power (MW) | **1** |
| Speed (RPM) | **14966** |
| Total Current (A) | **40090** |
| LMB Current Density A/cm² | **500** |
| Max Rotor Tip Speed (m/s) | **200** |
| Max Coil Radius (mm) | **105** |
| Brush Contact Area (cm²) | **80** |
| Rotor Radius (mm) | **128** |
| Rotor Material | **Aluminium** |
| Rotor Weight Estimate (kg) | **6** |
| Super Conductive Wire | **$Nb_3Sn$** |
| SC Wire Length (km) based on ϕ 0.85 mm wire | **6.4** |
| SC Wire Weight (kg) | **26** |
| SC Wire Packing Factor | **0.6** |
| SC Wire current density (A/mm²) | **260** |
| Peak Field on wire (T) | **12** |
| Peak force between coils (kN) | **169** |
| Cryogenic Temperature (K) | **4** |

# 5 MW G1 SUPER-TRON ELECTROMAGNETIC TURBINE

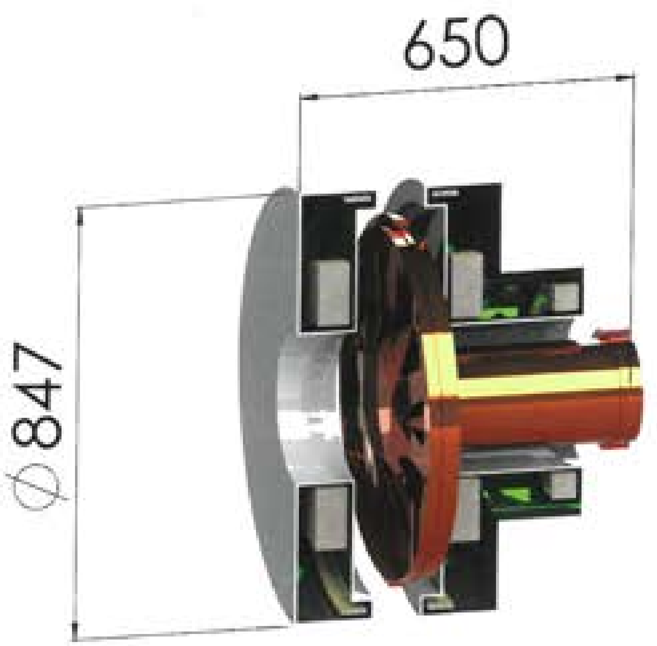



Overall Dimensions without Stray Field Cancelling Coils

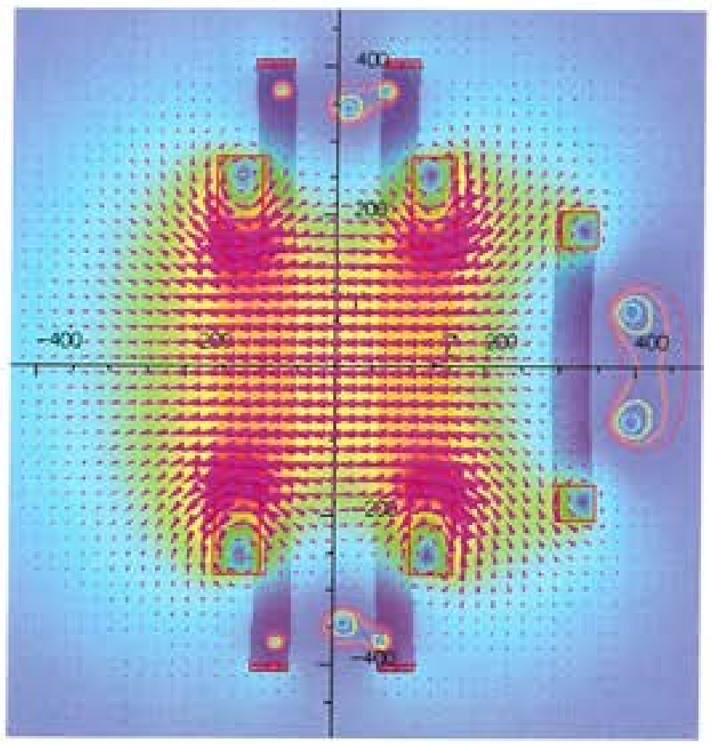


| | |
|---|---|
| Power (MW) | **5** |
| Speed (RPM) | **7507** |
| Total Current (A) | **79920** |
| LMB Current Density A/cm² | **500** |
| Max Rotor Tip Speed (m/s) | **200** |
| Max Coil Radius (mm) | **300** |
| Brush Contact Area (cm²) | **160** |
| Rotor Radius (mm) | **254** |
| Rotor Material | **Aluminium** |
| Rotor Weight Estimate (kg) | **30** |
| Super Conductive Wire | **$Nb_3Sn$** |
| SC Wire Length (km) based on ϕ 0.85 mm wire | **18** |
| SC Wire Weight (kg) | **72** |
| SC Wire Packing Factor | **0.6** |
| SC Wire current density (A/mm²) | **260** |
| Peak Field on wire (T) | **12** |
| Peak force between coils (kN) | **1100** |
| Cryogenic Temperature (K) | **4** |

# 10 MW G1 SUPER-TRON ELECTROMAGNETIC TURBINE

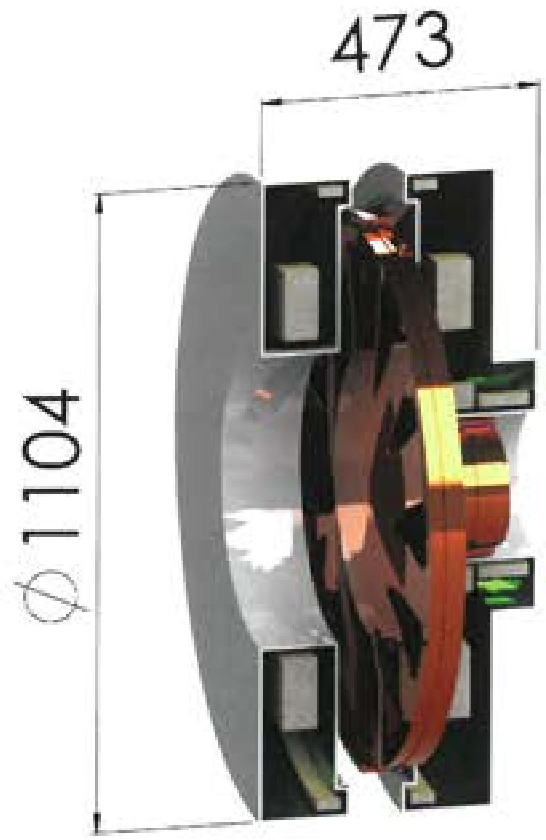


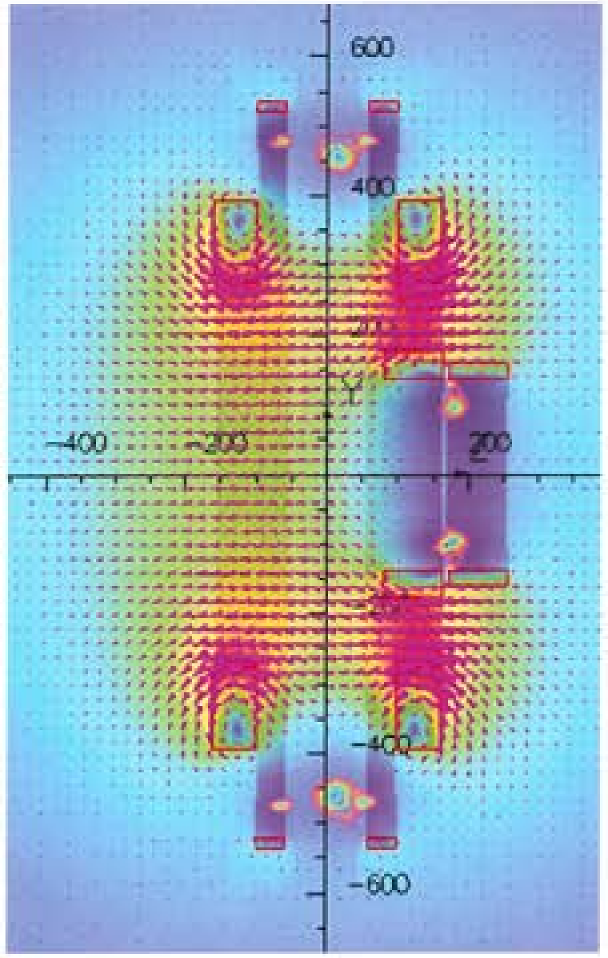

Overall Dimensions without Stray Field Cancelling Coils



| | |
|---|---|
| Power (MW) | **10** |
| Speed (RPM) | **5641** |
| Total Current (A) | **106358** |
| LMB Current Density A/cm² | **500** |
| Max Rotor Tip Speed (m/s) | **200** |
| Max Coil Radius (mm) | **409** |
| Brush Contact Area (cm²) | **213** |
| Rotor Radius (mm) | **339** |
| Rotor Material | **Aluminium** |
| Rotor Weight Estimate (kg) | **85** |
| Super Conductive Wire | **$Nb_3Sn$** |
| SC Wire Length (km) based on ϕ 0.85 mm wire | **32.6** |
| SC Wire Weight (kg) | **130** |
| SC Wire Packing Factor | **0.6** |
| SC Wire current density (A/mm²) | **260** |
| Peak Field on wire (T) | **12** |
| Peak force between coils (kN) | **2666** |
| Cryogenic Temperature (K) | **4** |

# 20 MW G1 SUPER-TRON ELECTROMAGNETIC TURBINE

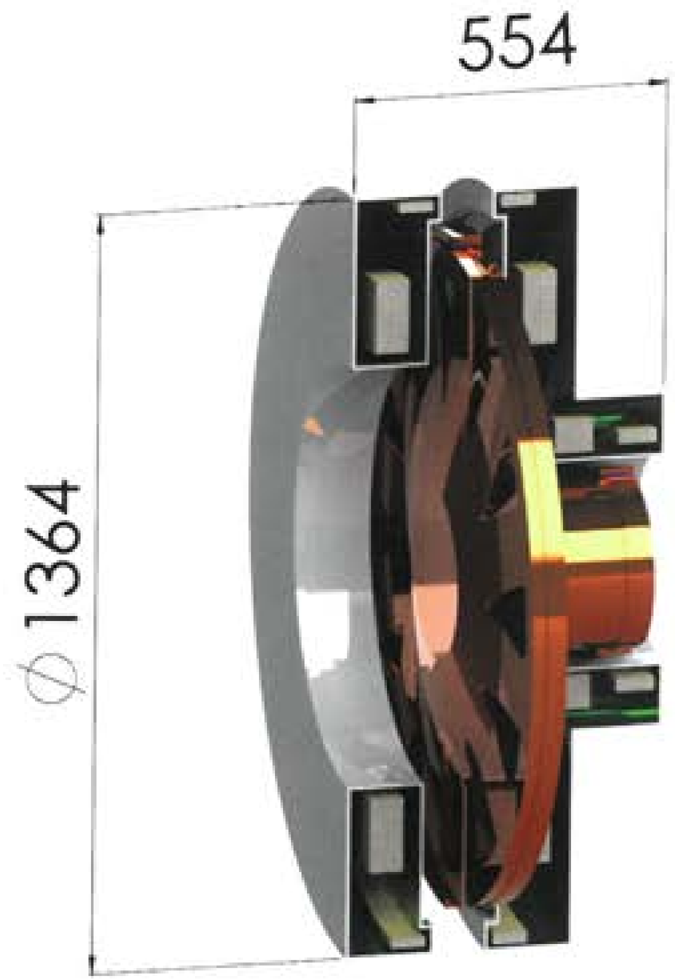


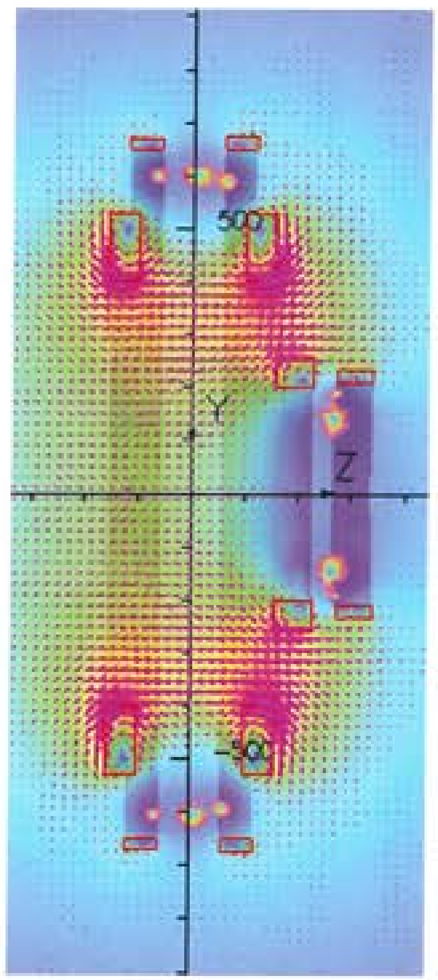




Overall Dimensions without Stray Field Cancelling Coils

| | |
|---|---|
| Power (MW) | **20** |
| Speed (RPM) | **4186** |
| Total Current (A) | **143312** |
| LMB Current Density A/cm$^2$ | **500** |
| Max Rotor Tip Speed (m/s) | **200** |
| Max Coil Radius (mm) | **537** |
| Brush Contact Area (cm$^2$) | **287** |
| Rotor Radius (mm) | **456** |
| Rotor Material | **Aluminium** |
| Rotor Weight Estimate (kg) | **106** |
| Super Conductive Wire | **$Nb_3Sn$** |
| SC Wire Length (km) based on $\phi$ 0.85 mm wire | **50.4** |
| SC Wire Weight (kg) | **200** |
| SC Wire Packing Factor | **0.6** |
| SC Wire current density (A/mm$^2$) | **260** |
| Peak Field on wire (T) | **12** |
| Peak force between coils (kN) | **3967** |
| Cryogenic Temperature (K) | **4** |

# 40 MW G1 SUPER-TRON ELECTROMAGNETIC TURBINE




Overall Dimensions without Stray Field Cancelling Coils

| | |
|---|---|
| Power (MW) | 40 |
| Speed (RPM) | 3295 |
| Total Current (A) | 182085 |
| LMB Current Density A/cm² | 500 |
| Max Rotor Tip Speed (m/s) | 200 |
| Max Coil Radius (mm) | 671 |
| Brush Contact Area (cm²) | 364 |
| Rotor Radius (mm) | 580 |
| Rotor Material | Aluminium |
| Rotor Weight Estimate (kg) | 214 |
| Super Conductive Wire | $Nb_3Sn$ |
| SC Wire Length (km) based on ϕ 0.85 mm wire | 78.5 |
| SC Wire Weight (kg) | 312 |
| SC Wire Packing Factor | 0.6 |
| SC Wire current density (A/mm²) | 260 |
| Peak Field on wire (T) | 12 |
| Peak force between coils (kN) | 8939 |
| Cryogenic Temperature (K) | 4 |

# 60 MW G1 SUPER-TRON ELECTROMAGNETIC TURBINE

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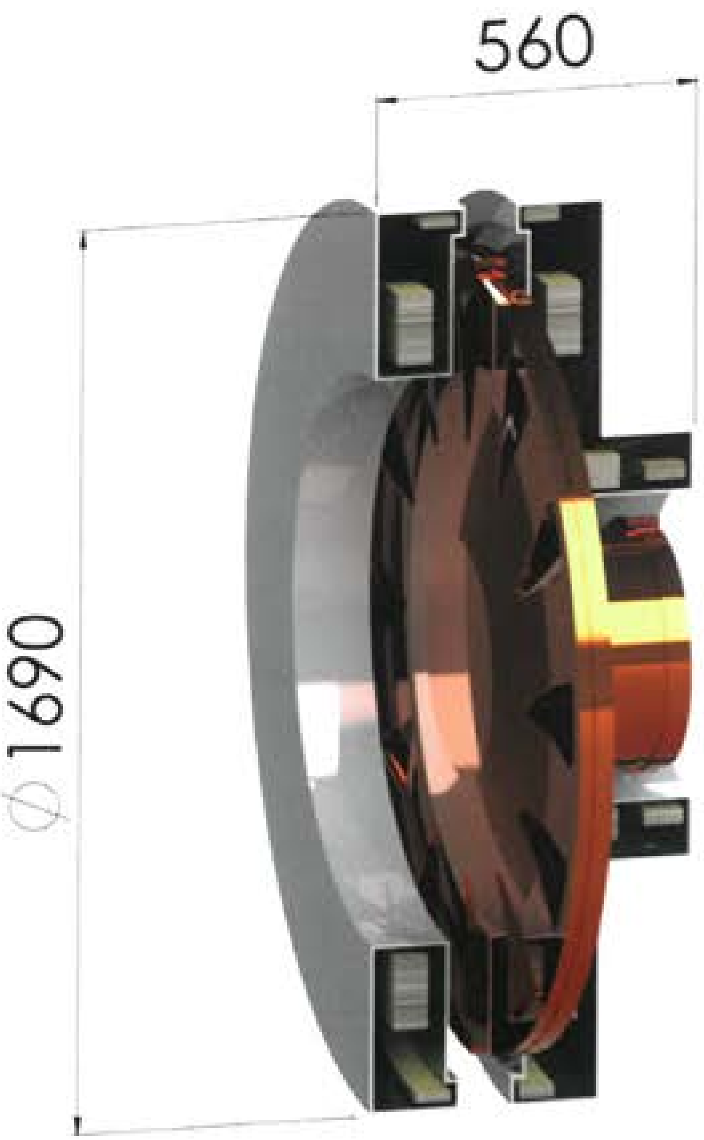
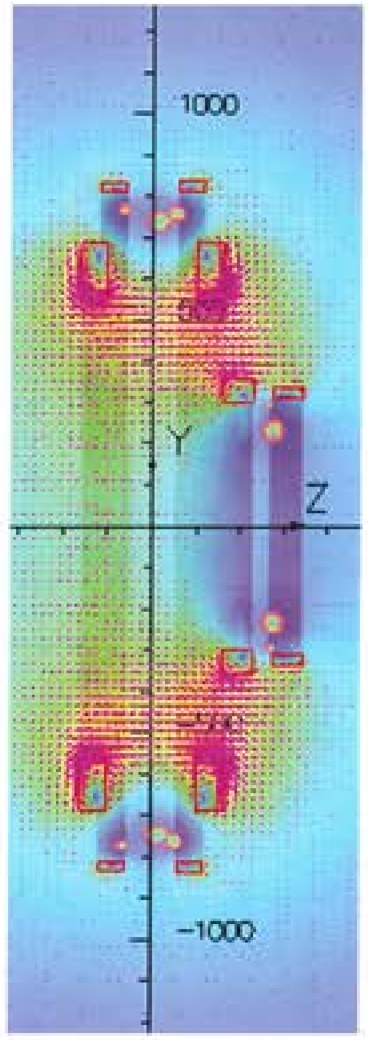



Overall Dimensions without Stray Field Cancelling Coils

| | |
|---|---|
| Power (MW) | **60** |
| Speed (RPM) | **2639** |
| Total Current (A) | **227294** |
| LMB Current Density A/cm$^2$ | **500** |
| Max Rotor Tip Speed (m/s) | **200** |
| Max Coil Radius (mm) | **834** |
| Brush Contact Area (cm$^2$) | **455** |
| Rotor Radius (mm) | **724** |
| Rotor Material | **Aluminium** |
| Rotor Weight Estimate (kg) | **375** |
| Super Conductive Wire | **$Nb_3Sn$** |
| SC Wire Length (km) based on $\phi$ 0.85 mm wire | **111** |
| SC Wire Weight (kg) | **441** |
| SC Wire Packing Factor | **0.6** |
| SC Wire current density (A/mm$^2$) | **260** |
| Peak Field on wire (T) | **12** |
| Peak force between coils (kN) | **13876** |
| Cryogenic Temperature (K) | **4** |

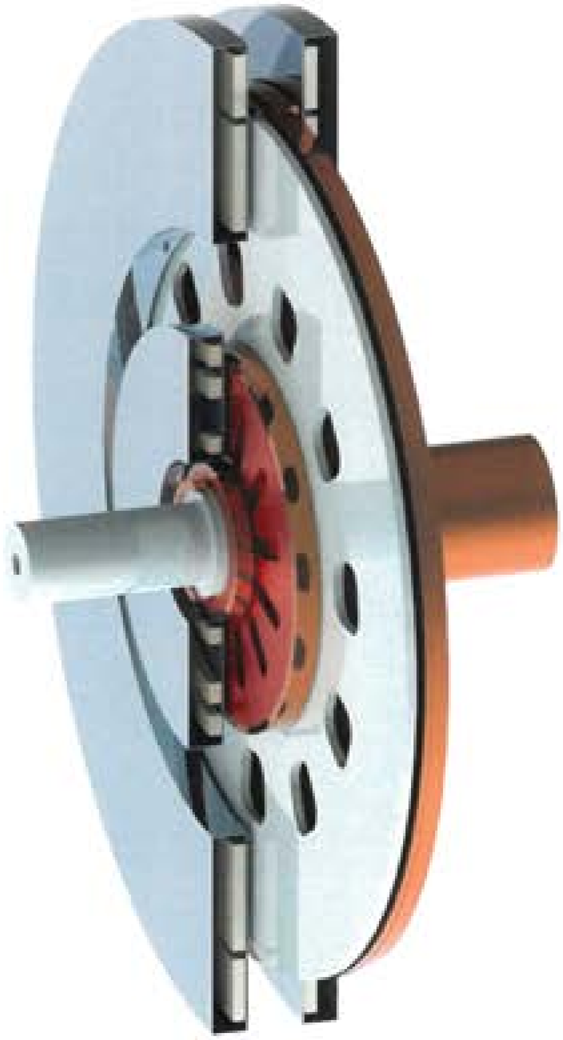
# PRESENTING:
# ELECTROMAGNETIC POWER CONVERTERS & GEARBOXES

# SECTION OUTLINE

- What is an Electromagnetic Power Converter?
- DC-DC Transformer
- Electromagnetic Gearbox
- 3 Stage System
- Prototype Development
- Application Examples

# ELECTROMAGNETIC POWER CONVERTER

## What is an Electromagnetic Power Converter?



- Contactless electromagnetic gearbox for mechanical power transmission.
- DC – DC converter (step up or down DC voltages, effectively a DC 'transformer').
- DC Generator (high torque, low speed applications – e.g. Direct Drive Wind Turbine).
- DC Motor (high torque, low speed applications – e.g. Direct Drive Ship Propulsion).

# ELECTROMAGNETIC POWER CONVERTER

Our Electromagnetic Power Converters can be used as transformers for stepping up or down DC voltage and current to transform electrical energy to a form suitable for the intended application. These converters are very efficient and simple devices that use no power electronics and have very little heat loss. They are ideal DC transformers.

In addition to stepping up and down DC Voltage and Current our Electromagnetic Power Converters can also step up and down speed and mechanical torque thereby functioning as an Electromagnetic Gearbox.

Our Electromagnetic Power Converters and Gearboxes expand the range in which our devices can operate to include low speed and high torque applications.

Our Electromagnetic Power Converters have application across a wide range of industries including:

- The production of hydrogen fuel via electrolysis.
- Electrowinning.
- Smelting.
- Electroplating.
- Electromagnetic gearboxes for mechanical transfer.

# ELECTROMAGNETIC POWER CONVERTER

In tandem with an AC generator or motor they can be used as AC/DC or DC/AC converters. Additionally, they can operate as an electromagnetic mechanical gearbox (high speed to low speed or the reverse) and have many other industrial applications. As they are pure DC devices they operate without any voltage ripple.

This technology can also be coupled to AC generators in existing wind turbine installations in order to eliminate the need for electronic power converters and reduce thermal losses.

The advantages of our Electromagnetic Gearboxes include:

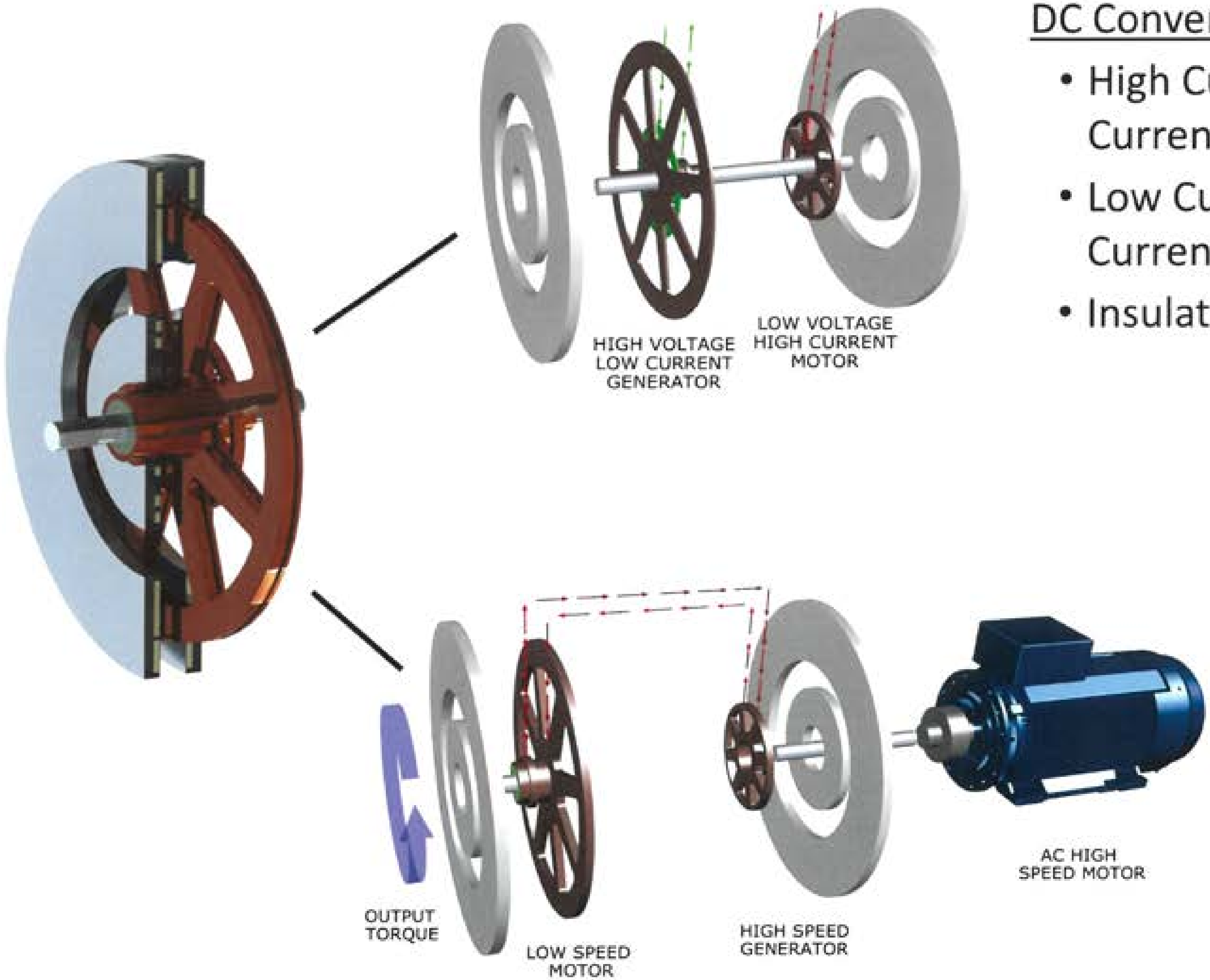
- They can be designed for a wide range of speeds from 6 RPM to 50,000+ RPM at power levels above 10kW.
- They can operate across a wide range of mechanical step up (1:40) or step down (40:1) ratios or as pure mechanical isolation (1:1) shock-proofing the system.
- They are fully reversible and able to operate in either step up or step down configuration.

# ELECTROMAGNETIC POWER CONVERTER

- They perform mechanical isolation between the input and output shafts as power transmission is accomplished electromagnetically. This electromagnetic coupling isolates the devices from mechanical shock from the input or output load.
- This mechanical isolation provides inherent transient overload protection in the event of fault conditions. It also significantly reduces the number of contacting surfaces and associated mechanical wear.
- They have the potential for electronically adjustable ratios – achieved by varying the relative strengths of the driving magnetic fields.
- They produce far lower noise and vibration when compared with competing technologies.
- They can transfer mechanical power more efficiently than conventional gearboxes, particularly at high speed and at large gear ratios.

Our Electromagnetic Gearbox technology is particularly suited to high speed applications, overcoming some of the major shortfalls of high speed mechanical power transmission.

# ELECTROMAGNETIC POWER CONVERTER




## DC Converters

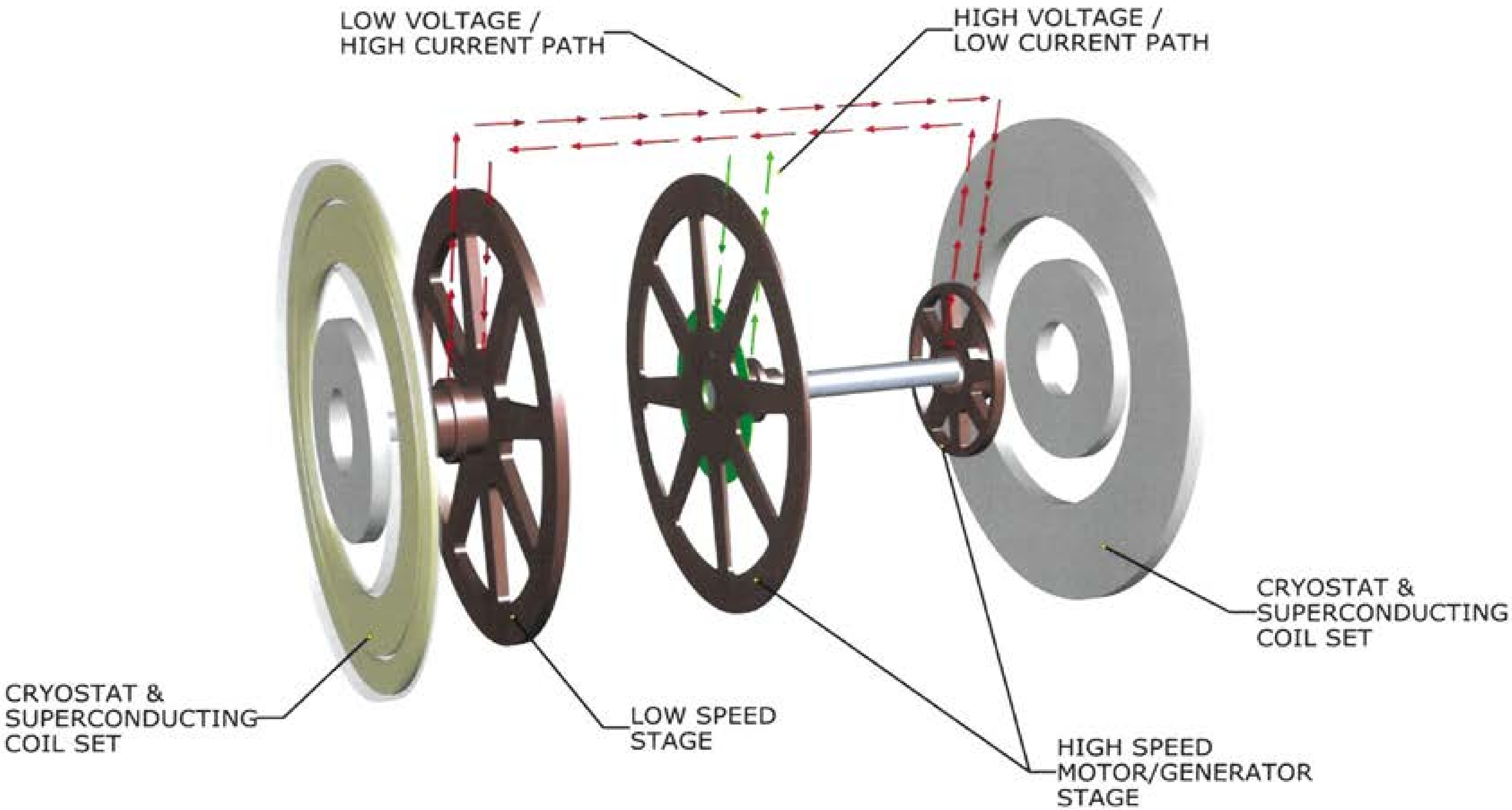
- High Current, Low Voltage to Low Current, High Voltage
- Low Current, High Voltage to High Current, Low Voltage
- Insulation of circuits

## Gearbox

- Low RPM to high RPM
- High RPM to low RPM
- Mechanical disconnection

# ELECTROMAGNETIC CONVERTERS & GEARBOXES

## NOMENCLATURE



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## DC TRANSFORMER

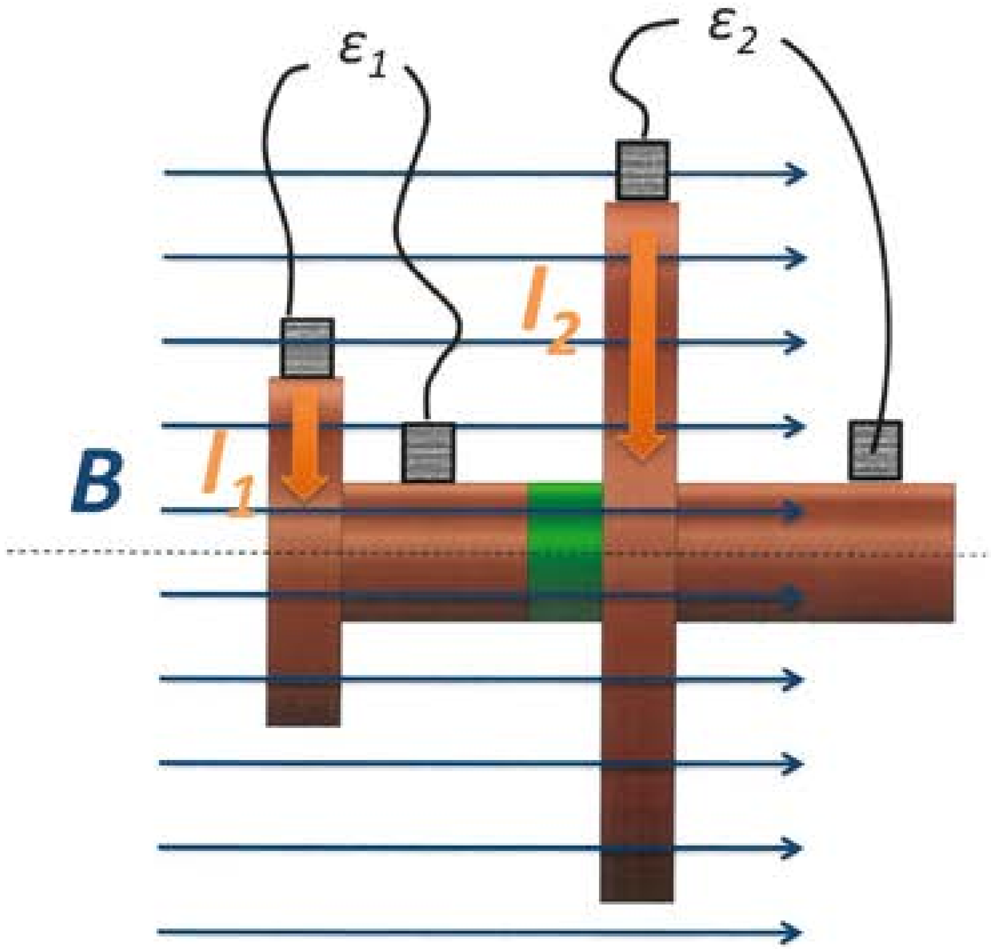
| Motor | | Generator |
|---|---|---|
| $P_1 = \tau_1 \omega$ | = | $P_2 = \tau_2 \omega$ |

$$\tau_1 = I_1 B \left( \frac{{r_{out,1}}^2 - {r_{in,1}}^2}{2} \right)$$

$$\tau_2 = I_2 B \left( \frac{{r_{out,2}}^2 - {r_{in,2}}^2}{2} \right)$$

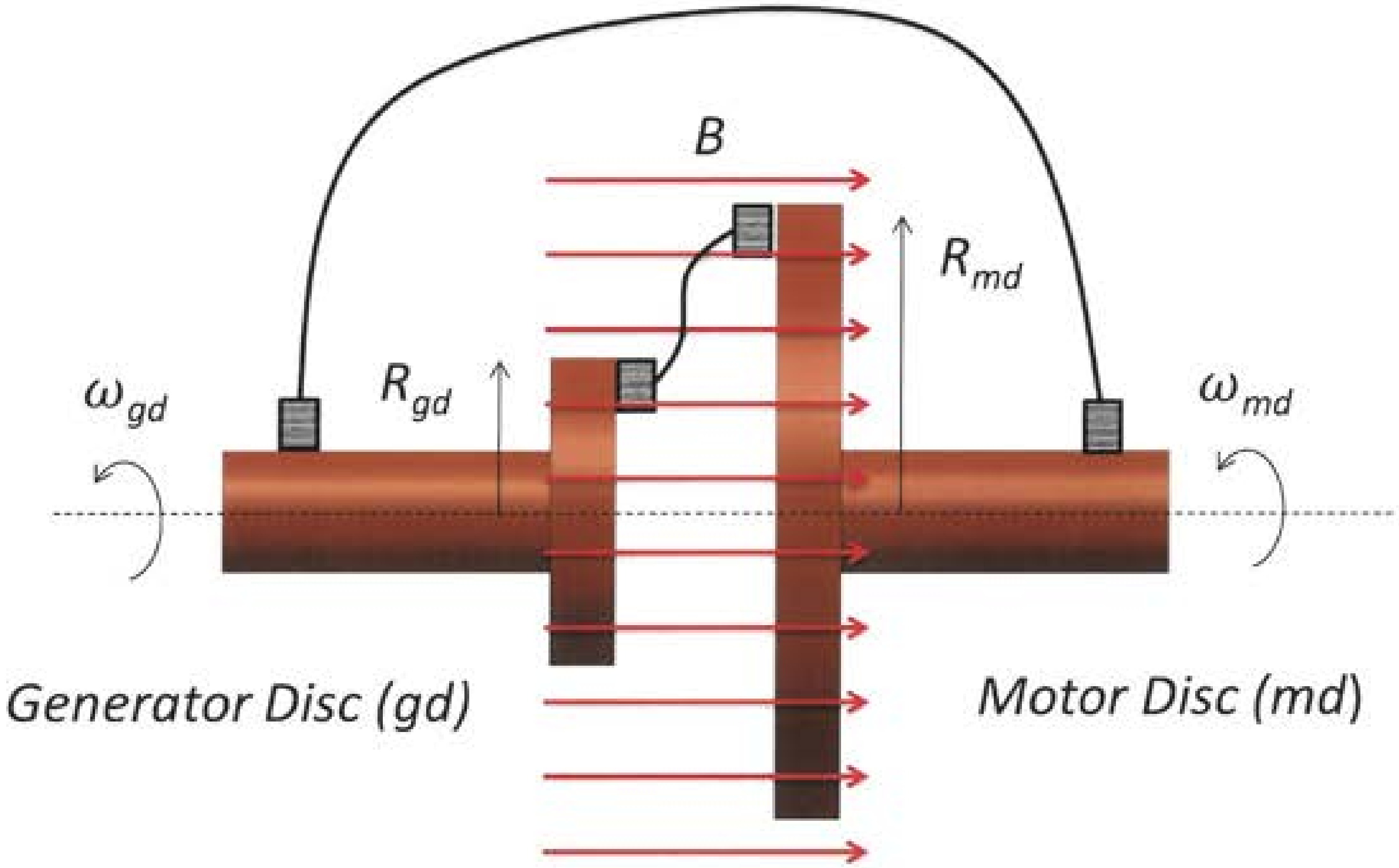
$$\boldsymbol{I_1\left({r_{out,1}}^2 - {r_{in,1}}^2\right) = I_2\left({r_{out,2}}^2 - {r_{in,2}}^2\right)}$$

$$\boldsymbol{V_1\left({r_{out,2}}^2 - {r_{in,2}}^2\right) = V_2\left({r_{out,1}}^2 - {r_{in,1}}^2\right)}$$




| Motor Disc | Generator Disc | Current | Voltage |
|---|---|---|---|
| Small | Large | Lower | Higher |
| Large | Small | Higher | Lower |

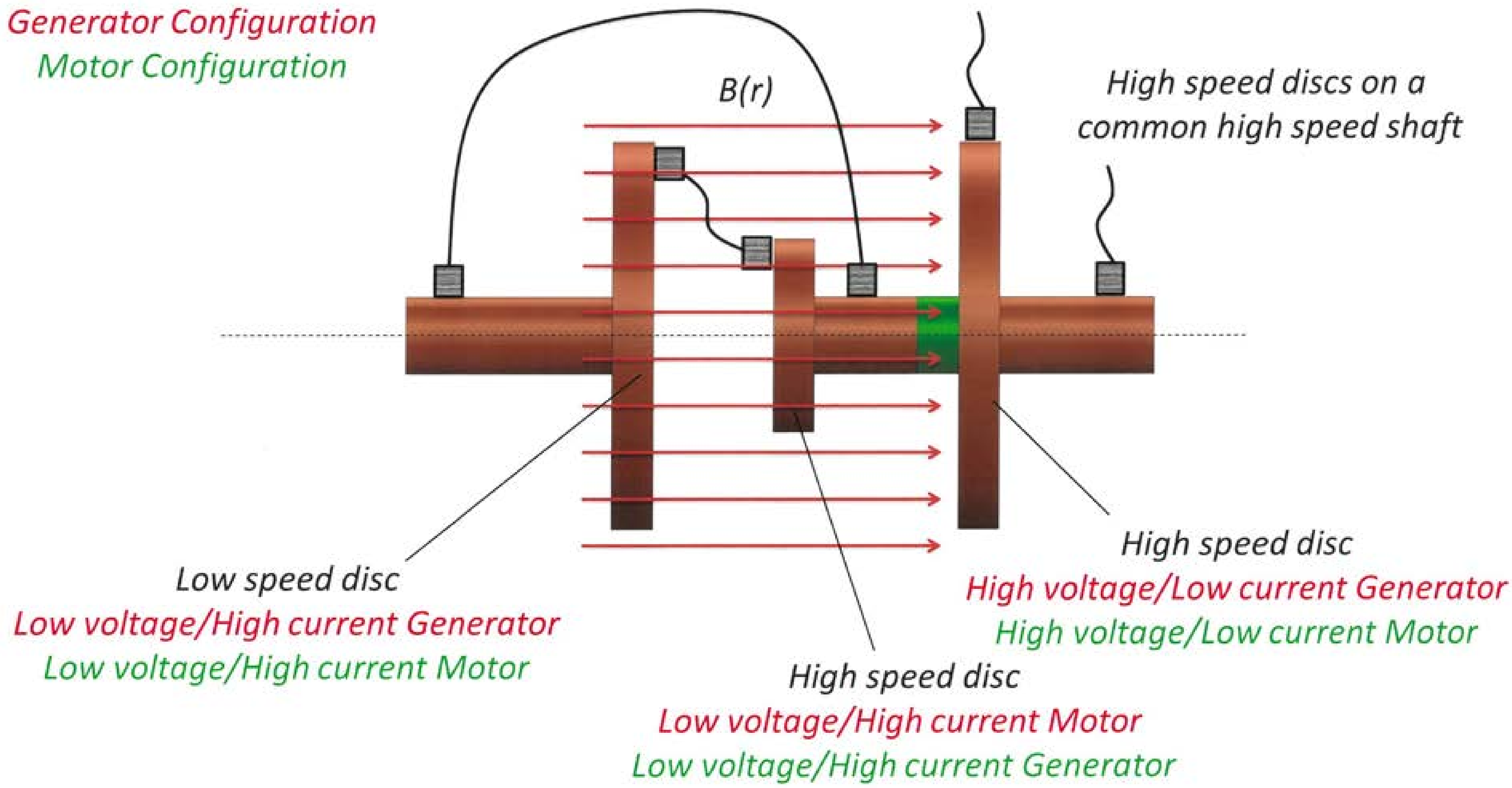
# 2 STAGE ELECTROMAGNETIC CONVERTER



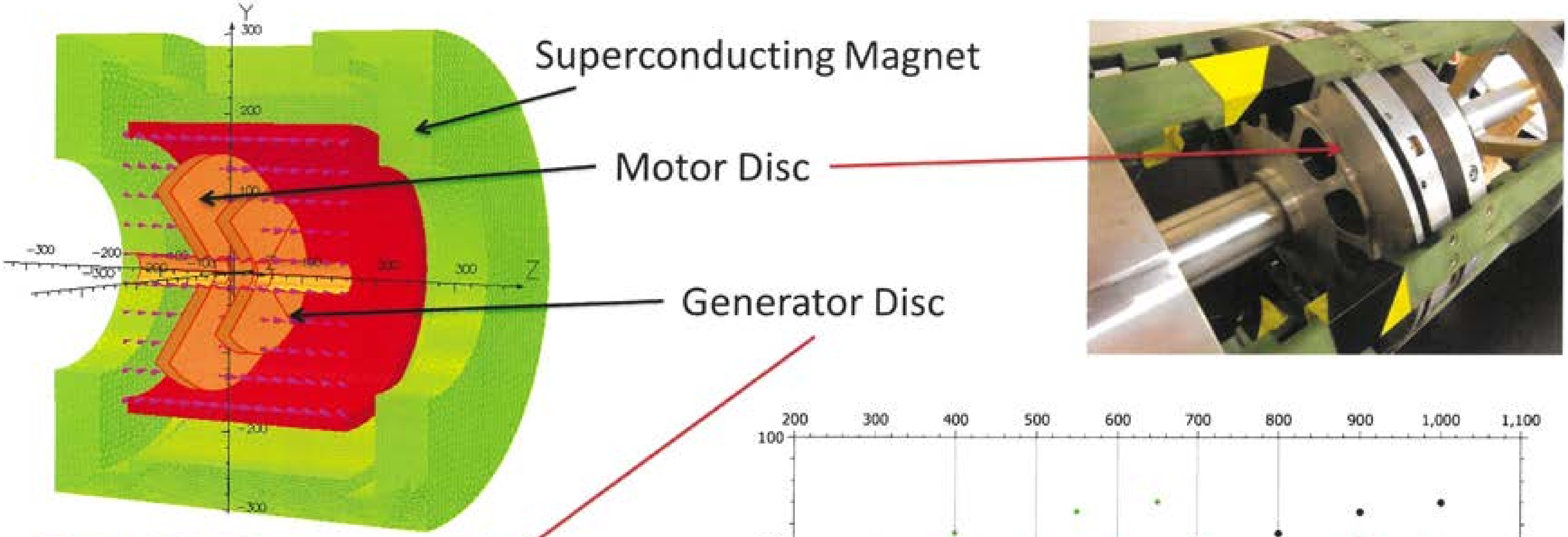

If the generator disc is used to power the motor disc: $\frac{R_{gd}^2}{2} B\omega_{gd} = \frac{R_{md}^2}{2} B\omega_{md}$

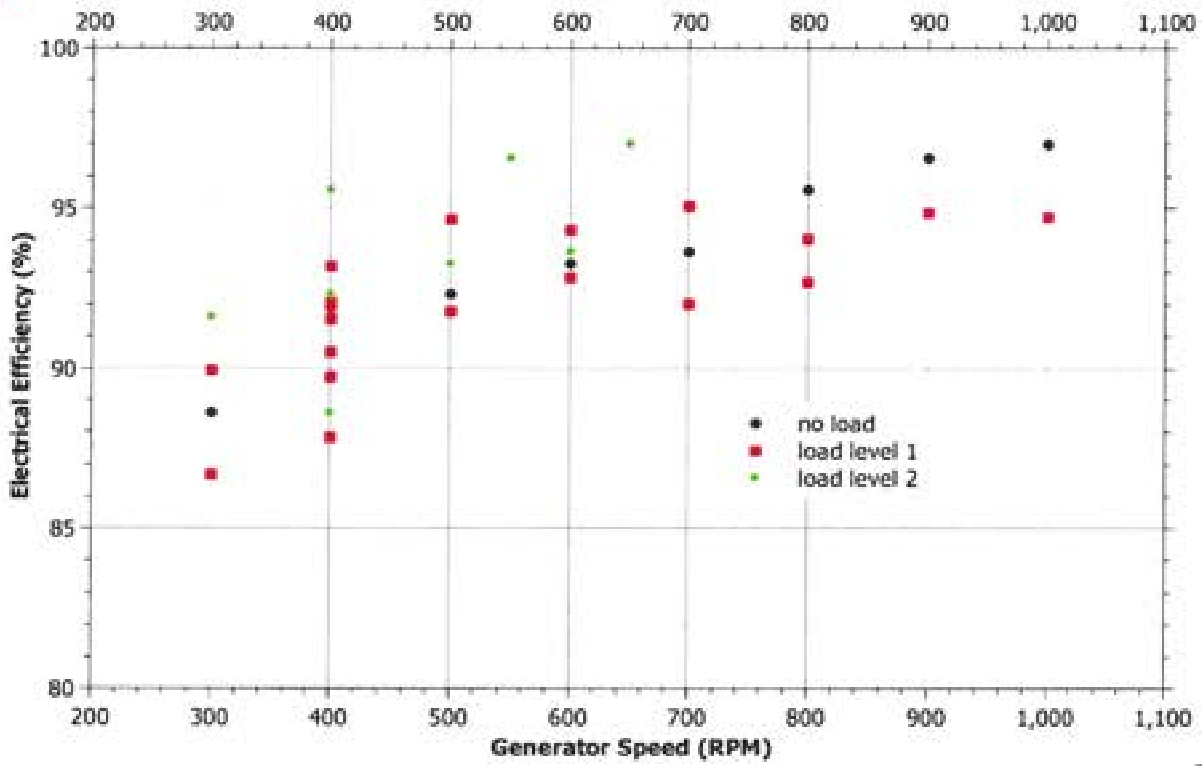
Resultant speed ratio between the motor and generator disc: $\omega_{md} = \frac{R_{gd}^2}{R_{md}^2}\omega_{gd}$

# 3 STAGE ELECTROMAGNETIC CONVERTER

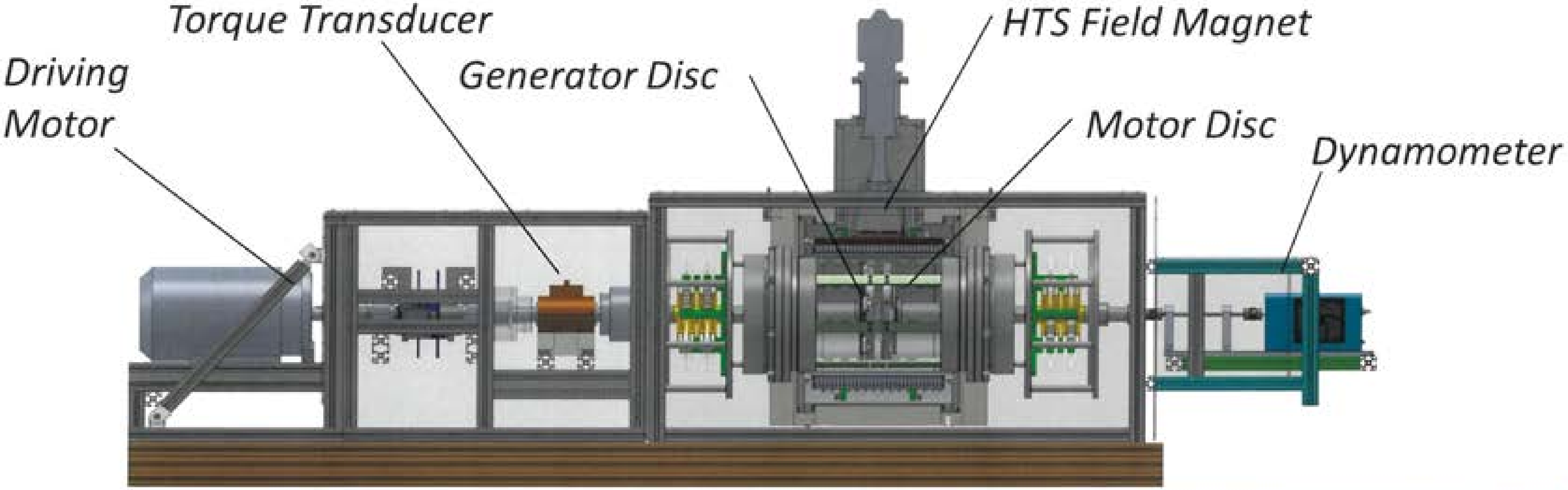


# Gearbox Test Run with Alpha-Tron Test Magnet



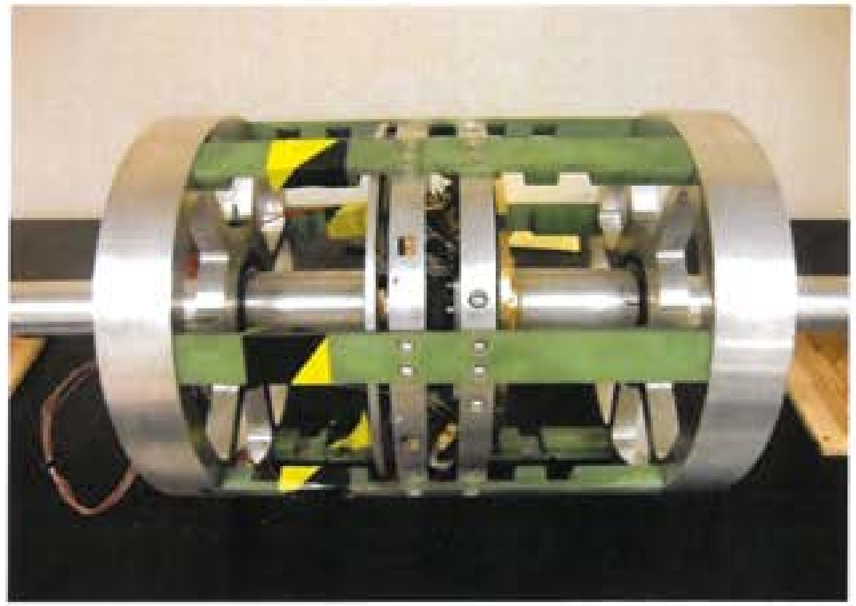



# ELECTROMAGNETIC POWER CONVERTER





Proof of Concept Test Platform



Generator Disc & Motor Disc

# PROTOTYPE DEVELOPMENT

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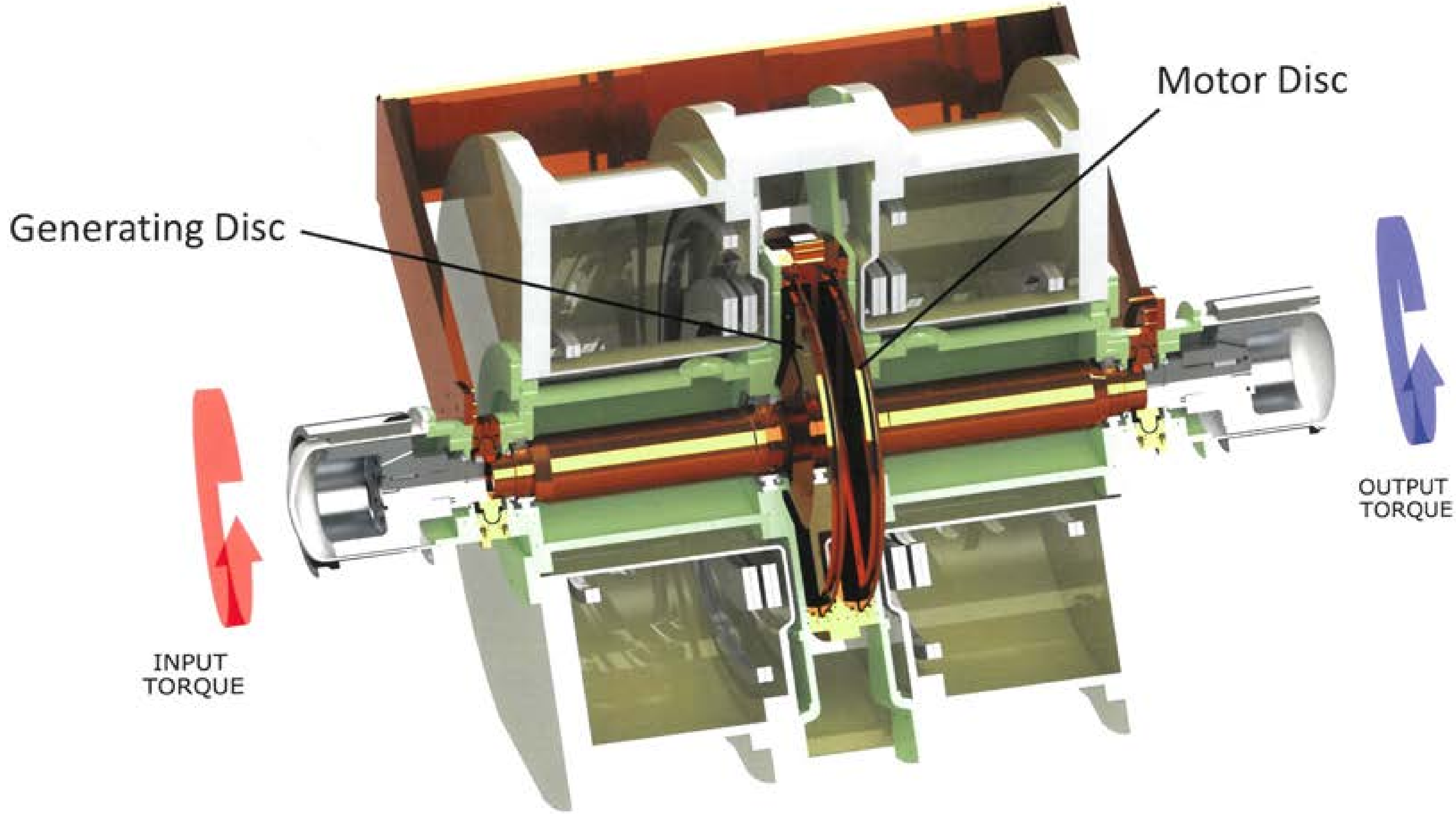
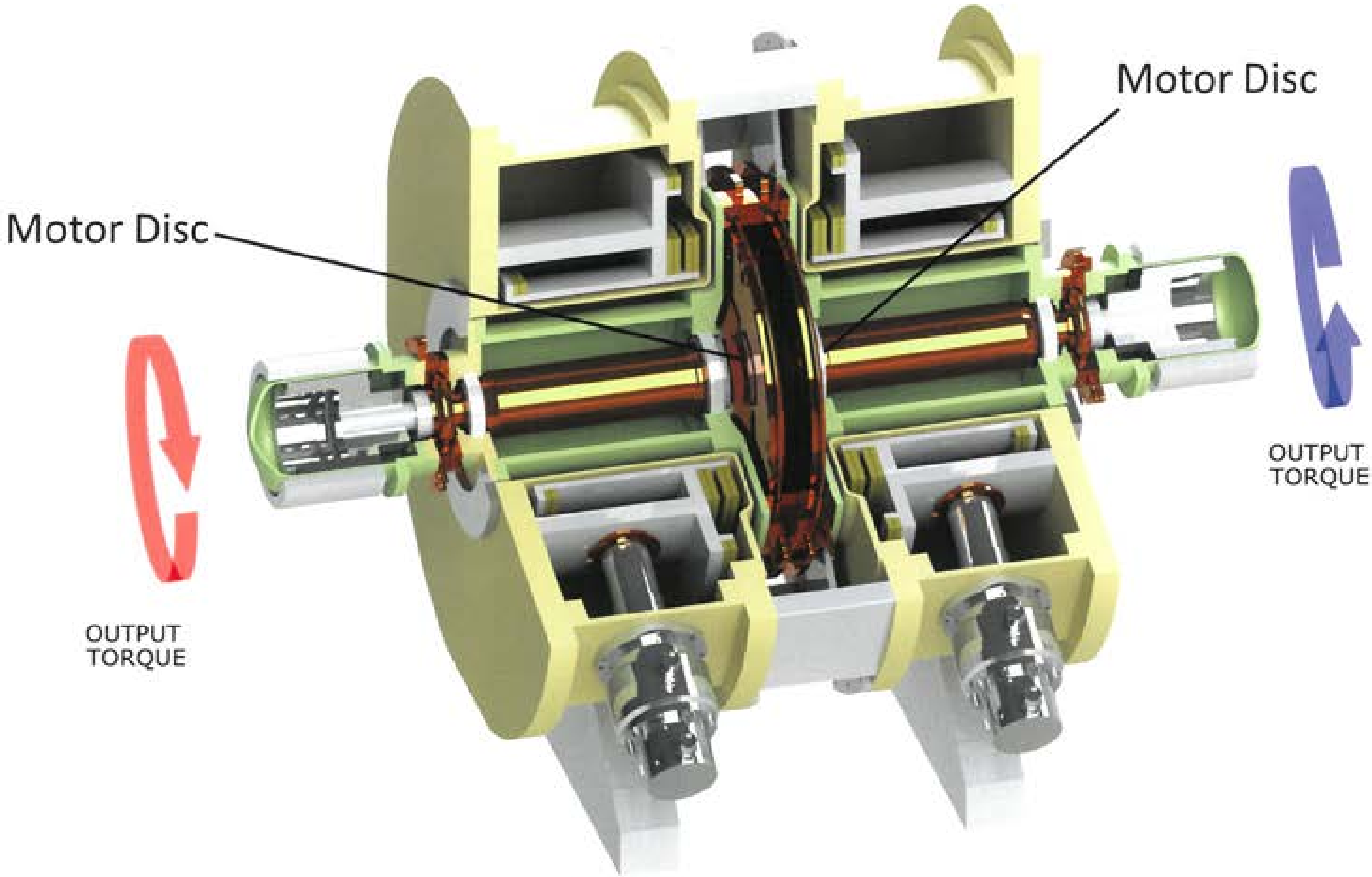
Two Discs in our existing superconducting magnet – Generator/Motor




Under construction

# PROTOTYPE DEVELOPMENT

## Two Discs in our existing superconducting magnet – Counter Rotating Motor

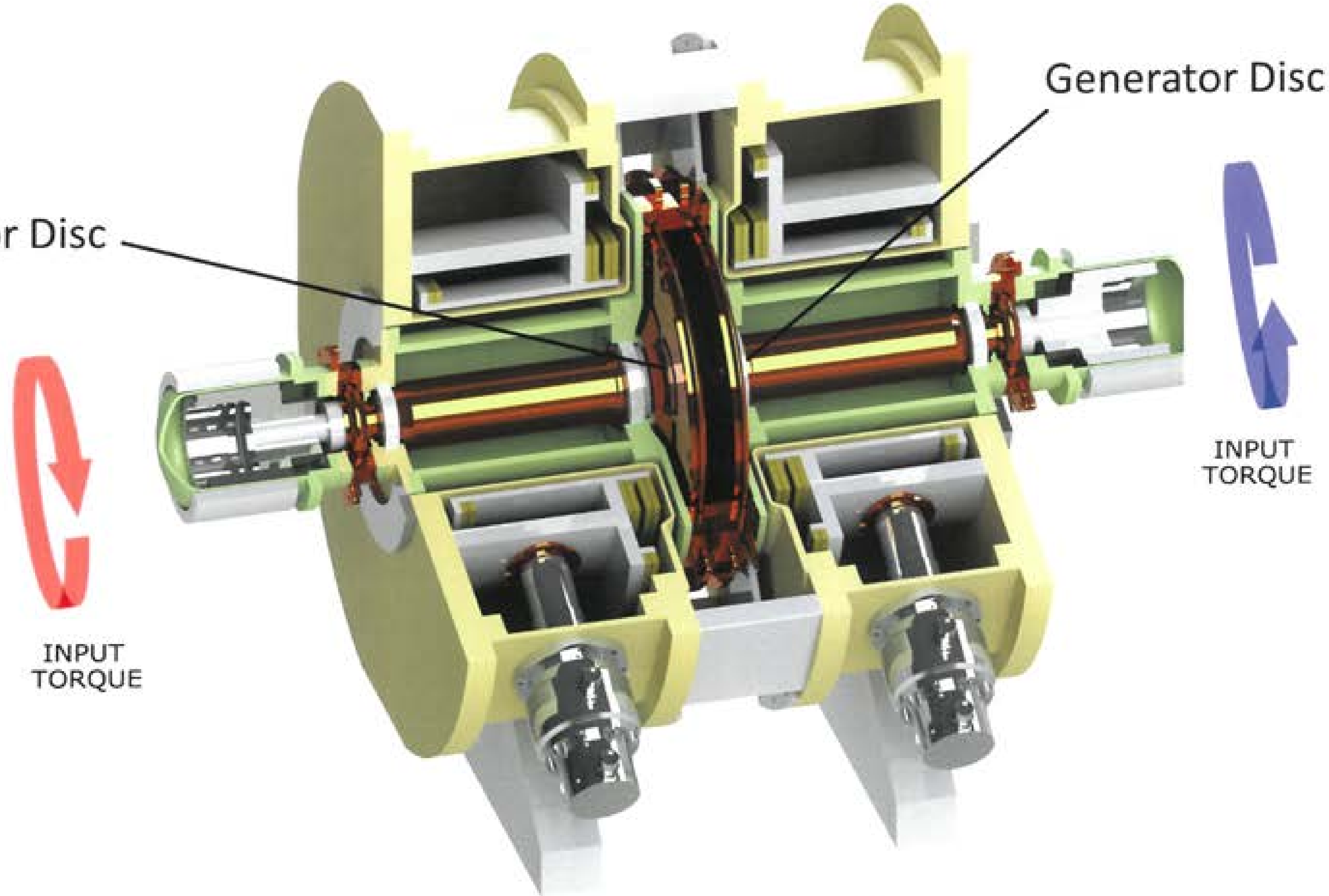



Under construction

# PROTOTYPE DEVELOPMENT

GUINA ENERGY GROUP

## Two Discs in our existing superconducting magnet – Generator/Generator



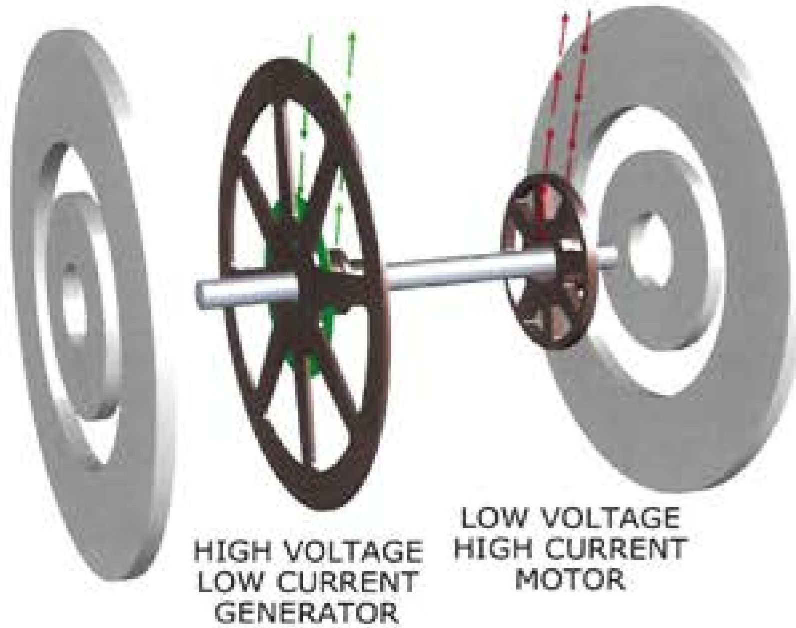

Under construction

# LOW VOLTAGE DC ⇔ HIGH VOLTAGE DC

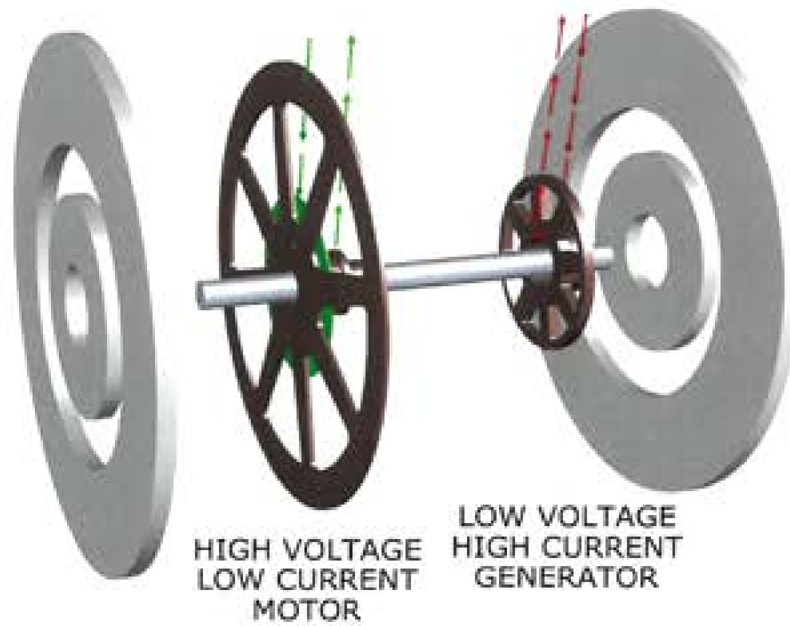
GUINA ENERGY GROUP

## Step up or down of DC Voltage and Current

2 Stage – Electromagnetic Power Converters Low Voltage DC- High Voltage DC

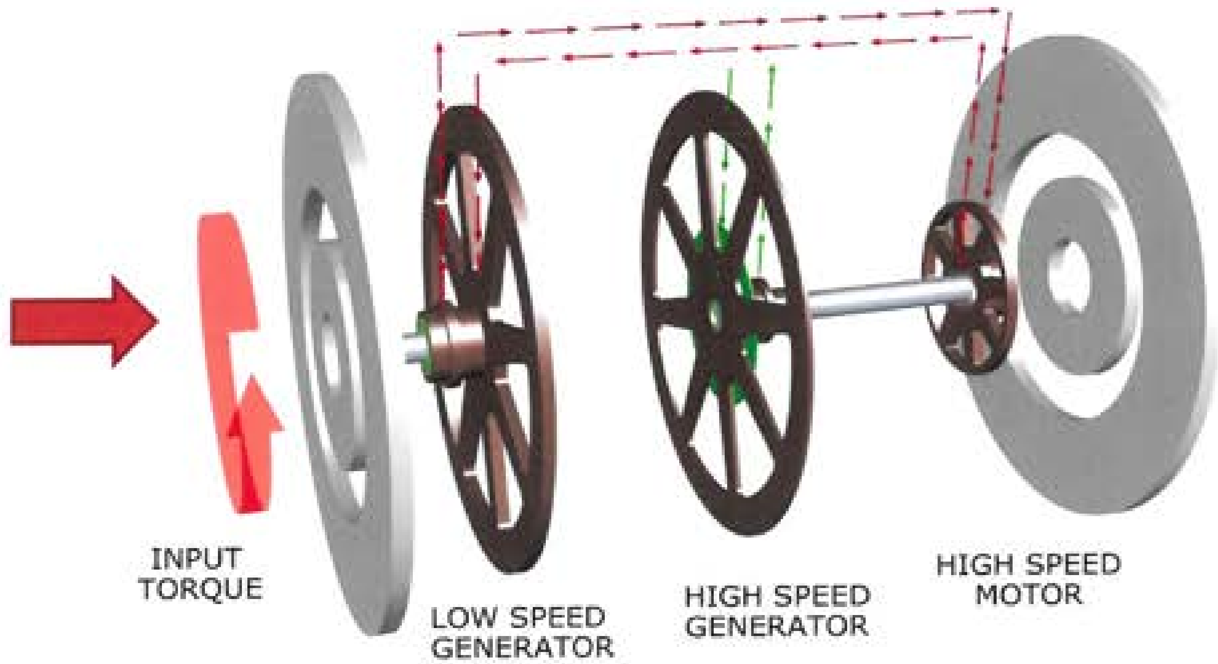



2 Stage – Electromagnetic Power Converters High Voltage DC- Low Voltage DC

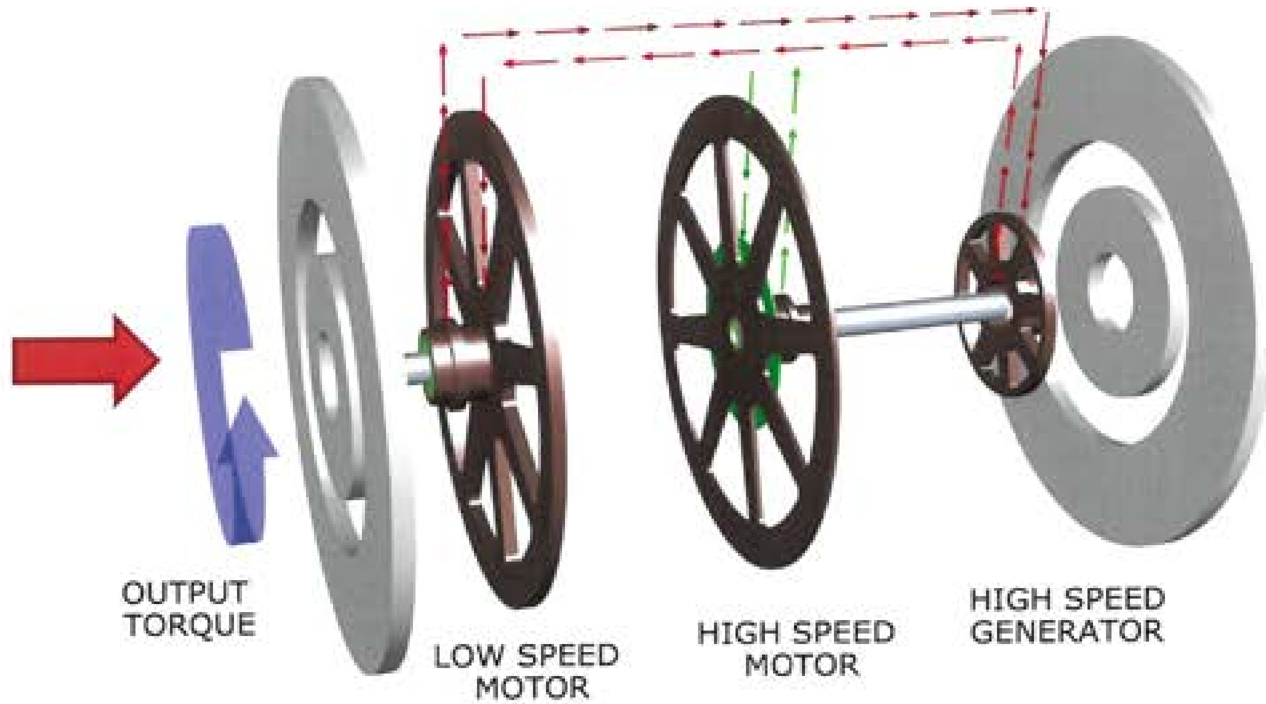


# 3 STAGE - LOW SPEED HIGH TORQUE ⇔ HIGH VOLTAGE DC

Low Speed High Torque
Input to High Voltage
DC Output
(Wind Turbine Generator)



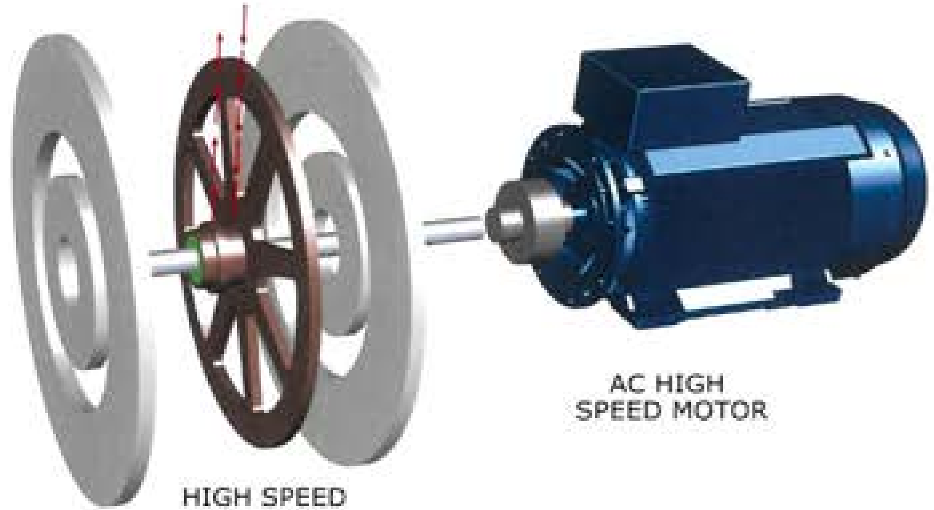

High Voltage DC Input to
Low Speed High Torque
Output
(Marine Pod Propulsion)



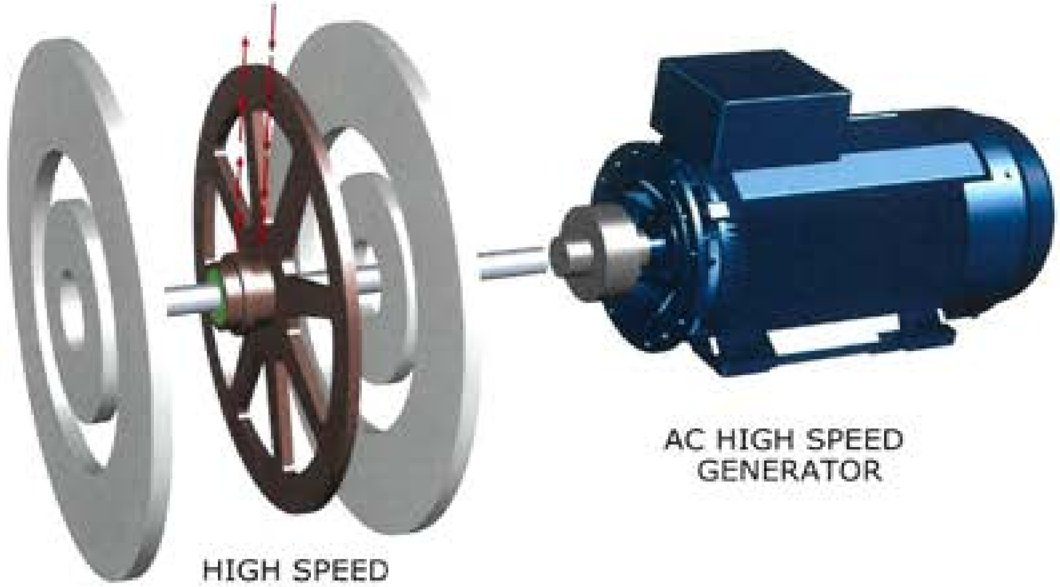
# POWER CONVERTERS AC ⇔ DC

## AC to DC conversion

2 Stage – Electromagnetic Power Converters AC-DC

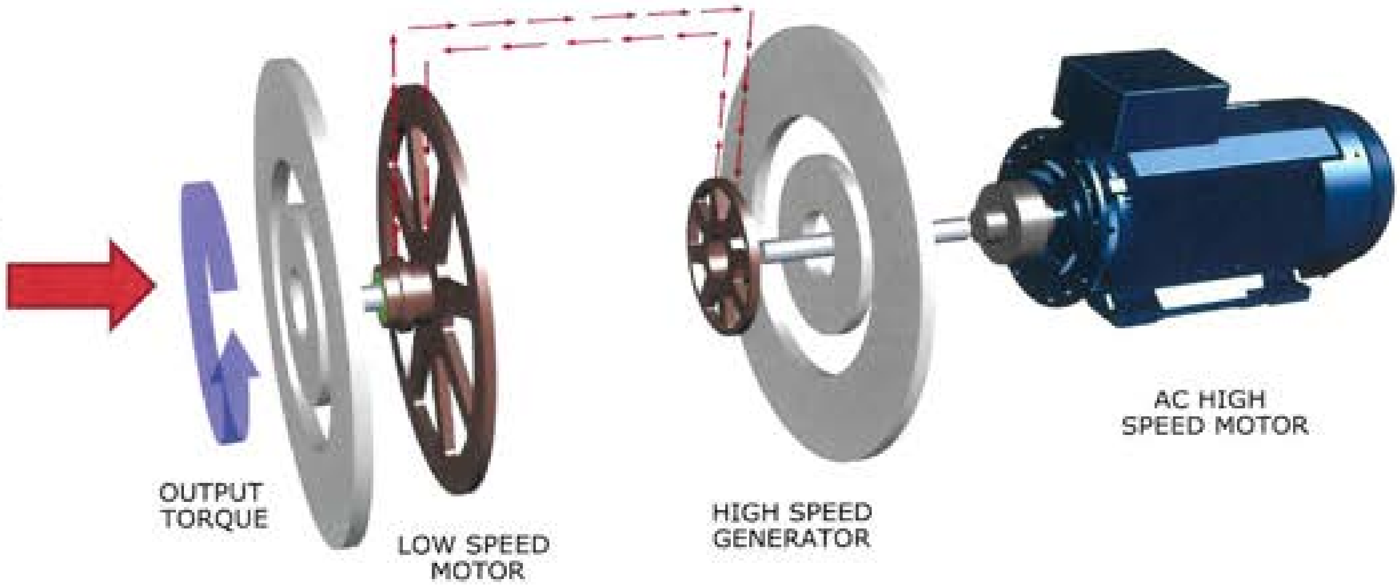



2 Stage – Electromagnetic Power Converters DC-AC

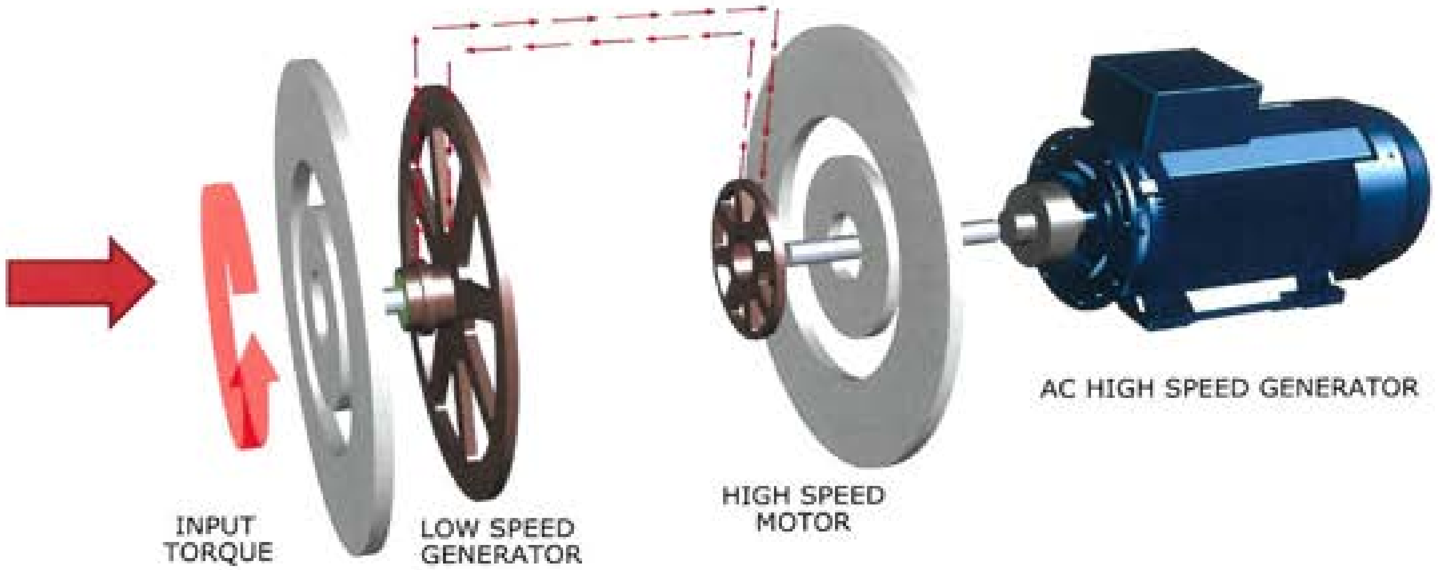


# 3 STAGE - HIGH VOLTAGE AC ⇔ LOW SPEED HIGH TORQUE

High Voltage AC Input to Low Speed High Torque Output



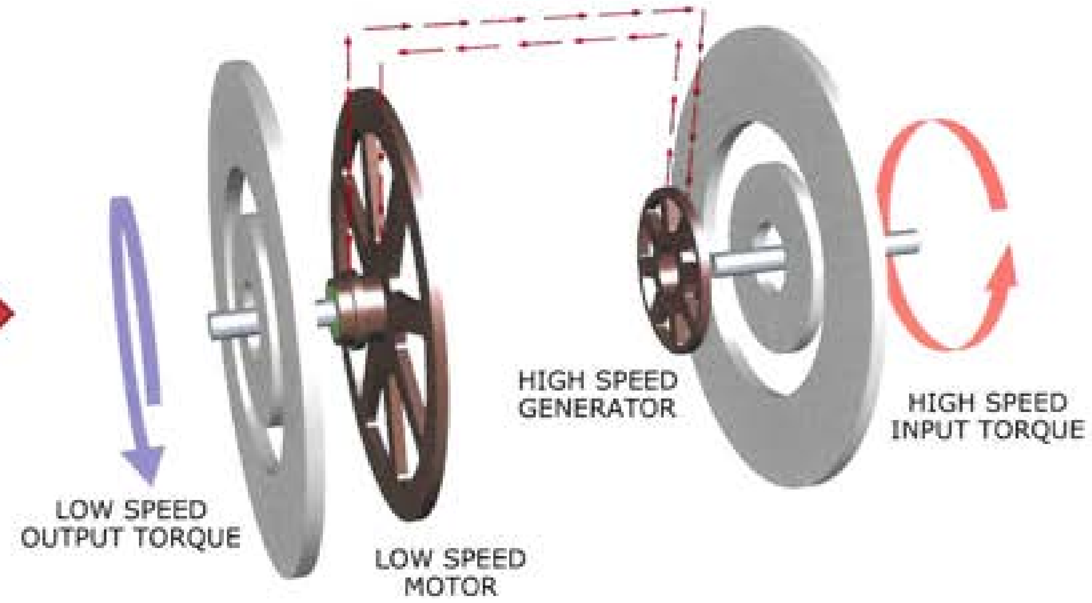

Low Speed High Torque Input to High Voltage AC Output



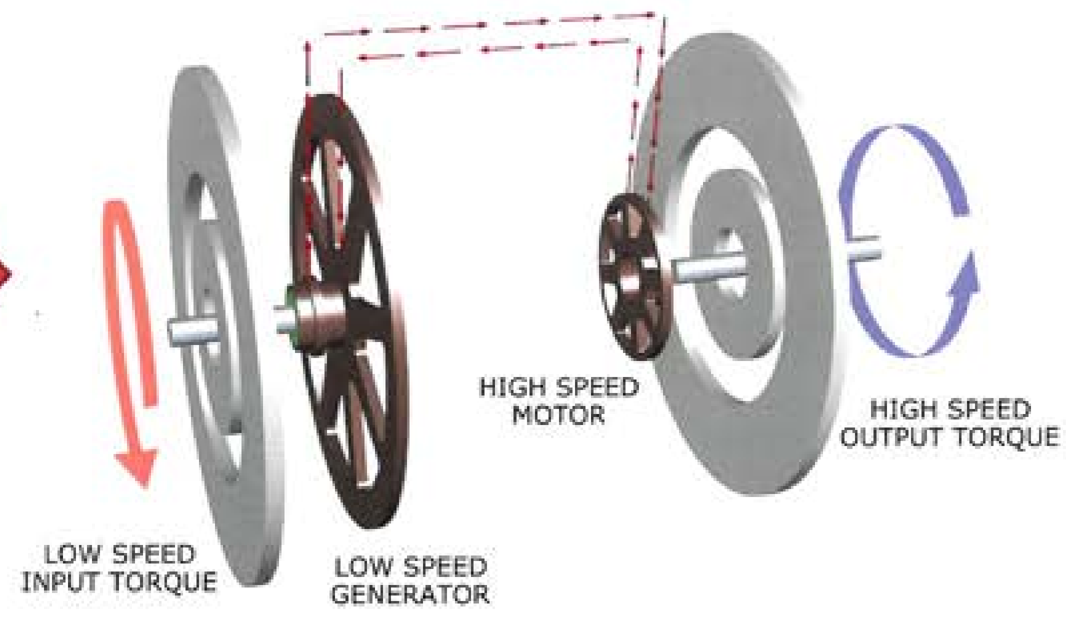
# LOW SPEED SHAFT ⇔ HIGH SPEED SHAFT

## Mechanical Gearbox; step up or down shaft speeds and torques

High Speed, Low Torque Input to Low Speed, High Torque Output




Low Speed, High Torque Input to High Speed, Low Torque Output



# PRESENTING:
# APPLICATIONS OF OUR HOMOPOLAR TECHNOLOGY

# Advantages

- Homopolar motors operate without any AC fields.
- DC power, as provided by batteries, fuel cells or capacitors, can be directly used as power source.
- The torque is completely homogenous and constant during one rotation.
- Speed, torque and power can be simply regulated by DC electrical controllers.
- The motor can operate over a wide range of speeds and loads with very high efficiency.

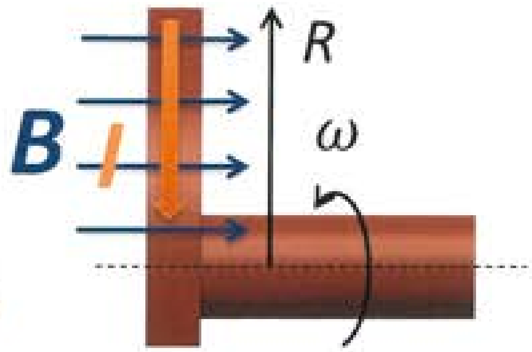
# HOMOPOLAR MOTOR DESIGN

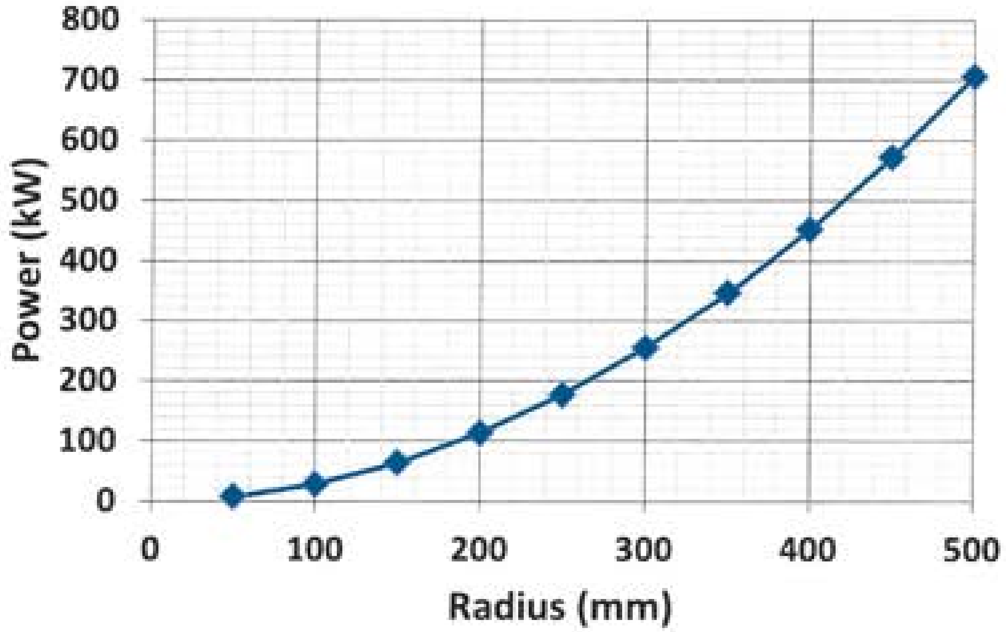
When designing a homopolar motor the main operating parameters have to be matched to the application. Torque, speed, size and weight are only a few parameters which are normally considered as well as the total motor power. Some of the parameters are defined by a range while others have to be matched exactly. This allows us to design a motor optimised for efficiency, energy density and the operating environment.
The main parameters which determine the homopolar motor's power are summarised in the table below. Each parameter has a different influence on the power curve and related losses. Some of the parameters are interdependent and can't be varied individually.

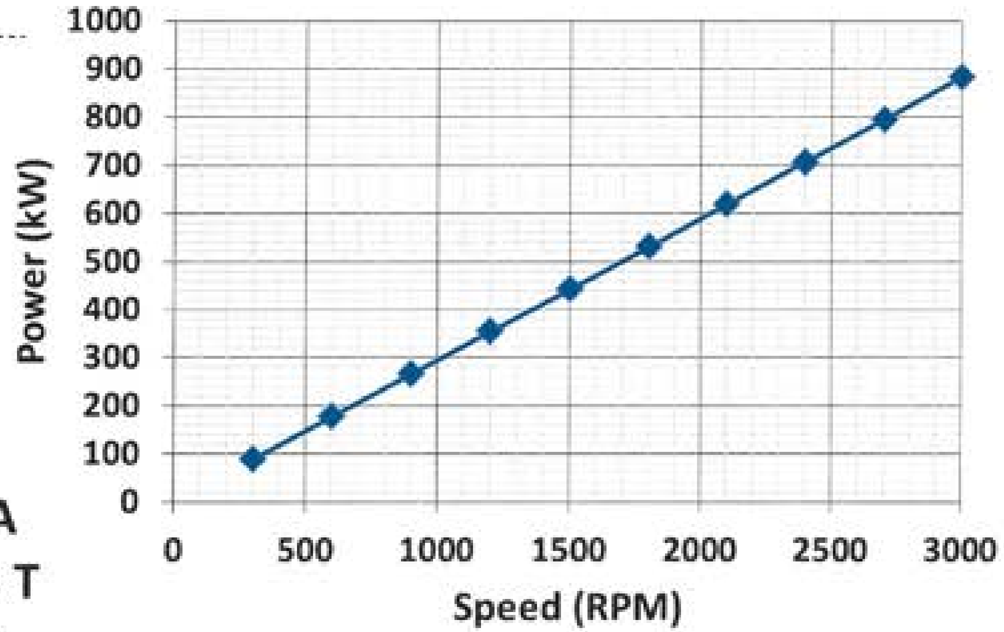
| | **Maximum when Considering Current Technology** | **Optimum Operation with Current Technology** |
|---|---|---|
| **Current Density** | 1000 A/cm$^2$ (not physically limited) | 100 - 500 A/cm$^2$ |
| **Magnetic Field** | < 0.6 T (permanent magnets)<br>< 1.5 T (electromagnets)<br>< 17 T (superconductor) | 6 – 12 T |
| **Radius** | Mechanical Limits Applies for Weight and Stress | 0.4 – 1.5 m |
| **Surface Speed** | ~ 200 m/s (continuous operation) | 30 -120 m/s |

# POWER CURVE EXAMPLES

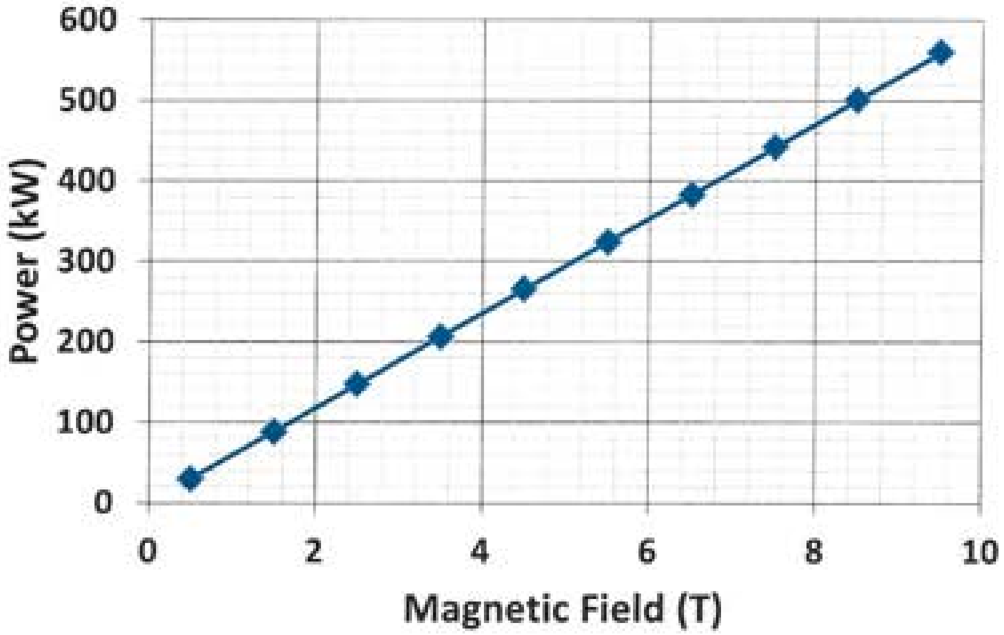
$$P = \tau\omega = IB\frac{R^2}{2}2\pi\frac{RPM}{60}$$

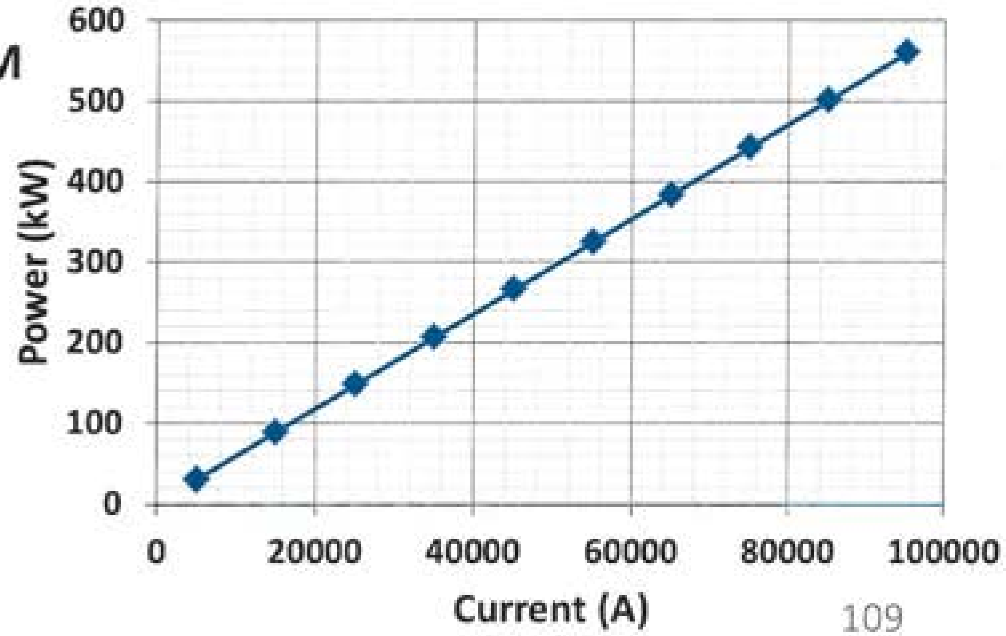


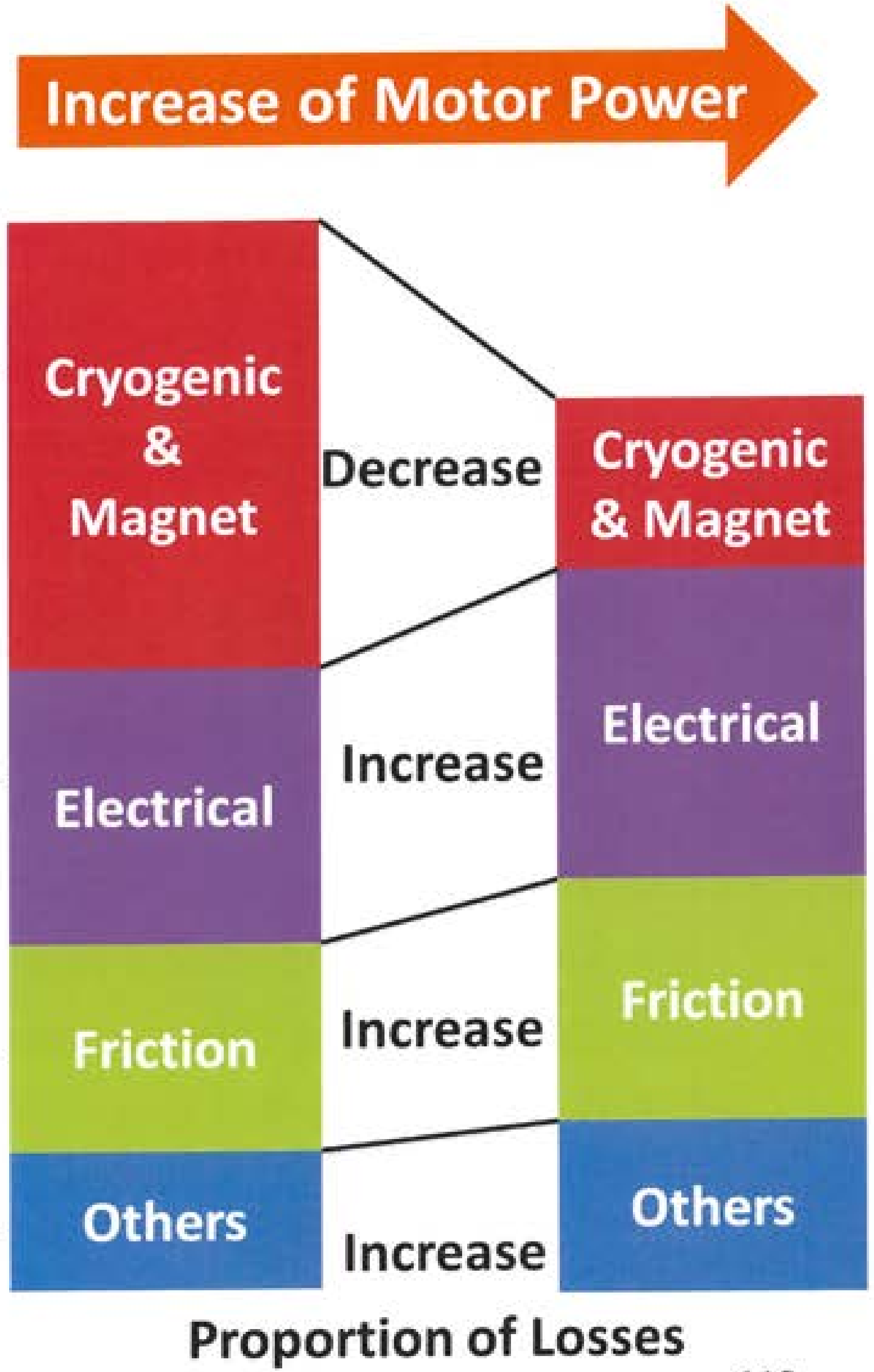

**Current: I = 30,000 A**
**Magnetic Field: B = 3 T**
**Radius: R = 250 mm**
**Speed: RPM = 600 RPM**



# LOSS COMPONENTS

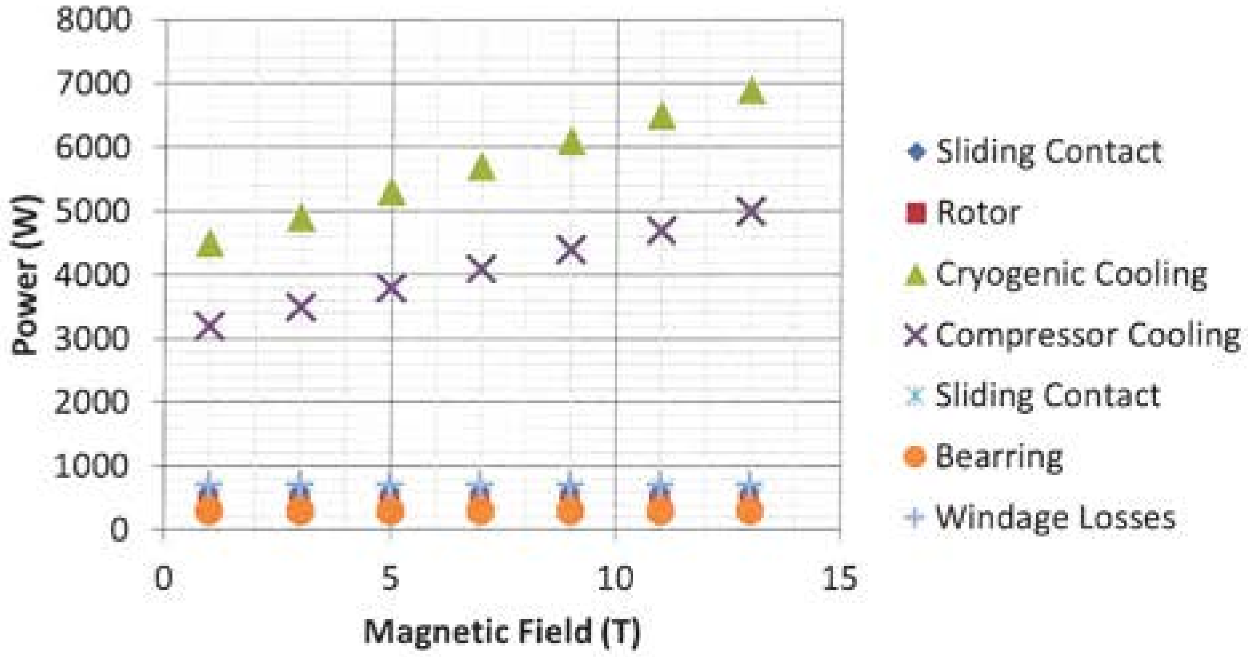
| Component | Dependence |
|---|---|
| **Cryogenic & Magnet** | |
| - Coldhead & Compressor | Cryostat Size, Design, (Field) |
| - Compressor Cooling | Cryostat Size, Design, (Field) |
| - Magnet Power Supply | Coil Design, Operating Conditions |
| **Electrical** | |
| - Sliding Contact | Current, Speed, Geometry, Contact Area |
| - Rotor | Current, Material, Cross-section, Working Length |
| - Stator & Clamps | Current, Length |
| **Friction** | |
| - Sliding Contact | Geometry, Contact Area, Speed |
| - Bearings | Weight, Speed |
| - Windage | Rotor Size, Clearance, Surface, Geometry |
| **Others** | |
| - Engine Cooling | Losses Generated, Cooling Concept |
| - Torque Transfer | Speed, Torque, Power |



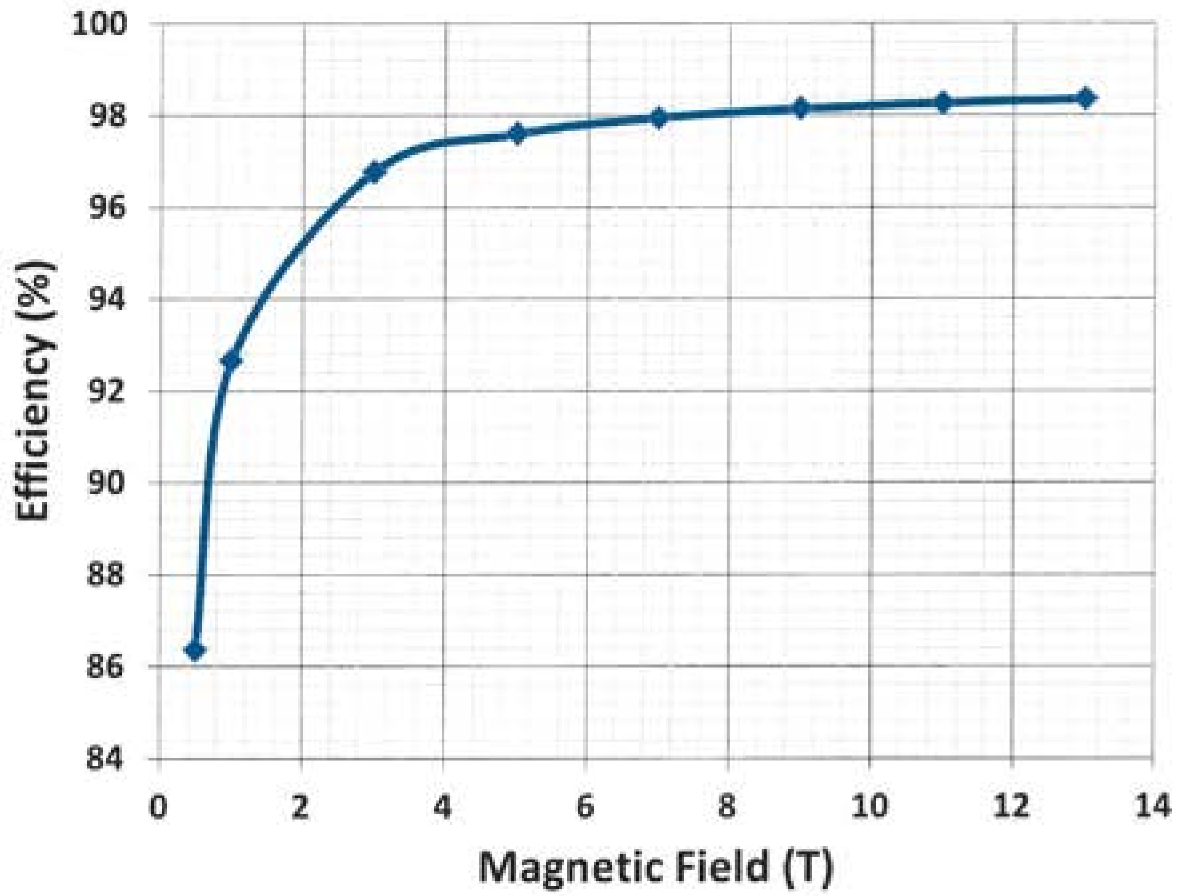
# INCREASING MAGNETIC FIELD

GUINA ENERGY GROUP

**An increase in magnetic field does not proportionally increase the cryogenic loss.**

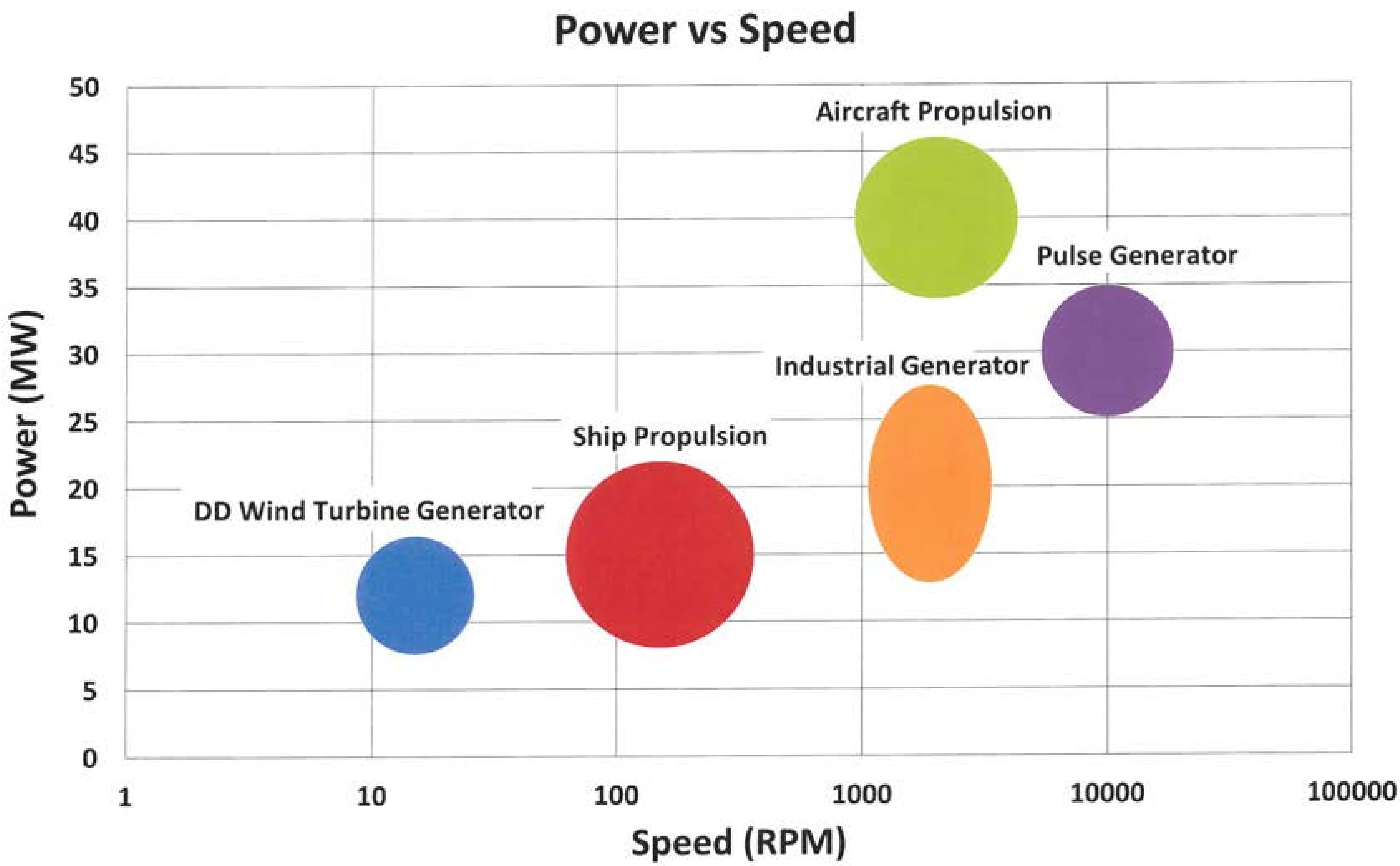



**Therefore the efficiency of a machine can be increased with higher magnetic field.**




**Increasing the magnetic field by a factor of 5 leads to the engine having 5 times the power but the increase in the losses can be by a factor as small as 1.5.**

# APPLICATIONS: POWER VS SPEED MATRIX



# PRESENTING:
# MARINE INTEGRATED ELECTRIC PROPULSION

# WHY ELECTRICAL PROPULSION?

GUINA ENERGY GROUP

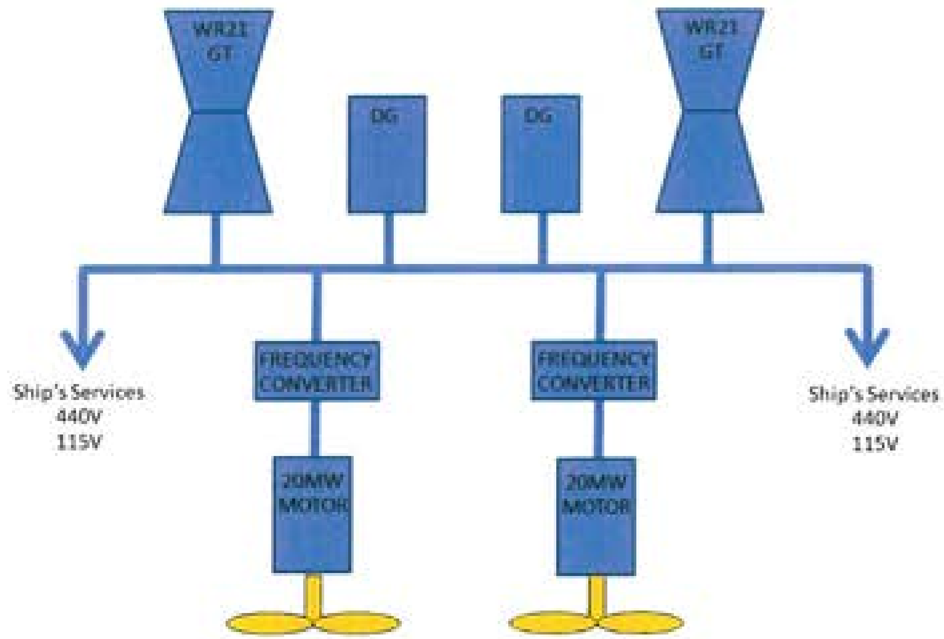
**Integrated Electric Propulsion (IEP)** is an arrangement of marine propulsion systems such that gas turbines and/or diesel generators generate electricity which is then used to power electric motors.

<u>Advantages:</u>

- Increased freedom in the placement of engines
- Acoustical decoupling of the engines
- Higher efficiency due to always running in optimum RPM range for the generators
- Reduction in overall weight of the drive system
- Decoupling of shaft speed and propeller speed
- Lower maintenance costs

<u>Disadvantages:</u>

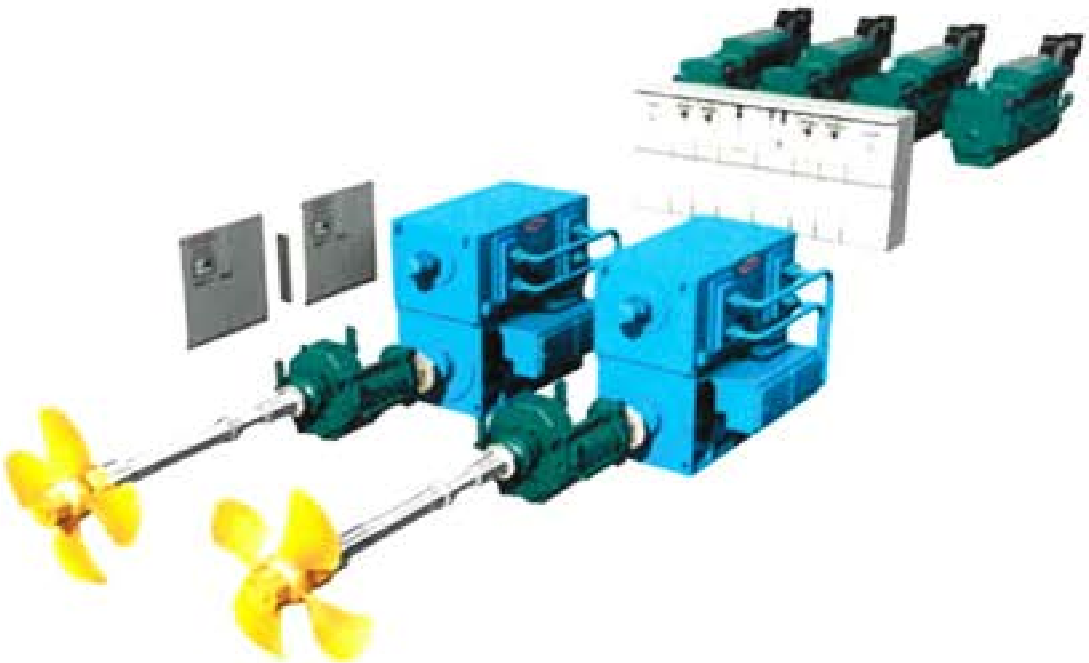
- High power electronics are required
- The structure becomes more complicated
- Higher costs (especially pod systems)




Example of IEP system for ship propulsion (Wikipedia)

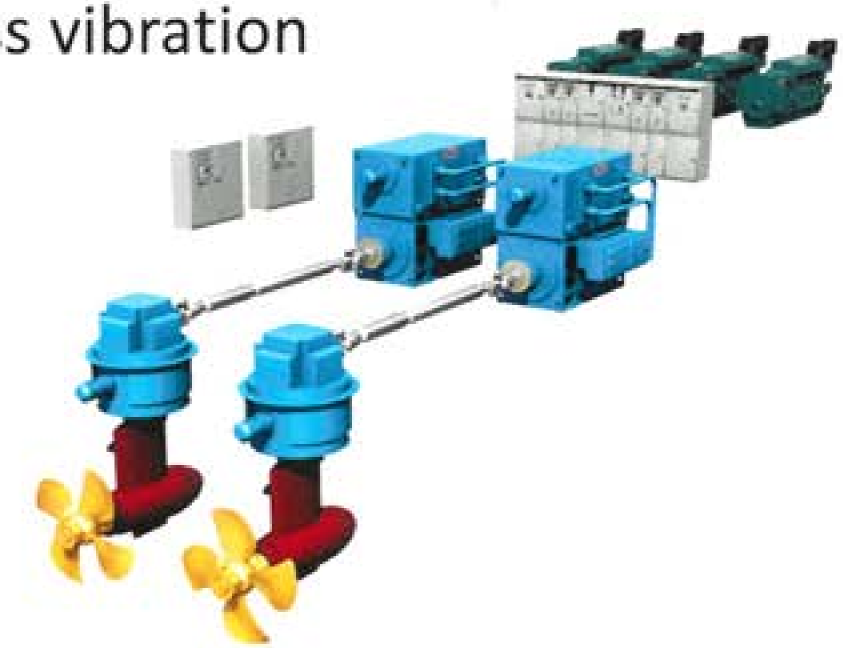
## Fixed Propeller

- Easier to implement
- Rudder and propeller separately controlled
- Implementation of gearbox possible



## Azimuth Thruster (Pod Systems)

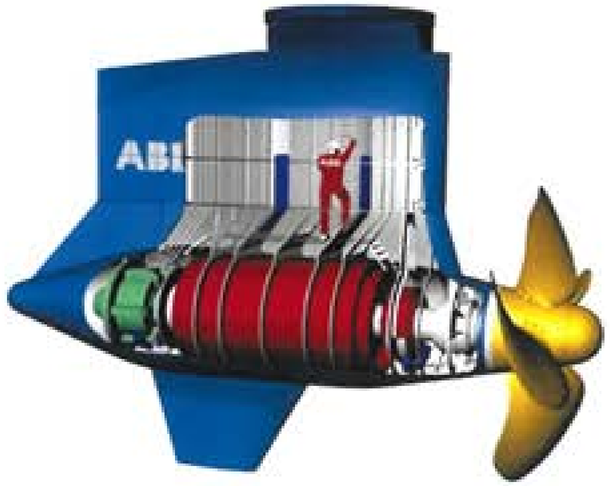
- Demonstrated efficiency improvements
- Better manoeuvrability (smaller turning circle, faster stop)
- Lighter and smaller
- The motor can be more easily cooled by direct contact with the sea water
- Less vibration

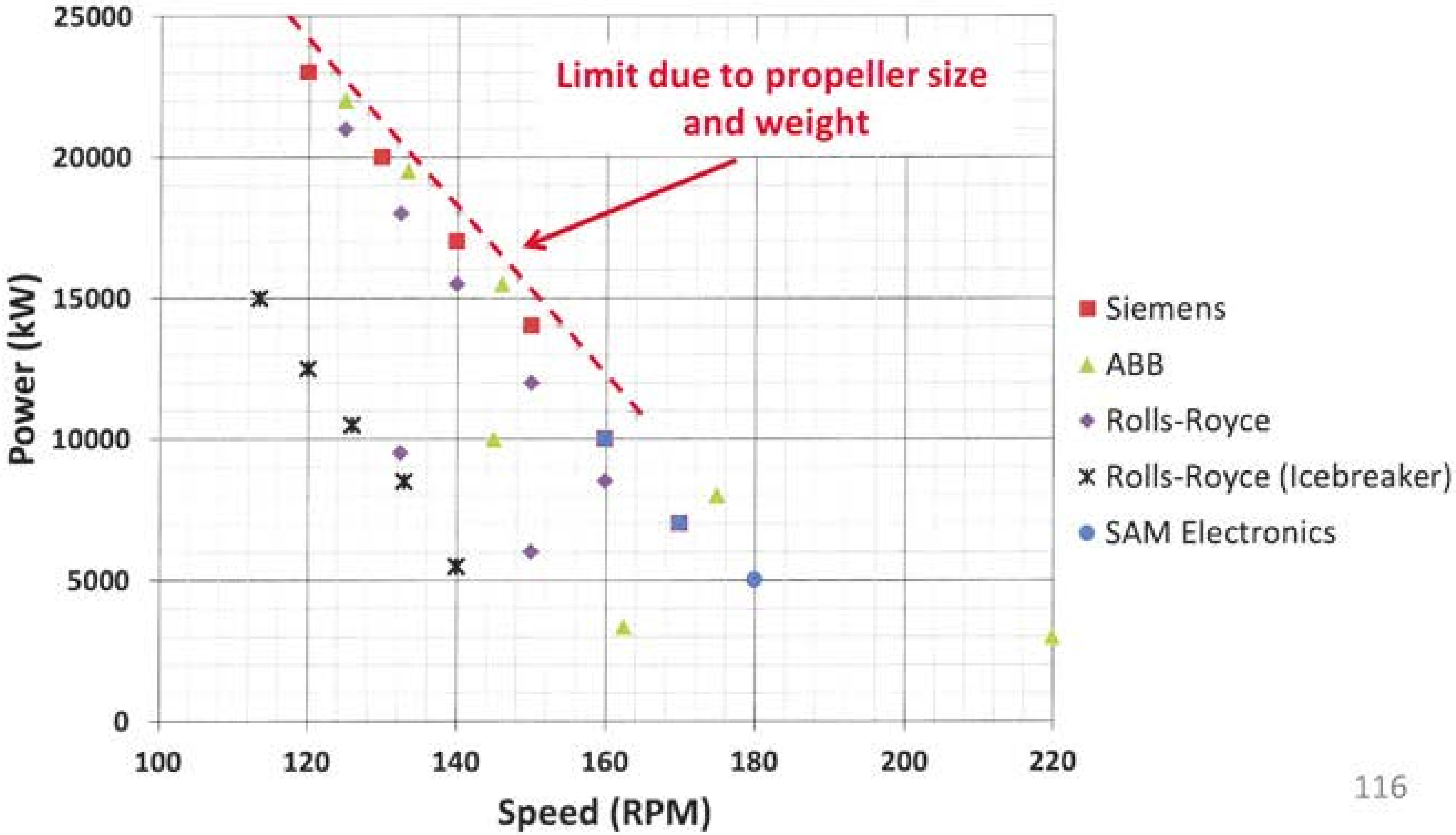


# ELECTRIC MARINE POD OVERVIEW

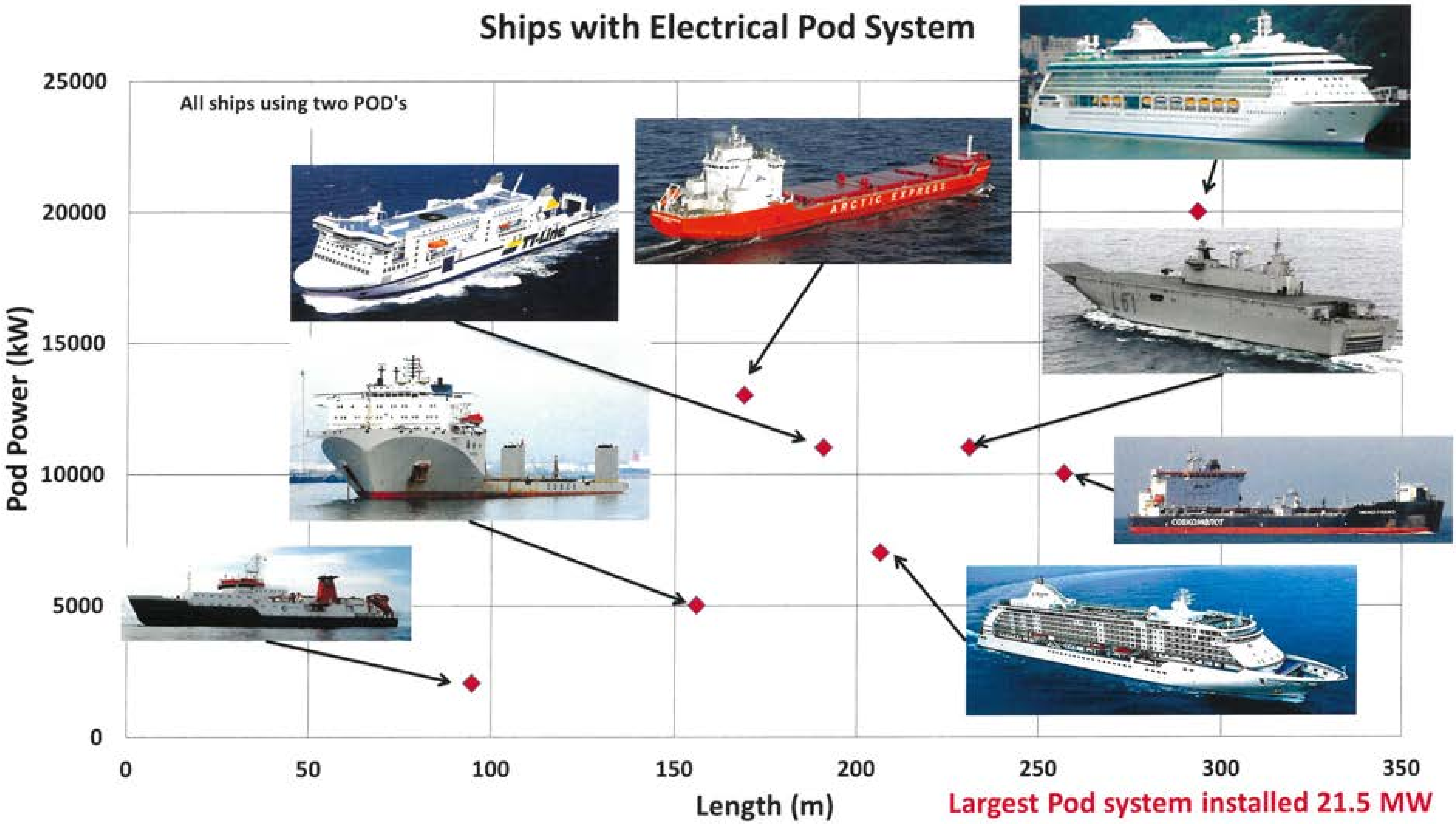
Manufacturer

- ABB (Azipod)
- Siemens (eSiPOD)
- Rolls-Royce & GE (Mermaid)
- SAM Electronics (DOLPHIN)
- ...





# SHIP SIZE AND POD POWER




**Largest Pod system installed 21.5 MW**

# THE IMPACT OF GUINA ENERGY'S TECHNOLOGY

**Power Electronics**

- Guina Energy's DC motor/generators reduce the required number of converters and simplify the electric grid on the ship. Converters are a significant source of losses and faults. Our Electromagnetic Power Converters can be directly implemented into the motor or generator to provide convenient power levels (High voltage, low current ⇔ Low voltage, high current).

**Power to Size**

- Guina Energy's homopolar motors are smaller and have better power to weight ratios than conventional motors. Smaller motors allow smaller pod's and hence reduce drag in the water. The required low speeds and high torques suit the homopolar motor.

**Counter Rotating**

- Studies have shown that counter rotating propeller systems can increase propulsion efficiency due to the decrease of turbulence. Our counter rotating homopolar motor designs are suitable for direct drive and eliminate the need for gearboxes or mechanical transmission systems.

**Power transmission**

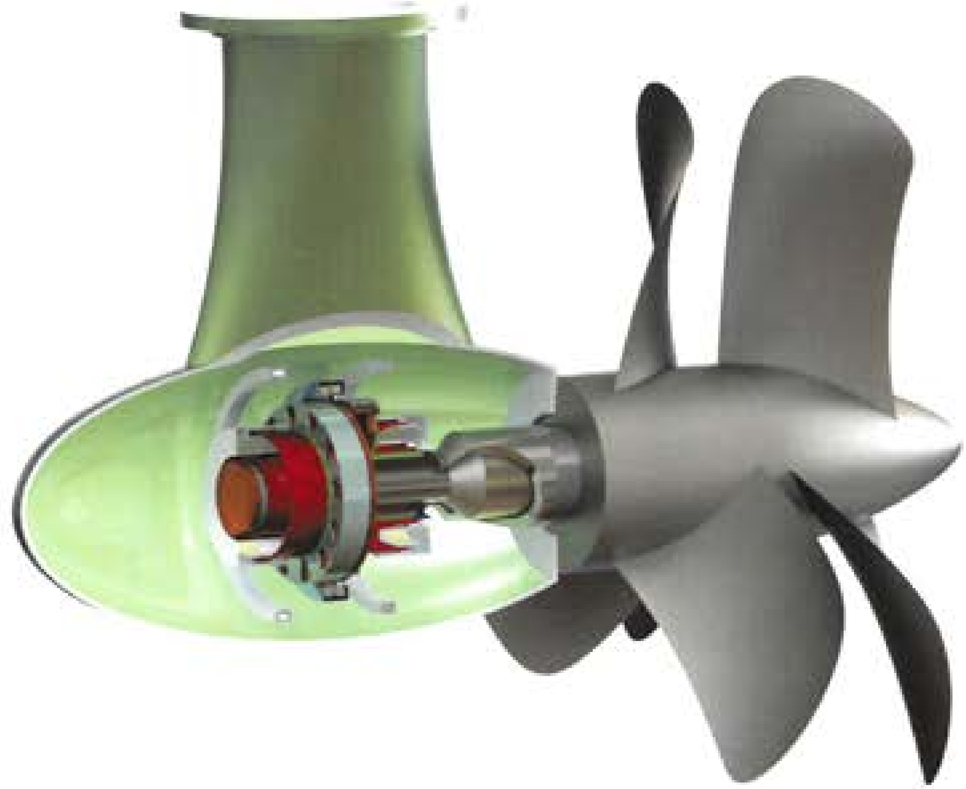
- A contact-less magnetic coupling may be used to transmit the torque to the final drive shaft. This would result in a system where the electrical systems are completely isolated from the marine environment.

**Smart Energy Utilisation**

- Our propulsion pod technology could be readily integrated with highly efficient electrical energy storage systems (hydrogen fuel cell, batteries, ...).

# HOMOPOLAR MARINE POD CONCEPTS

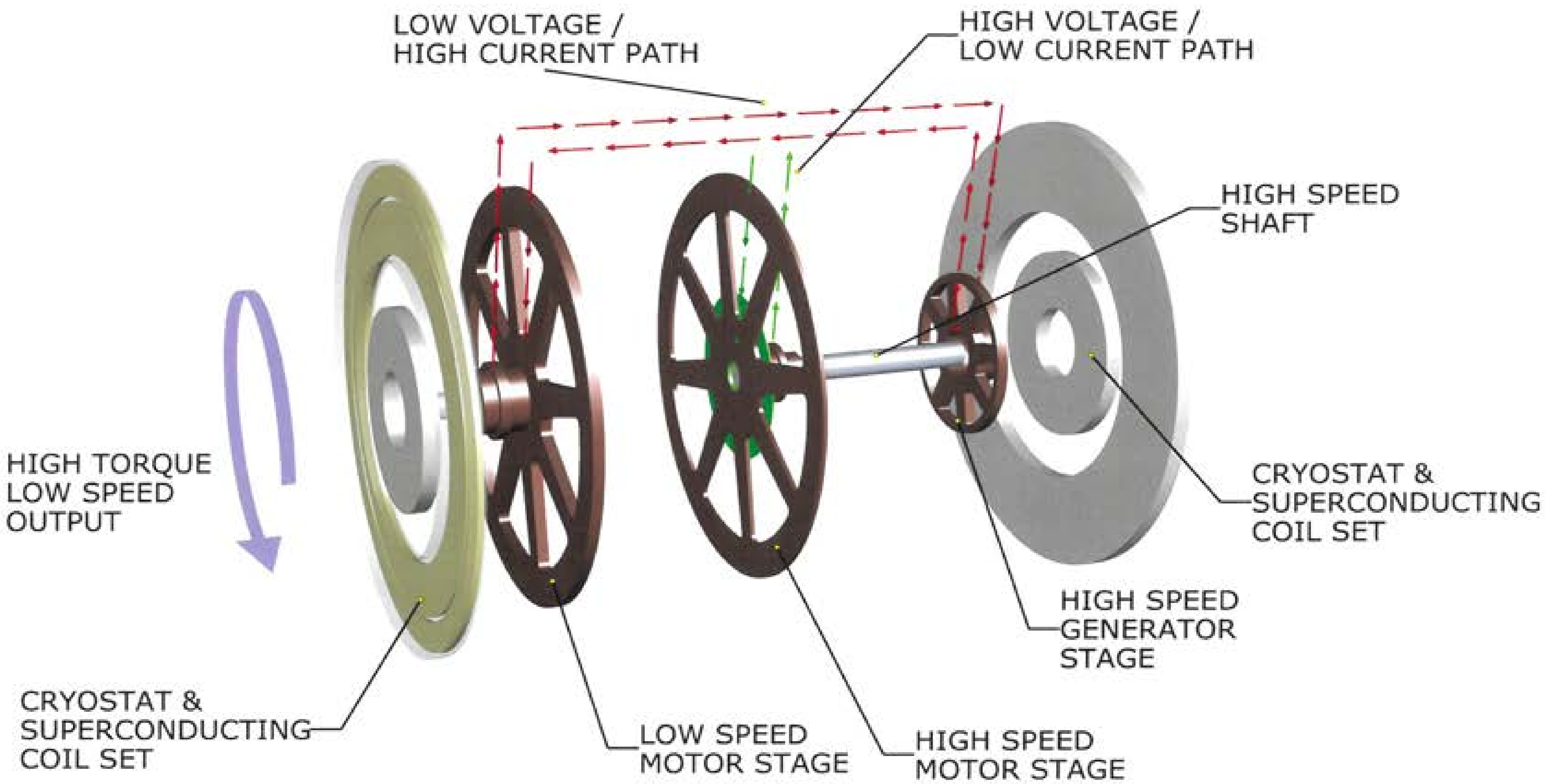
Twin counter rotating pod – dual end



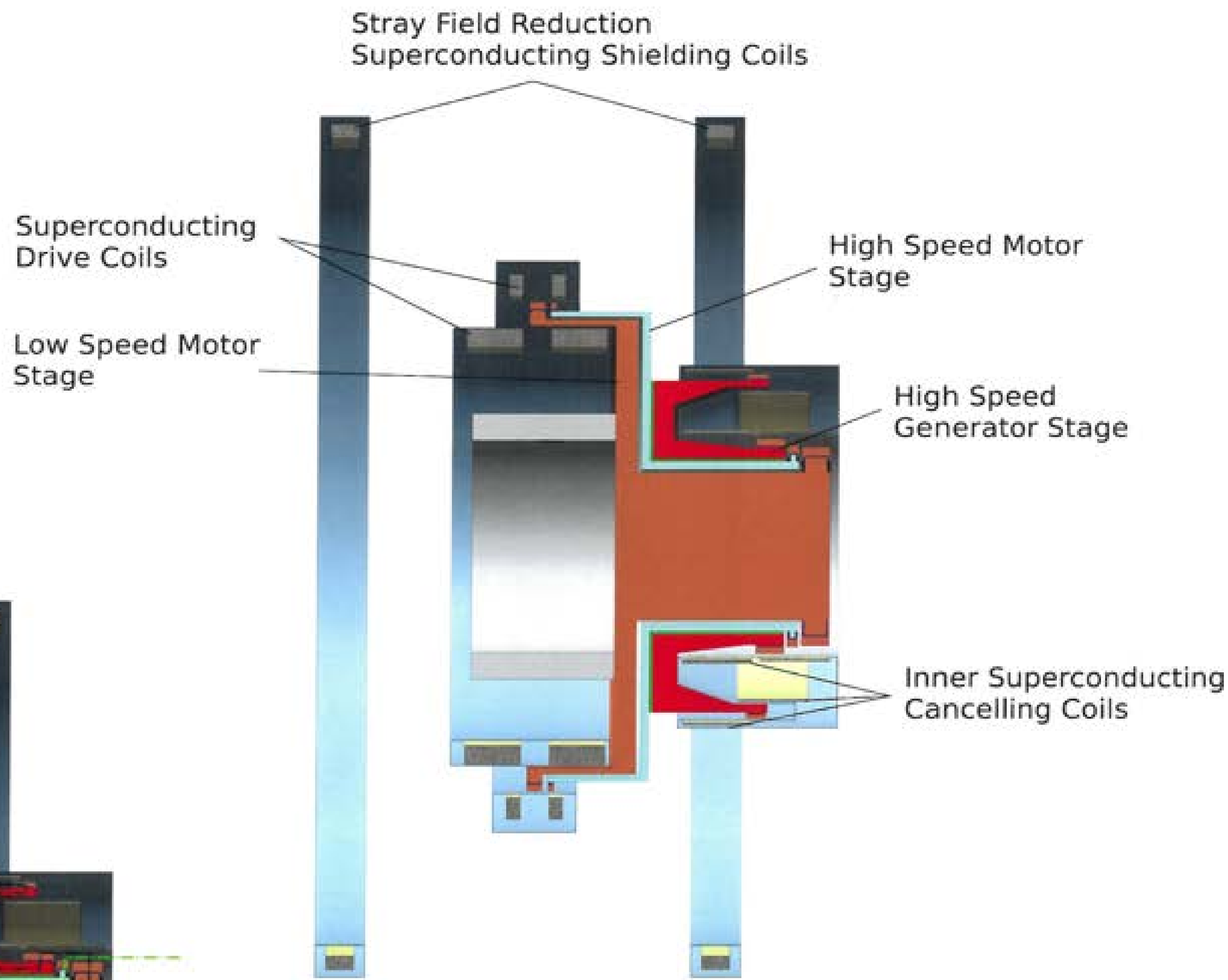
Twin counter rotating pod – single end

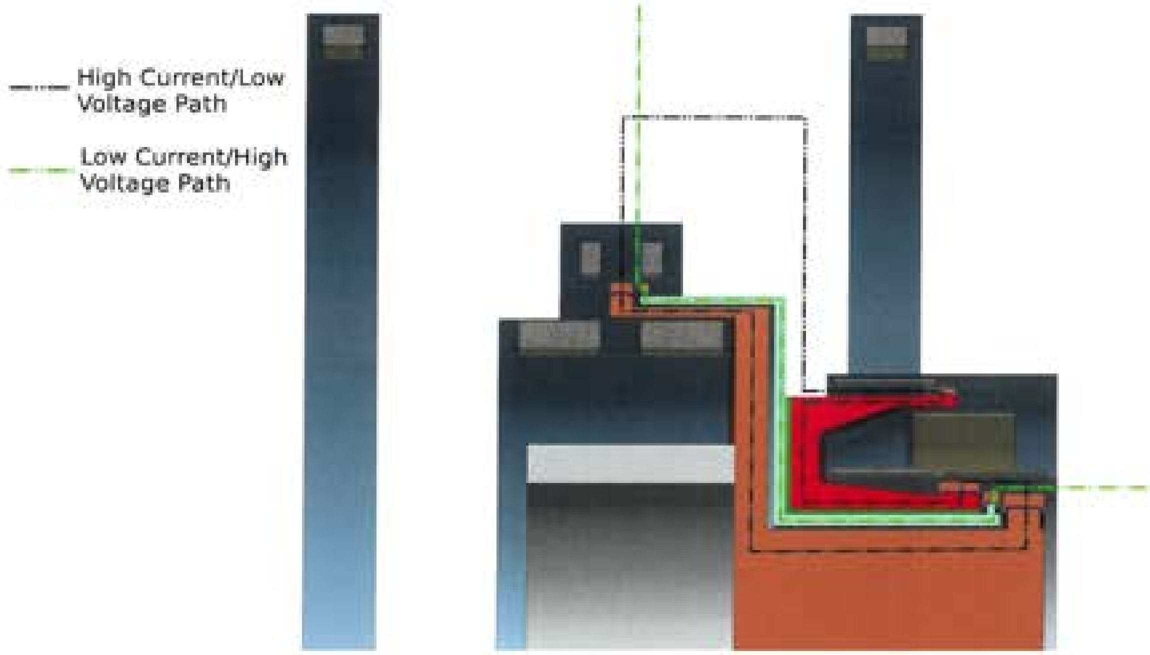
MULTI-MEGAWATT PROPULSION

Multi-megawatt low speed, high torque design for Marine Propulsion incorporating our Electromagnetic Gearbox



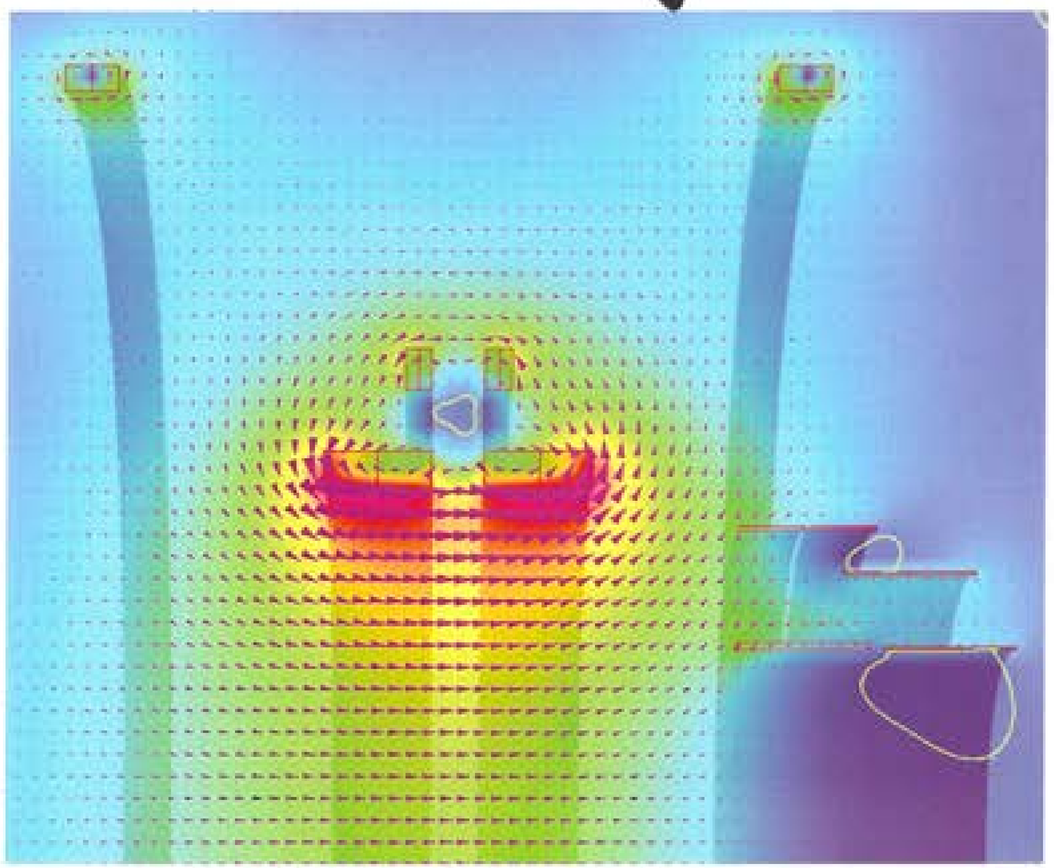
# 3 STAGE APPLICATION– MARINE PROPULSION

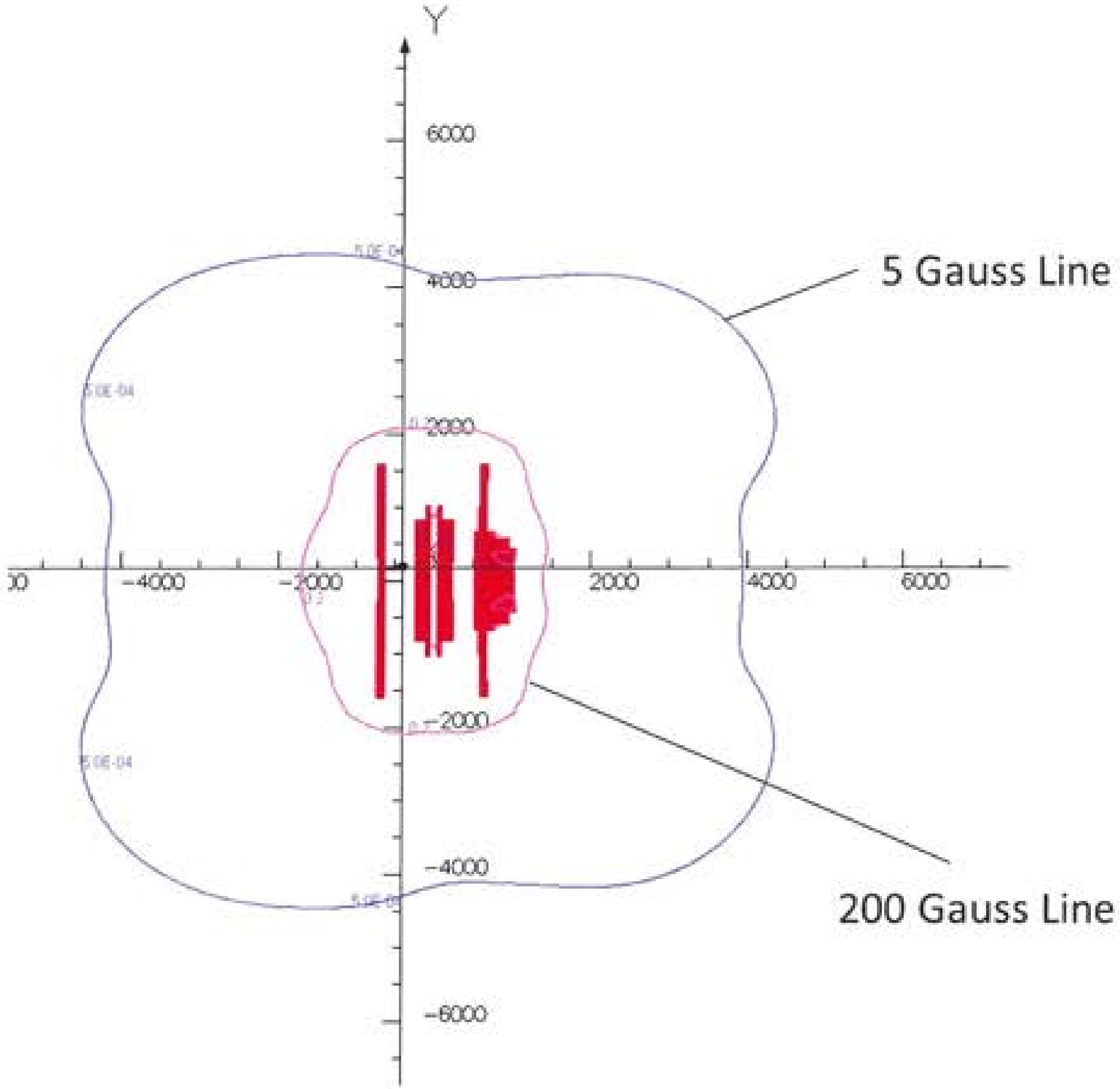


# 3 STAGE APPLICATION– MARINE PROPULSION

## 12 MW Marine Propulsion Pod – Magnetic Field Plots



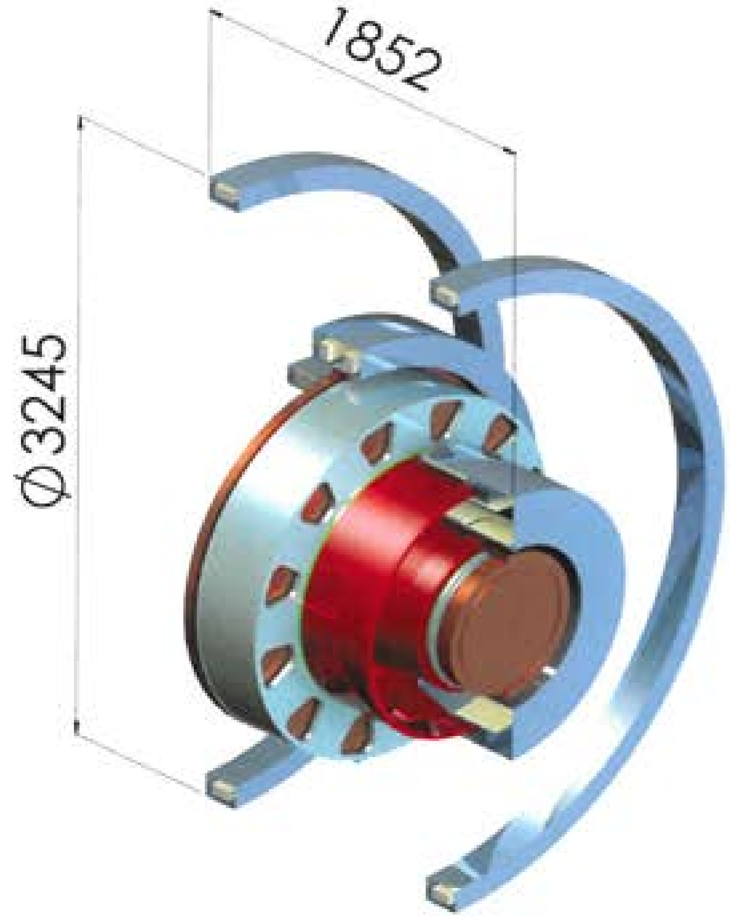


# 12 MW MARINE PROPULSION POD

## DATA SHEET

| | |
|---|---|
| Power (MW) | 12 |
| Speed (RPM) | 120 |
| Total Current (A) | 511780 |
| LMB Current Density A/cm$^2$ | 500 |
| Max Rotor Tip Speed (m/s) | 123 |
| Max Coil Diameter (mm) | 3245 |
| Rotor Radius (mm) | 900 |
| Rotor Material | Aluminium |
| Super Conductive Wire | $Nb_3Sn$ |
| SC Wire Length (km) based on $\phi$ 0.85 mm wire | 354 |
| SC Wire Weight (kg) | 1406 |
| SC Wire Packing Factor | 0.6 |
| SC Wire current density (A/mm$^2$) | 240 |
| Peak Field on wire (T) | 13.2 |
| Cryogenic Temperature (K) | 4 |
| Low speed Stage Speed (RPM) | 120 |
| High Speed Stage Speed (RPM) | 1304 |
| Low speed Stage Current (A) | 511780 |
| Low Speed Stage Voltage (V) | 23.45 |
| High speed Stage Current (A) | 47094 |
| High Speed Stage Voltage (V) | 255 |

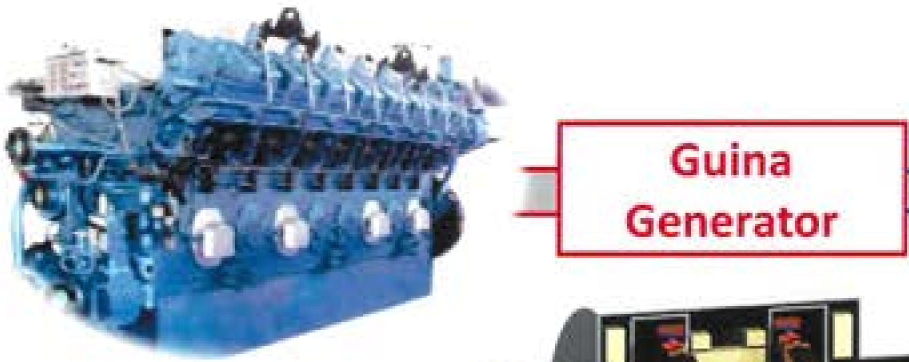
## OVERALL DIMENSIONS

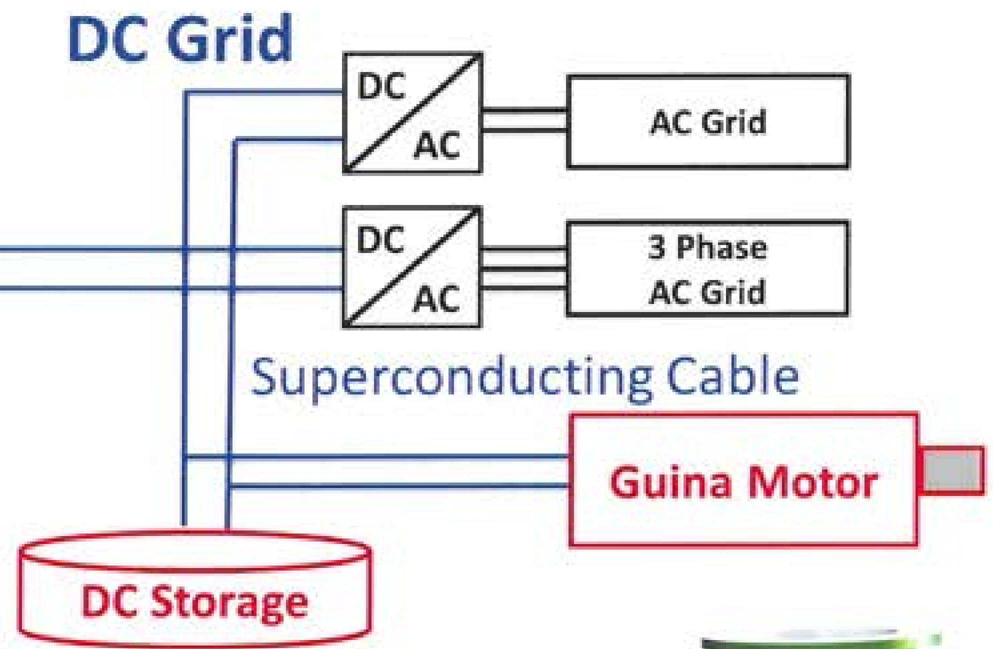


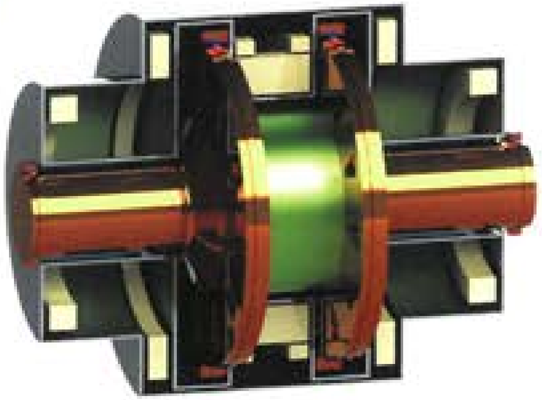

**All weights listed exclude Cryostat, support structures and return busses. Weights are approximate and could be reduced further with optimisation.**

# HIGH TORQUE LOW SPEED MOTOR OR GENERATOR

## Ship Propulsion

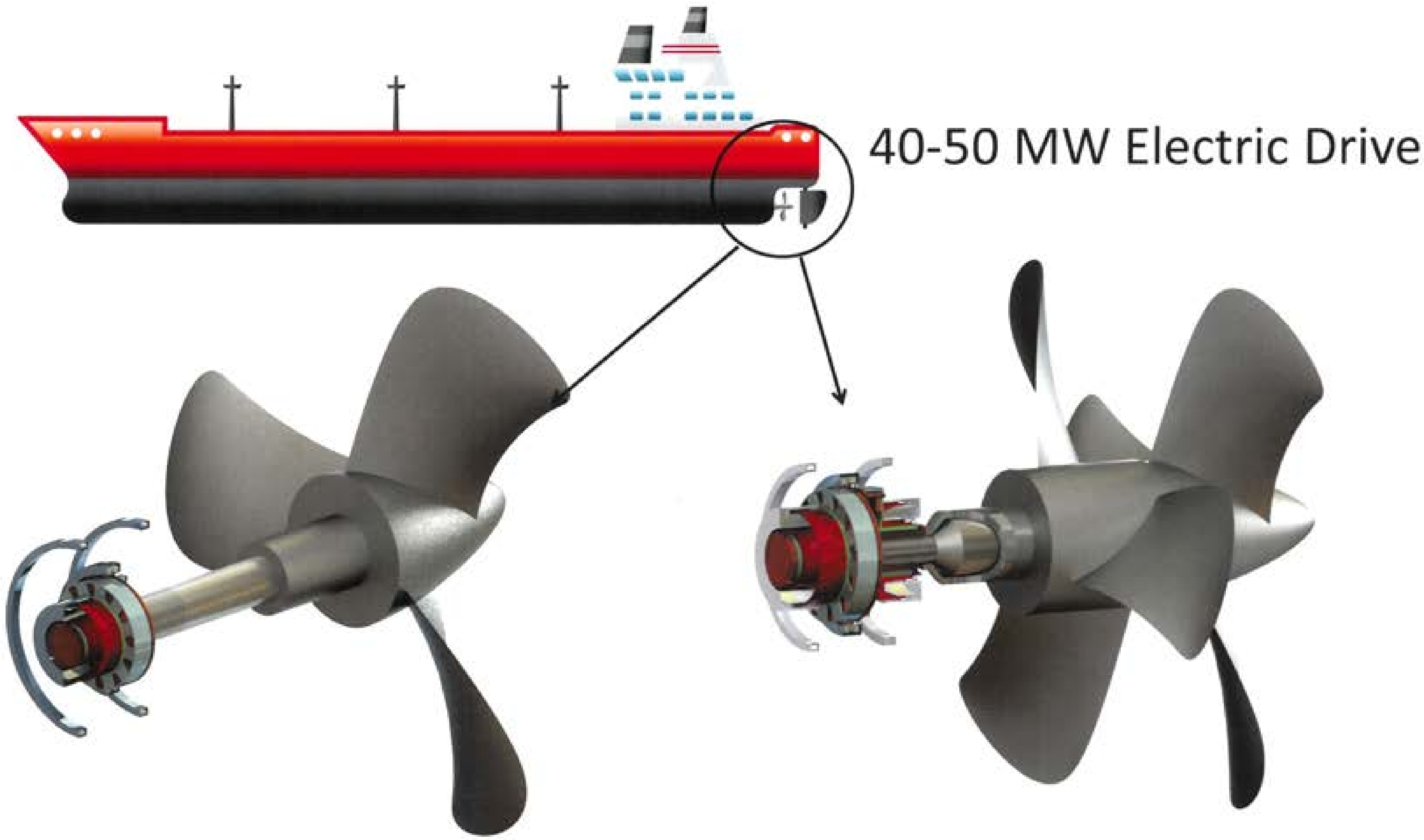


- ⇒ Increased end user efficiency
- ⇒ Reduced grid complexity
- ⇒ High power to weight ratios
- ⇒ Easy implementation of energy storage systems
- ⇒ Counter rotating motor

# FIXED PROPELLER MARINE PROPULSION

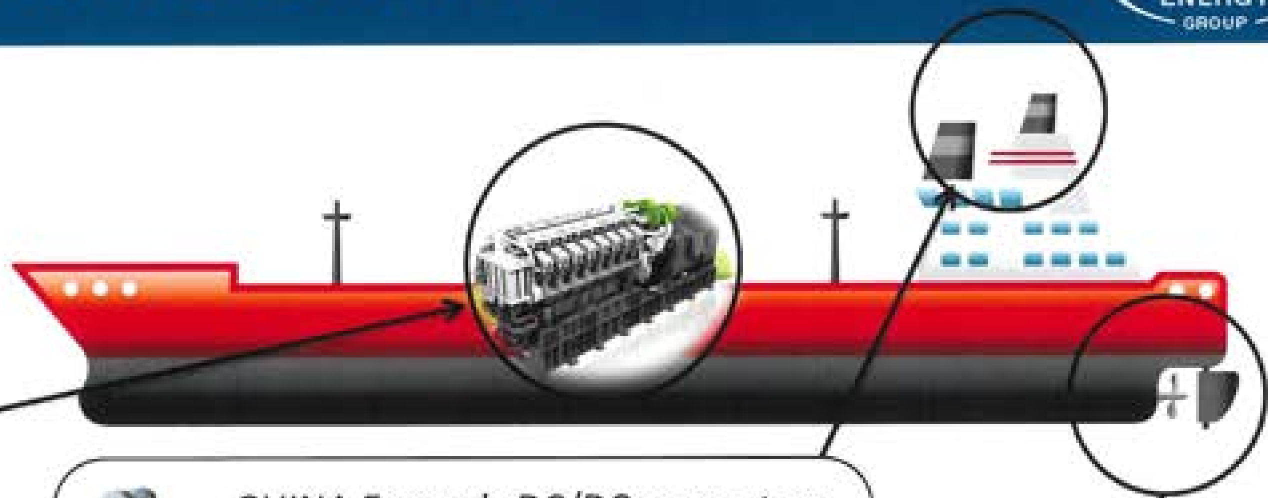


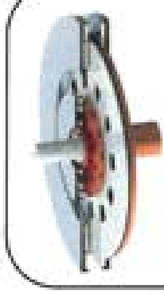

Direct Drive - Single Propeller

Direct Drive - Counter Rotating Propellers

# MARINE APPLICATION SUMMARY

Electric power generation on ships is becoming increasingly more important due to higher energy demands. High efficiency, reliability and simplicity are key requirements for marine applications. GUINA Energy's superconducting generators are highly suitable because of their power to size ratios and high power densities.

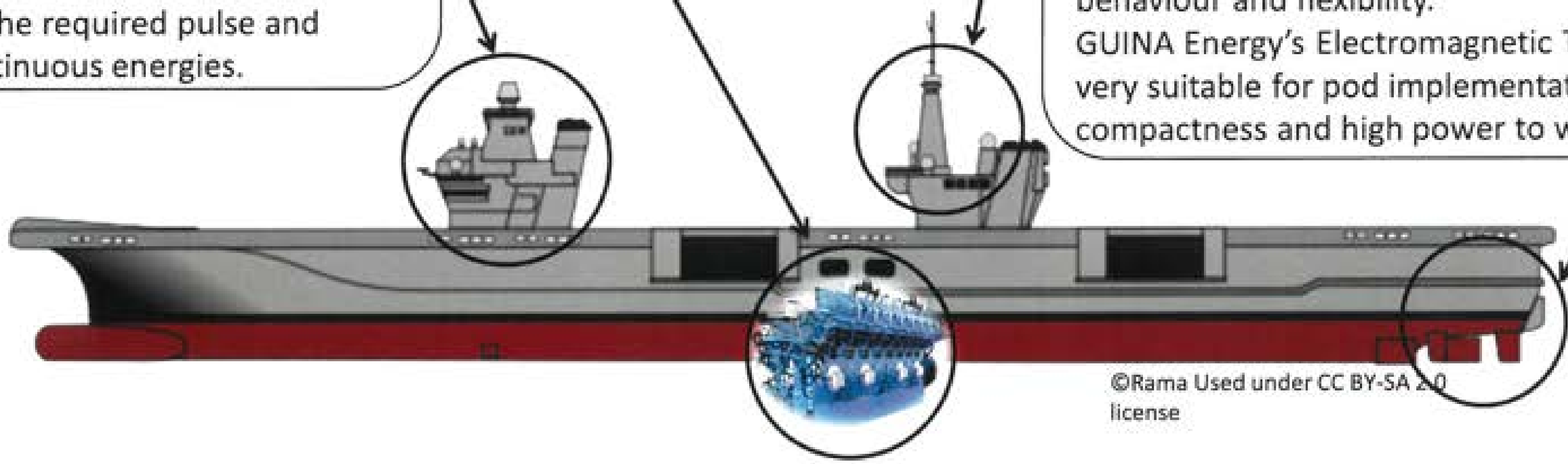




GUINA Energy's DC/DC converters can generate the required electrical energy levels and distribute this power efficiently to the applications.

Modern electric weapons play an important role in the future of warfare. These systems require high peak energy during usage as well as constant continuous supply. GUINA Energy's electromagnetic turbine generators and short term energy storage systems can provide the required pulse and continuous energies.

Electric ship propulsion systems are more efficient than conventional systems and make the drive system easier. Pod systems are a preferable solution due to better steering behaviour and flexibility.
GUINA Energy's Electromagnetic Turbine motors are very suitable for pod implementation because of their compactness and high power to weight ratios.



# PRESENTING:
# AVIATION RELATED PERSPECTIVES

# WHY ELECTRIC AIRCRAFT?

- **Increase in Efficiency**
- **Reduction of Environmental Impact**
- **Reduced Operating Cost**
- **Highest Safety Standards**

**How can electrification help to achieve these goals?**

- Electric devices have very high efficiencies.
- Power and weight can be easily distributed.
- Electrical energy can be stored and converted.
- Electric systems are lighter.

# STEPS TO ACHIEVE A CLEANER AIRCRAFT

GUINA ENERGY GROUP

## More Electric Aircraft

- Replacing pneumatic, hydraulic and mechanical systems with more efficient electrical systems.
- Implementation of high power electrical energy storage systems.

## Hybrid Aircraft

- High efficiency turbine and generator units producing electrical power for propulsion and aircraft operation.
- Several electrical propulsion engines are placed in an aerodynamically favourable position to produce thrust.

## Full Electric Aircraft

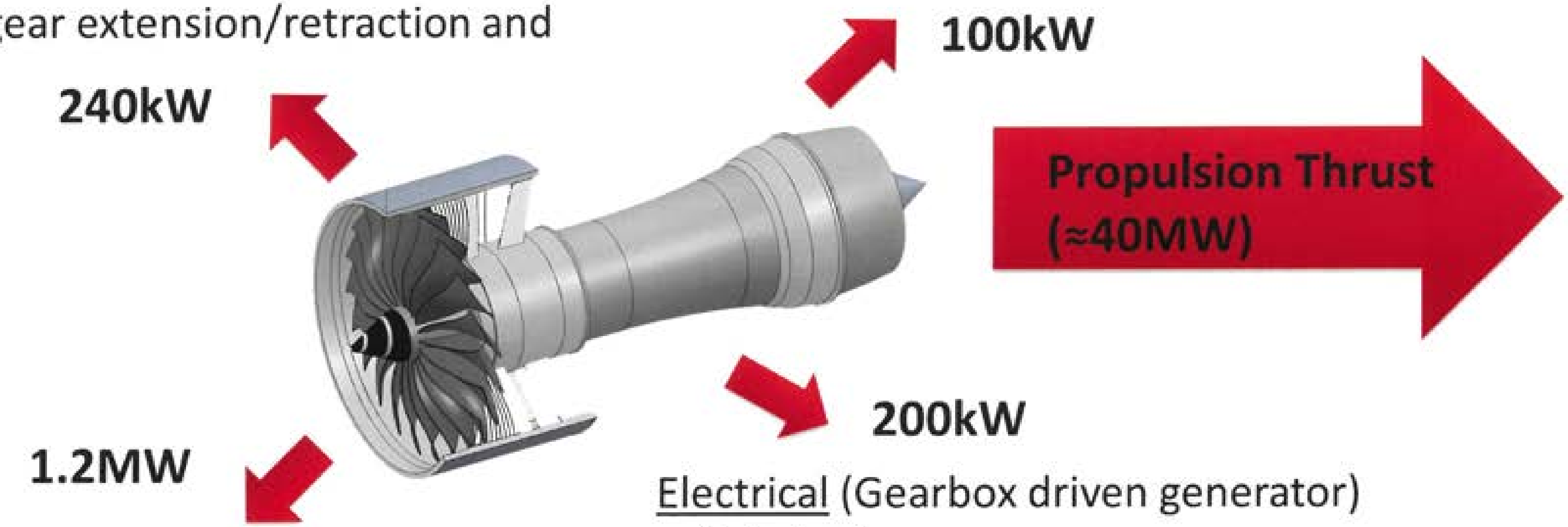
- Electric storage systems and "green" power sources provide the power during flight.

# MORE ELECTRIC AIRCRAFT

A modern power unit (engine) in an aircraft has to provide electrical, pneumatic, hydraulic and mechanical power in addition to the propulsion thrust. This is not economical and the overall efficiency can be increased by replacing some of the traditional systems with electrical systems.

<u>Hydraulic</u> (gearbox driven hydraulic pump)
- Flight control surface actuation
- Landing gear extension/retraction and steering
- Braking
- Doors

<u>Mechanical</u>
- Fuel and oil pumps local to engine

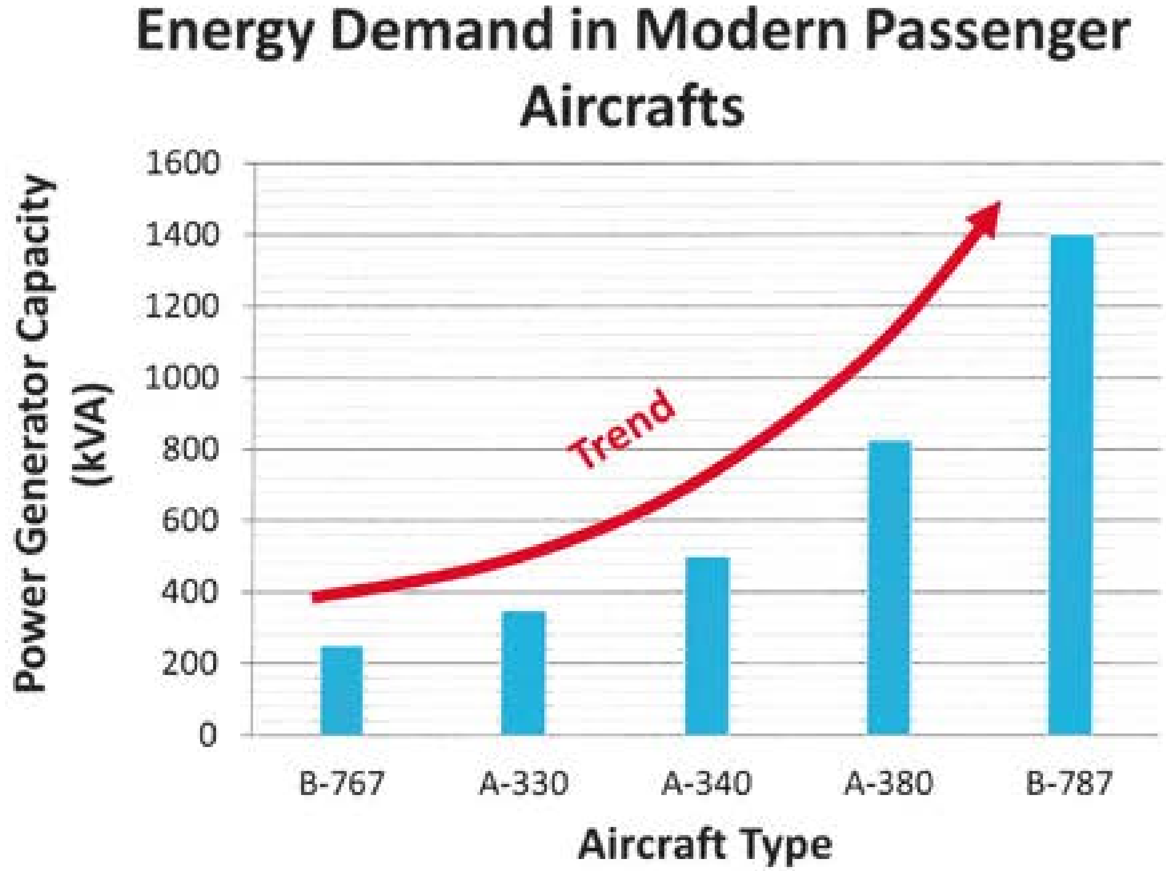



<u>Pneumatic</u> (high pressure air "bled" from engine)
- Cabin pressurisation
- Air conditioning
- Icing protection

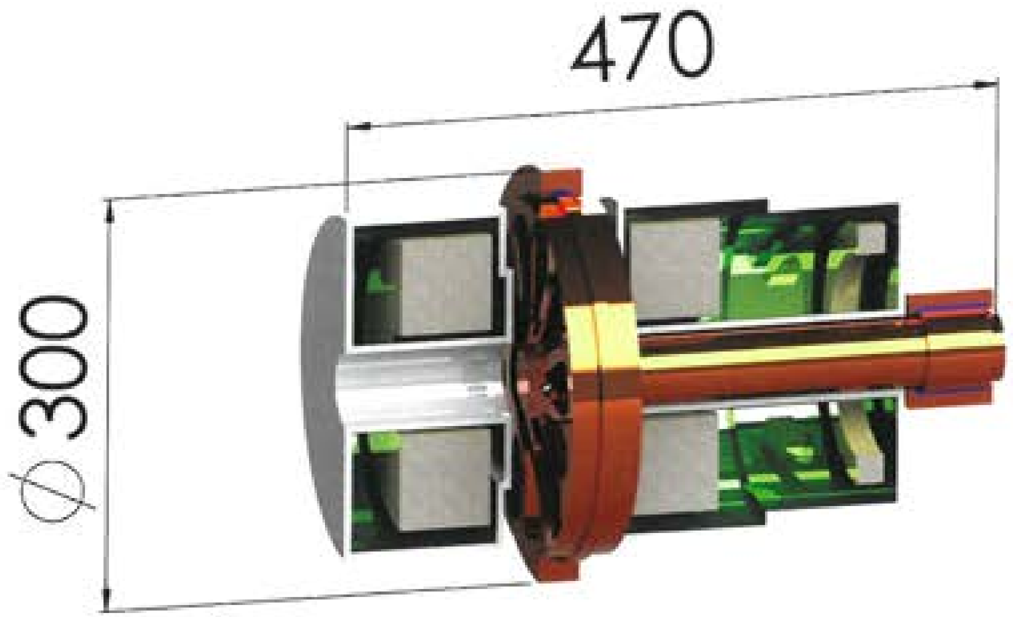
<u>Electrical</u> (Gearbox driven generator)
- Avionics
- Cabin (lights, galley, inflight entertainment etc.)
- Lights, pumps, fans
- 115V, 400Hz AC

# MORE ELECTRIC AIRCRAFT

Over the years the electrical power required by the aircraft has increased exponentially. Replacing pneumatic and/or hydraulic systems will further increase the electrical power demand. Future generators for aviation applications must be very light, robust and should handle the high RPM's from a jet engine.



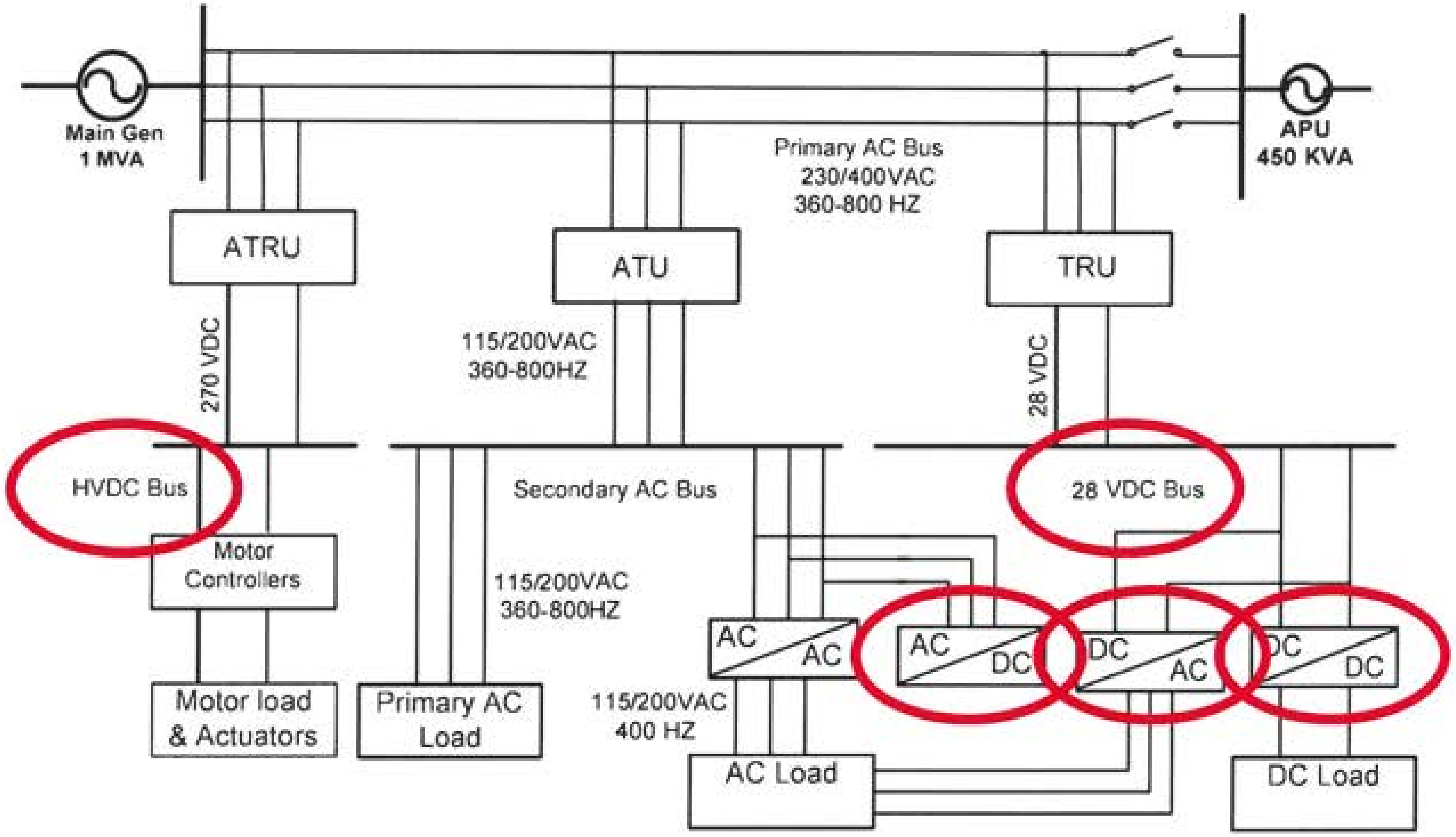

## 1 MW -Generator




Guina Energy's Electromagnetic Turbines are can be directly coupled to a jet turbine due to their high speed operation. High power to weight ratios and DC power generation are also ideally suited for aviation applications.

# MORE ELECTRIC AIRCRAFT

## B787/A380 aircraft power distribution system

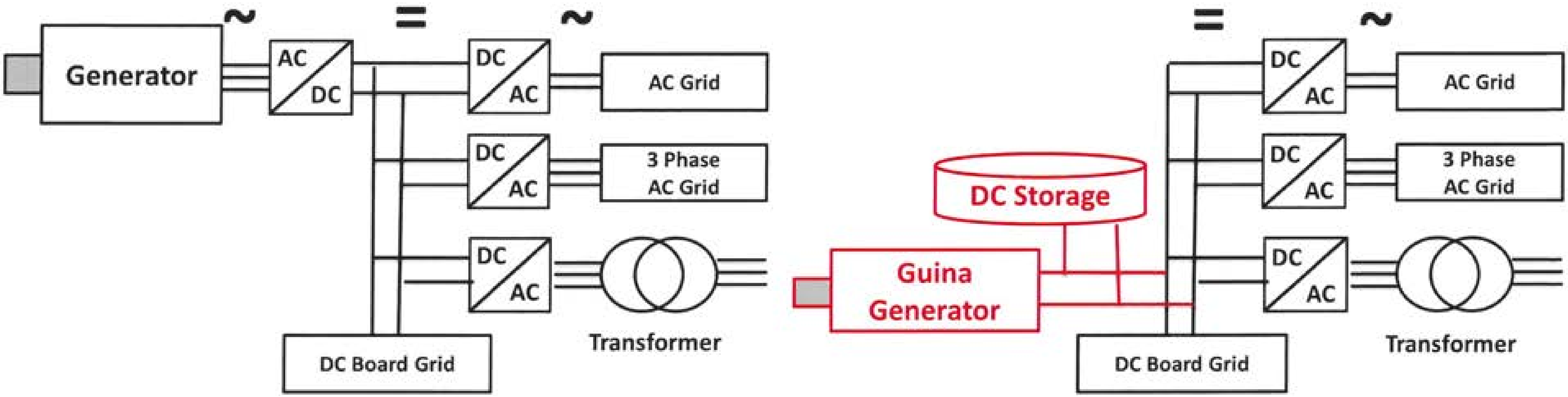



An aircraft's electrical grid can be very complicated due to differing requirements for different consumers. It is common to convert a significant portion of the energy into DC power. DC generators can simplify the grid system and reduce losses in the converter.

# MORE ELECTRIC AIRCRAFT

GUINA ENERGY GROUP

## Aircraft Energy Distribution Network

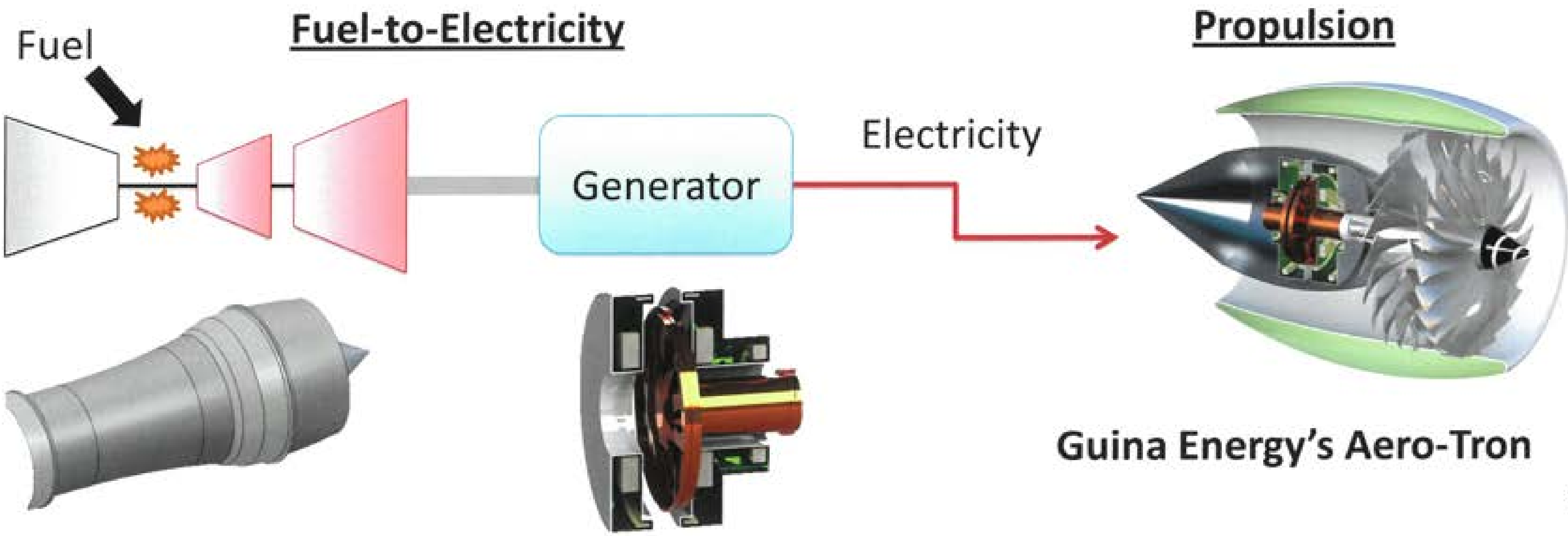



- Reduced grid complexity
- High power to weight ratios
- Easy implementation of energy storage systems
- Counter rotating motor

# HYBRID ELECTRIC AIRCRAFT

Hybrid cars are already present on nearly every road in the world. This combination of combustion engines and electric motors increases the efficiency of these vehicles. Similar effects can be achieved in aircraft by decoupling the combustion turbines from the propulsion fans and using:

- a combination of combustion turbines and electrical fans during high thrust demand (starting, climbing,...) and pure combustion propulsion during cruising;
- a central combustion turbine and generator unit supplying electrical power to electrically driven propellers or fans;
- electric storage systems together with combustion turbine and generator units that provide power for a purely electrically driven propulsion system.

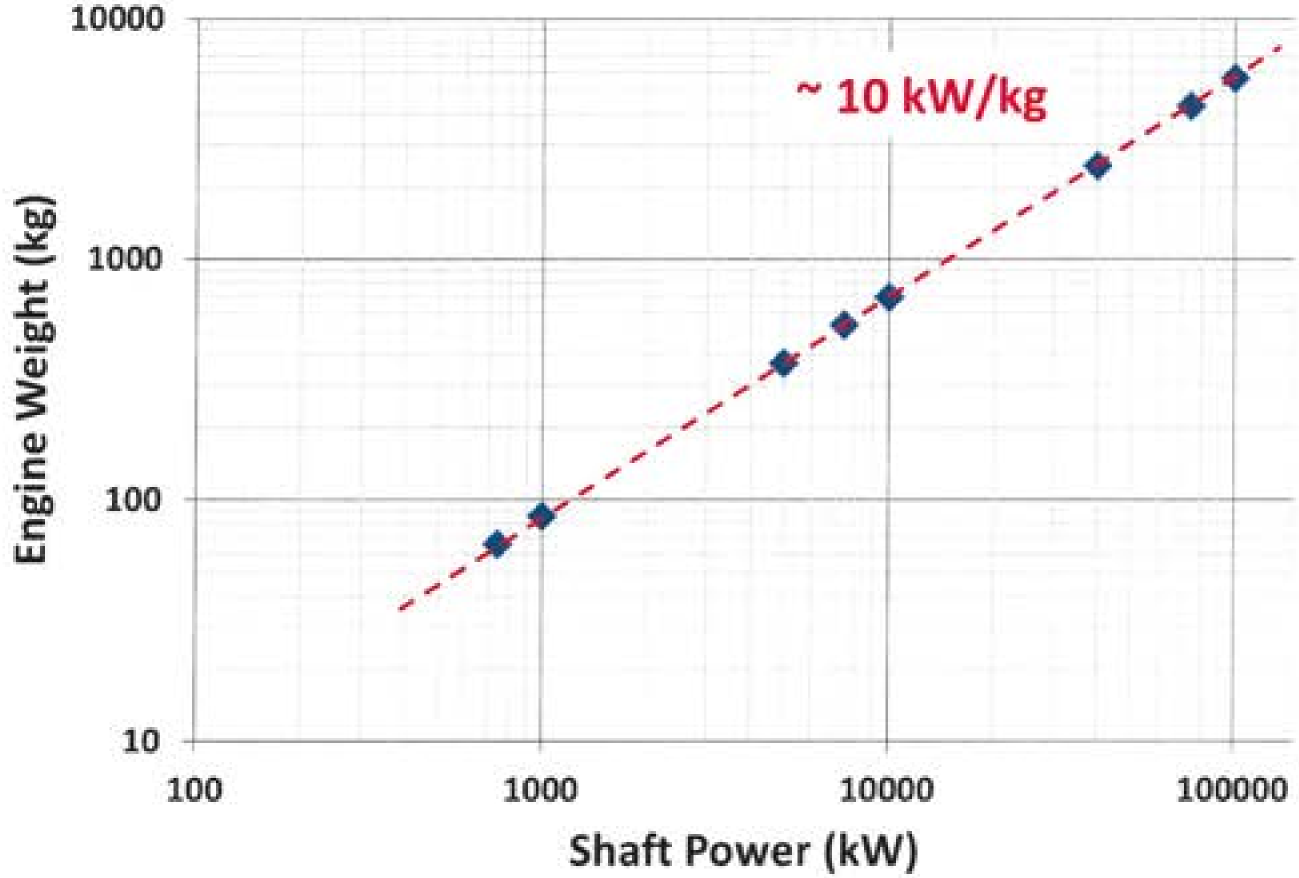



**Guina Energy's Aero-Tron**

## Engine Weight

| Power to Weight | Engine/Motor Type |
|---|---|
| 30 kW/kg | Cryogenic motor design |
| 16 kW/kg | Large turbine engines |
| 5.6 kW/kg | Advanced non-cryogenic motors |
| 2.3 kW/kg | Large industrial motors |
| 0.8 kW/kg | Small aircraft reciprocating engines |
| 0.3 kW/kg | Small industrial motors |

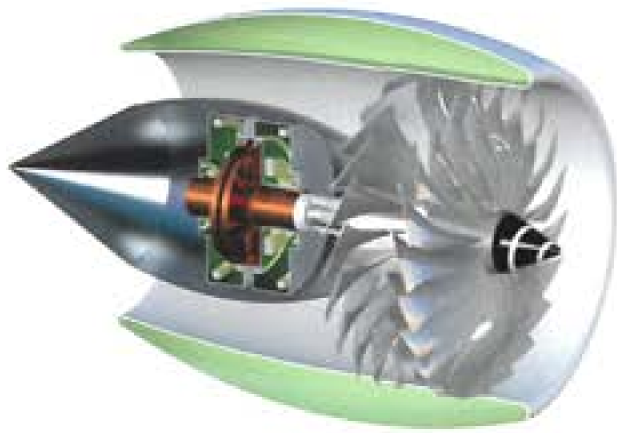
Turbofan engine weight as a function of effective replacement shaft power



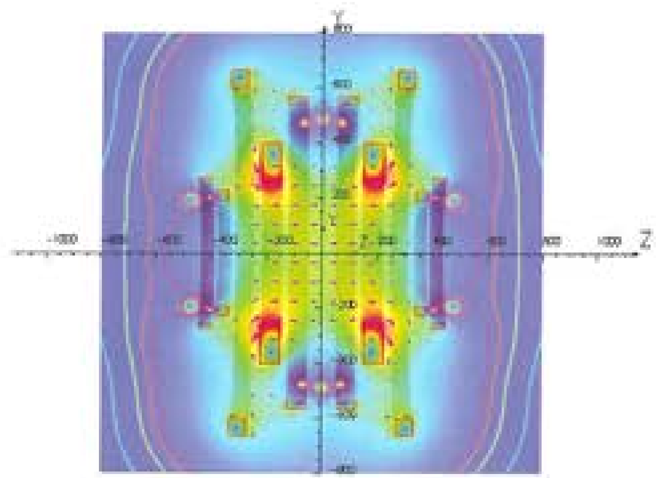

**The major issue with electric motors are their power to weight ratios. Different studies have shown that an increase in power density is required to compete with current turbines.**

# FULL ELECTRIC AIRCRAFT

In the long term, fully electric powered aircraft are being considered for civil aviation. In these planes the power is supplied by electric storage systems and/or “green” power sources. Electric propulsion systems with high efficiency and high power-to-weight ratios are only possible using superconducting motors. Our Electromagnetic Turbines offer extremely high power-to-weight ratios and overcome some of the traditional drawbacks of superconducting motors.



- New technologies are necessary to realise a very low or zero emission civil aircraft.
- Engineering challenges have to be overcome to incorporate these new technologies.
- Thinking outside of the box will be needed to make a full electric airplane possible.

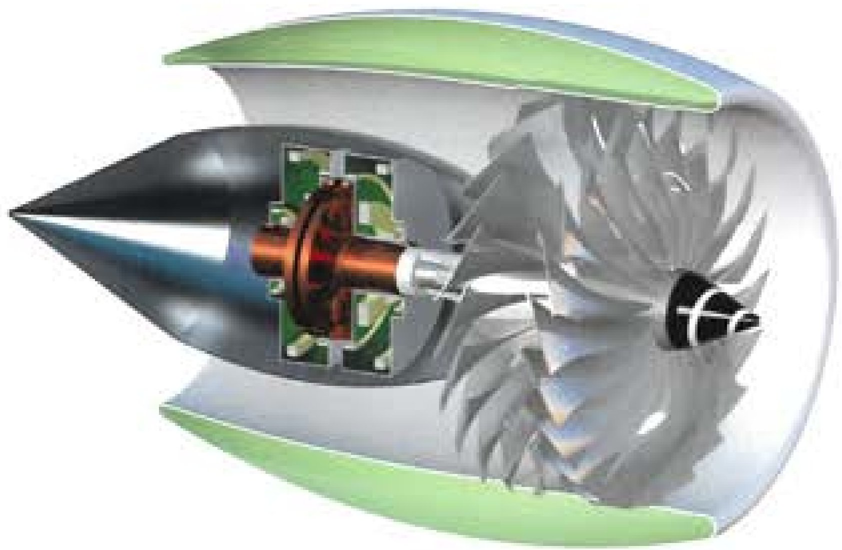


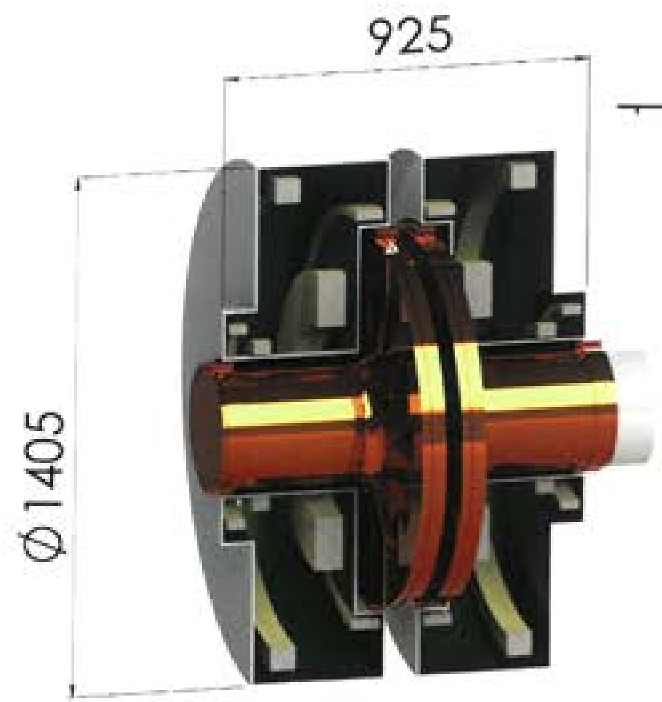
**Guina Energy Group — utilising the latest technology in novel ways to improve our future.**

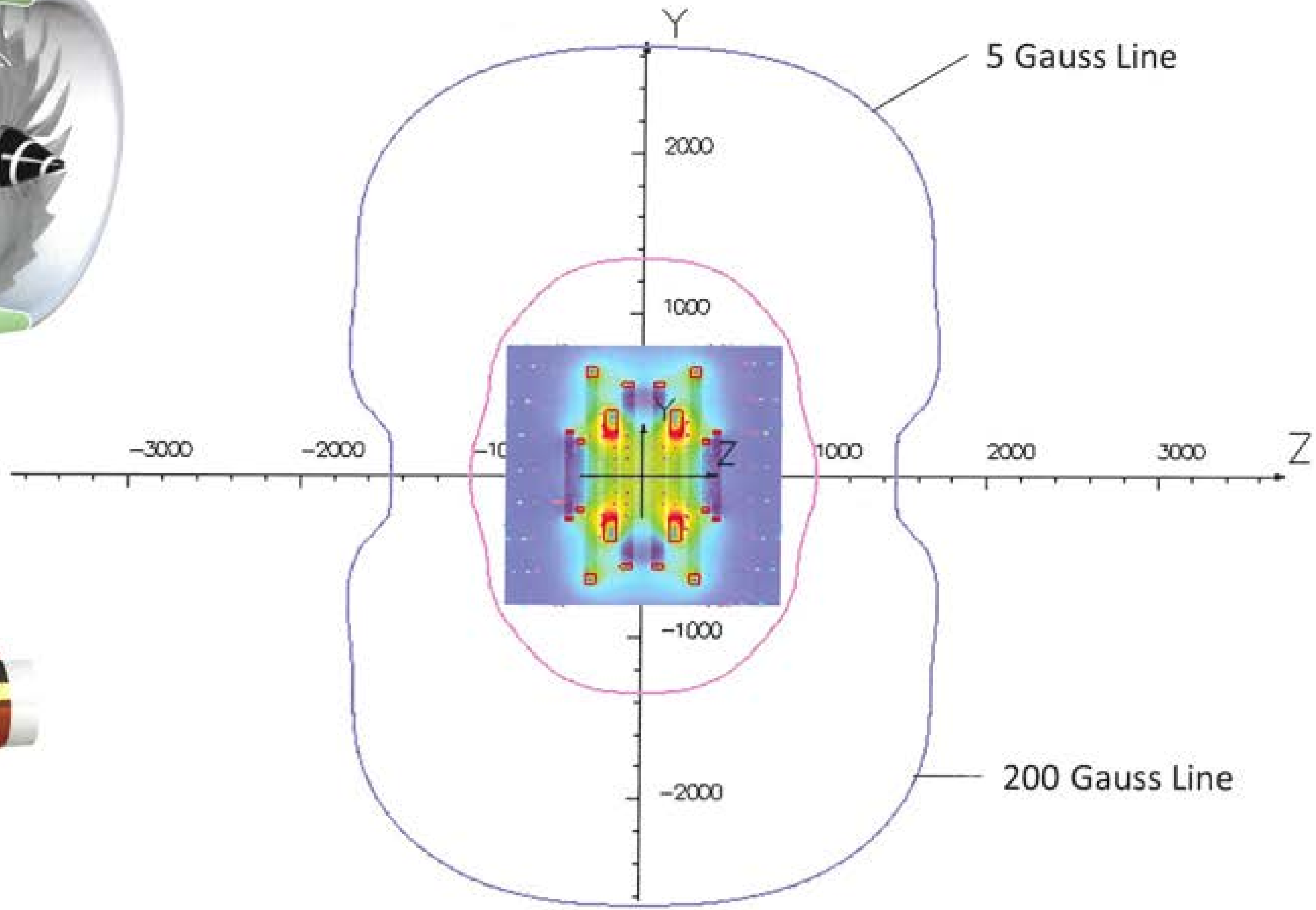
# 12 MW AERO-TRON COUNTER-ROTATING

GUINA ENERGY GROUP

| | |
|---|---|
| Power (MW) | **12** |
| Speed (RPM) | **2500** |

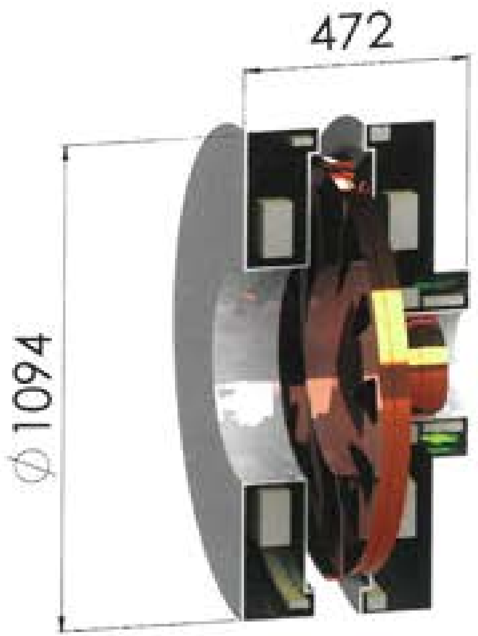


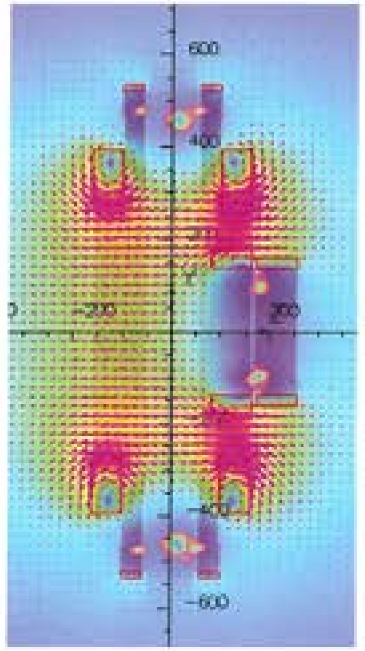


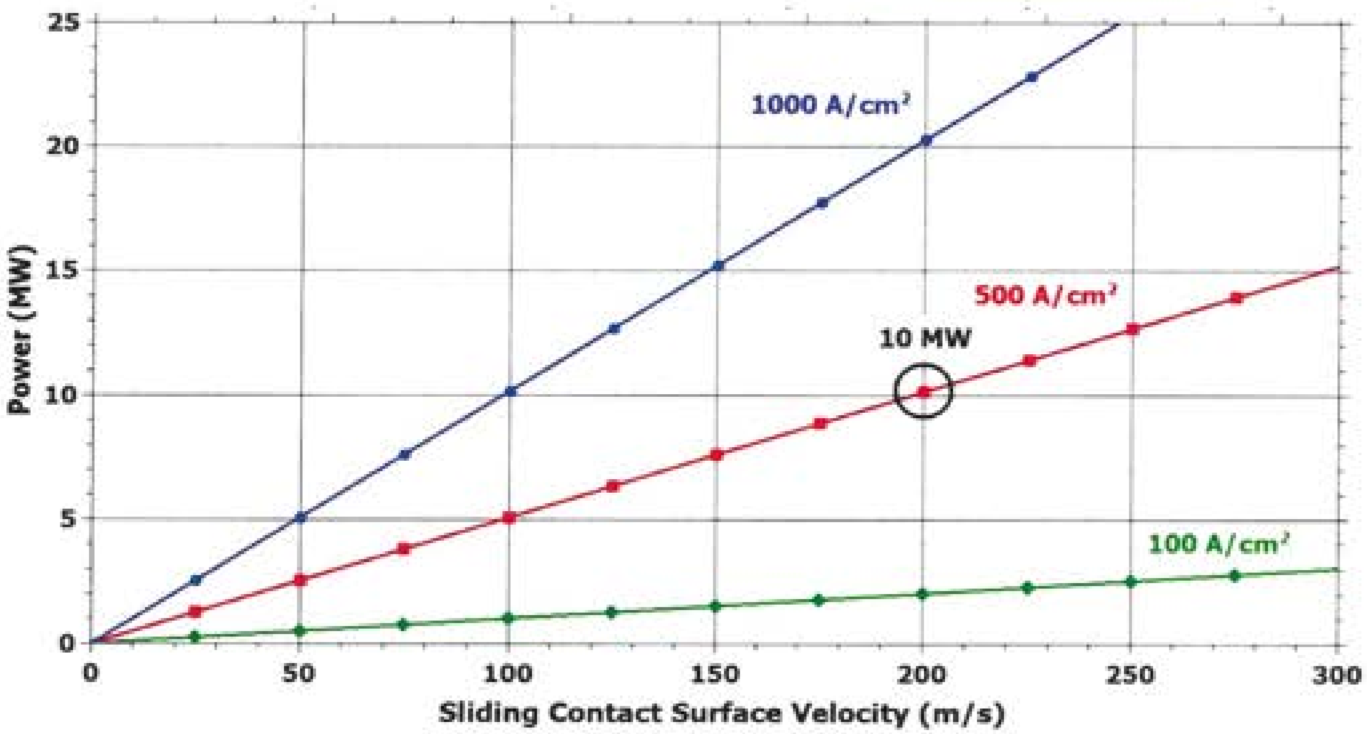

Incorporating Stray Field Reduction Technology

# 10 MW G1 AERO-TRON TURBINE MOTOR/GENERATOR DATA



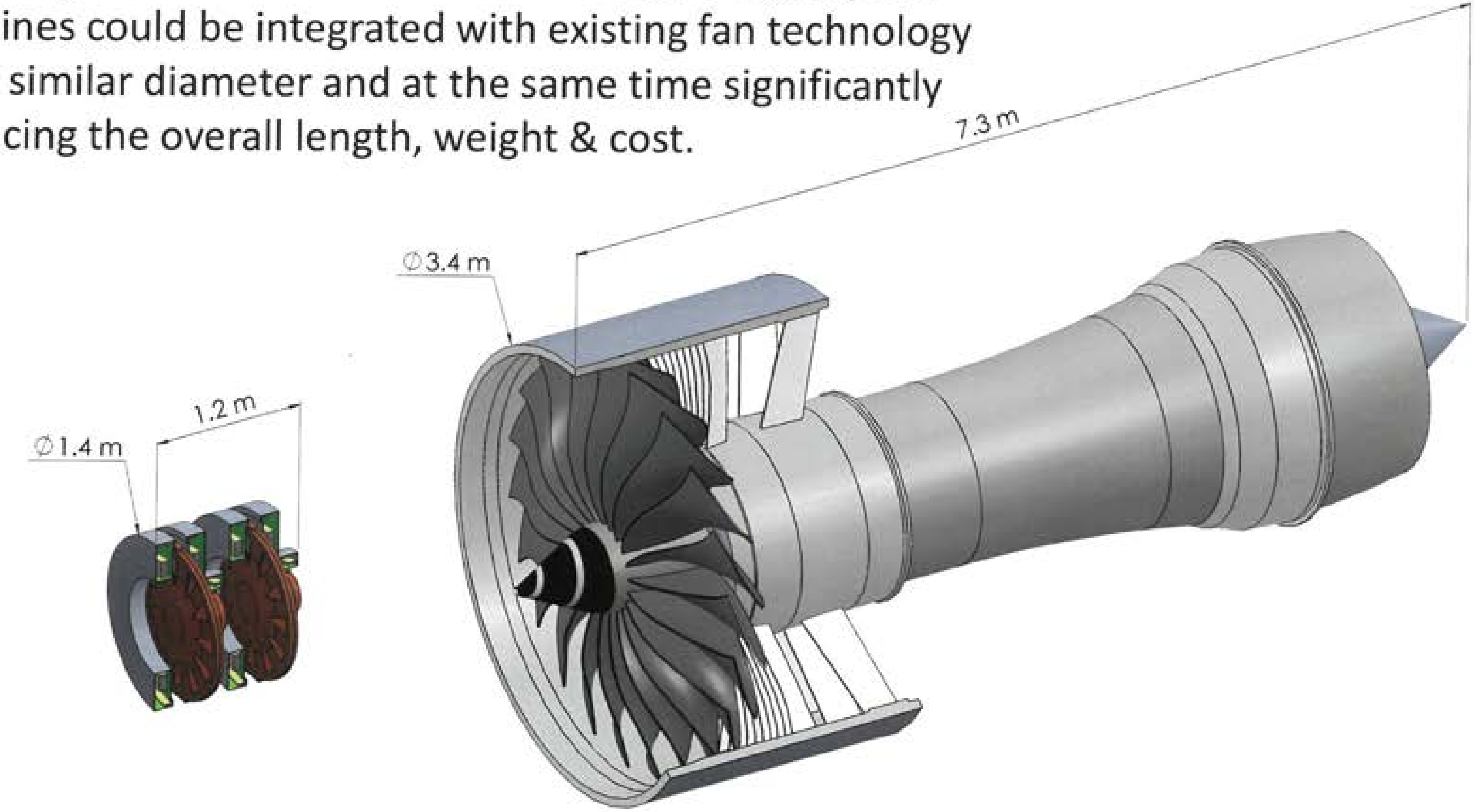
| | |
|---|---|
| Power (MW) | 10 |
| Speed (RPM) | 2500 |
| Total Current (A) | 138956 |
| LMB Current Density A/cm² | 500 |
| Max Rotor Tip Speed (m/s) | 116 |
| Max Coil Radius (mm) | 505 |
| Brush Contact Area (cm²) | 278 |
| Rotor Radius (mm) | 442 |
| Rotor Material | Aluminium |
| Rotor Weight Estimate (kg) | 105 |
| Super Conductive Wire | $Nb_3Sn$ |
| SC Wire Length (km) based on ϕ 0.85 mm wire | 49 |
| SC Wire Weight (kg) | 193 |
| SC Wire Packing Factor | 0.6 |
| SC Wire current density (A/mm²) | 260 |
| Peak Field on wire (T) | 12 |
| Peak force between coils (kN) | 4132 |
| Cryogenic Temperature (K) | 4 |




The graph shows the output power for different sliding contact current densities and surface velocities

# ENGINE SIZE COMPARISON

This Diagram illustrates how Guina Energy's High Speed Turbines could be integrated with existing fan technology with similar diameter and at the same time significantly reducing the overall length, weight & cost.



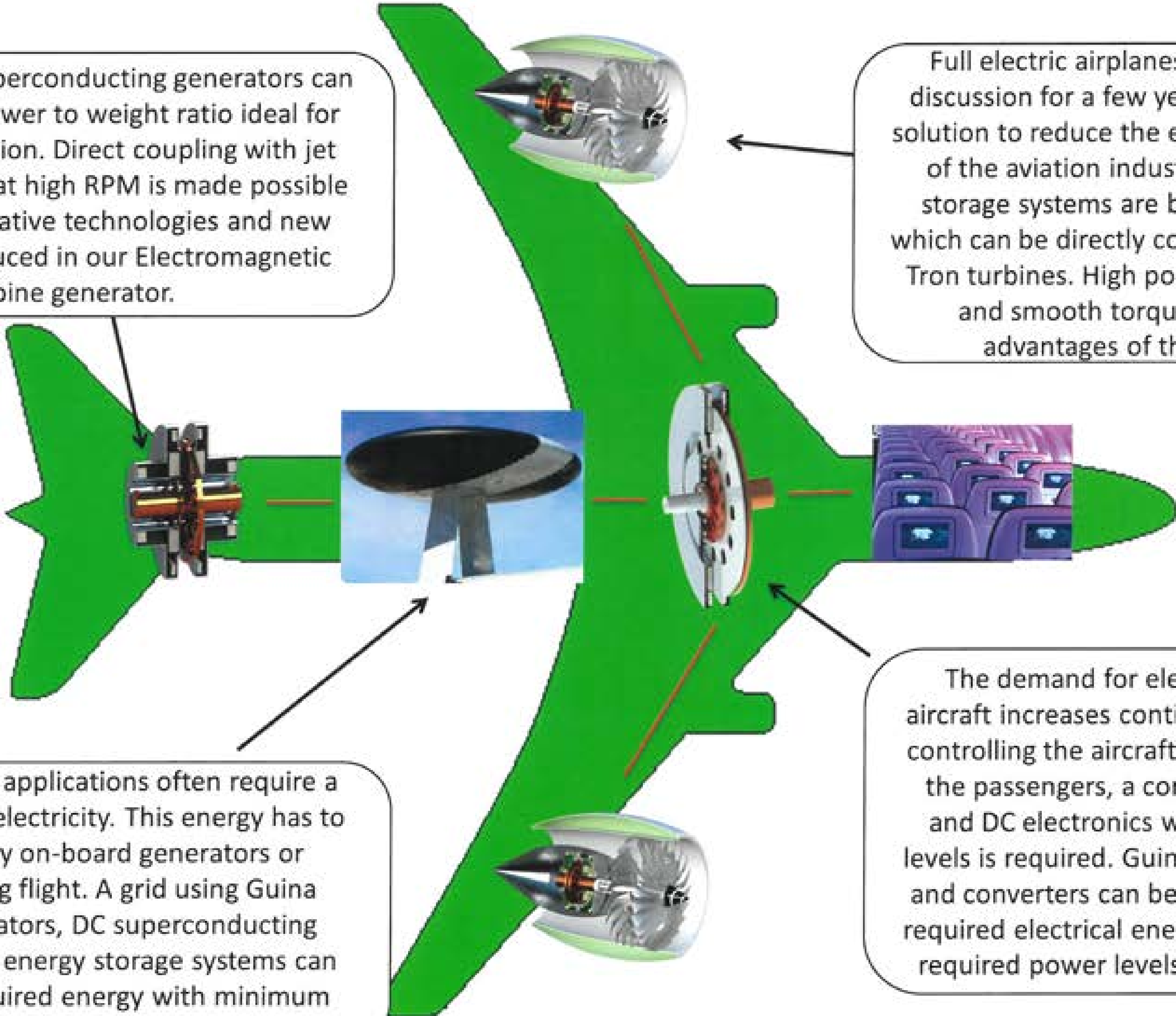

**Guina Energy's Turbine Overall Dimensions**
**80,000 kW (2X 40,000 kW Turbines)**
**- Approx 107,000 hp**

**Approximate turbofan engine dimensions (80,000 to 90,000 kW class) typically used by present-day large commercial aircraft**

# ELECTRIC AVIATION

Guina Energy's superconducting generators can achieve a high power to weight ratio ideal for airborne application. Direct coupling with jet turbines working at high RPM is made possible due to the innovative technologies and new materials introduced in our Electromagnetic Turbine generator.

Full electric airplanes have been under discussion for a few years now and offer a solution to reduce the environmental impact of the aviation industry. Electric energy storage systems are based on DC power which can be directly connected to our Aero-Tron turbines. High power to weight ratios and smooth torque are additional advantages of these turbines.



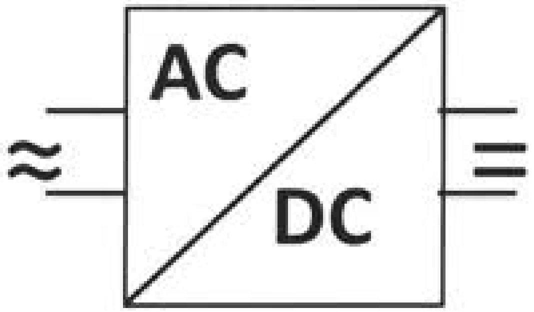
Modern military applications often require a huge amount of electricity. This energy has to be provided by on-board generators or batteries during flight. A grid using Guina Energy's generators, DC superconducting cables and short energy storage systems can provide the required energy with minimum weight.

The demand for electricity in modern aircraft increases continuously. Whether for controlling the aircraft or for the comfort of the passengers, a complicated grid of AC and DC electronics with different power levels is required. Guina Energy's generators and converters can be used to produce the required electrical energy and distribute the required power levels to the applications.

# PRESENTING:
# SMART GRID SOLUTIONS

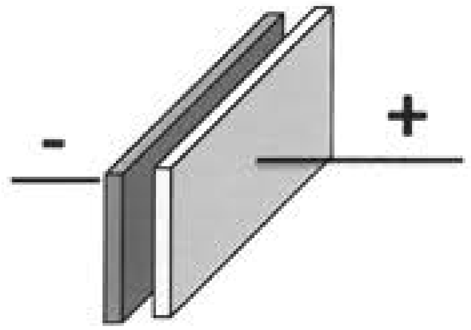
# MOTIVATION

## Mixed AC and DC Network

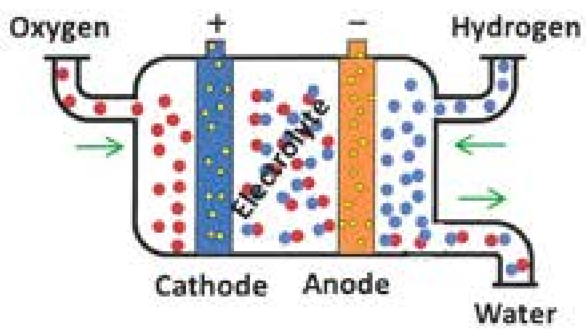




Battery




Capacitor




Fuel Cell

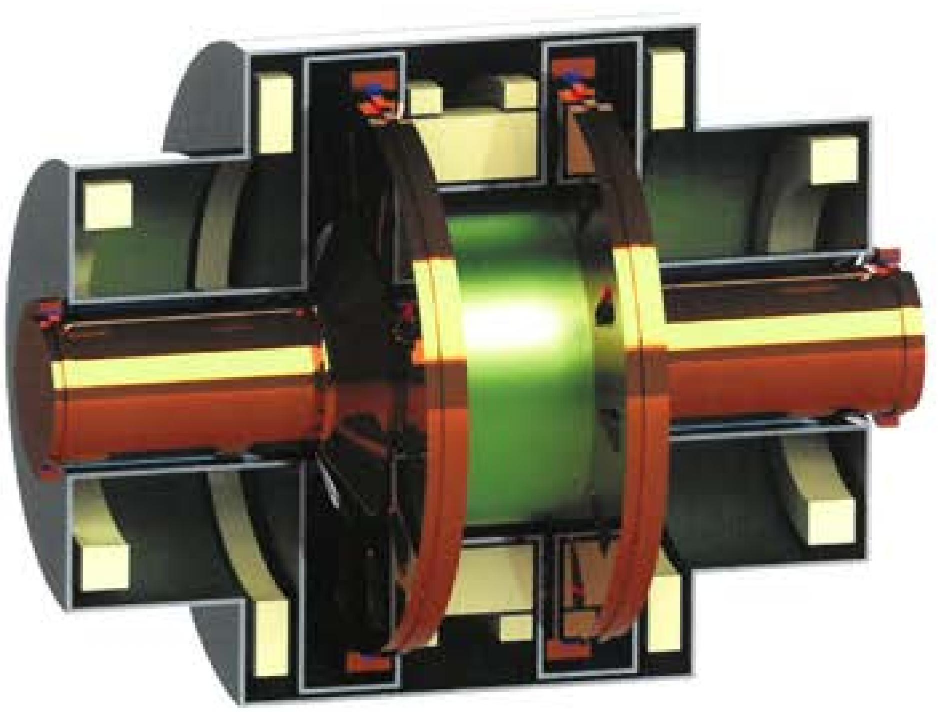
**AC Motor and Generator**

**Converter**

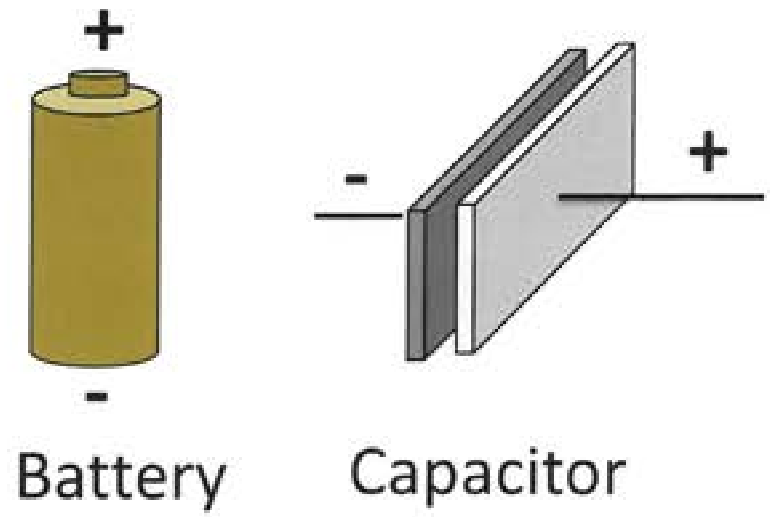
**DC Energy Storage Systems**

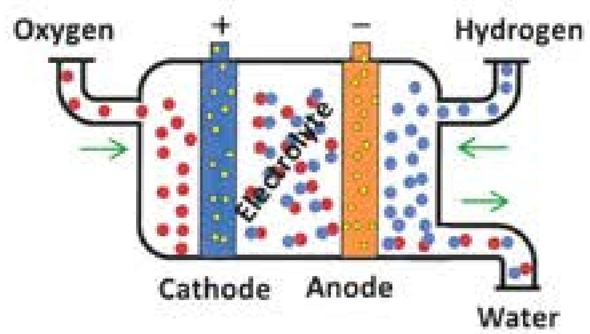
# MOTIVATION

## Pure DC Network



**DC Electromagnetic Turbines**



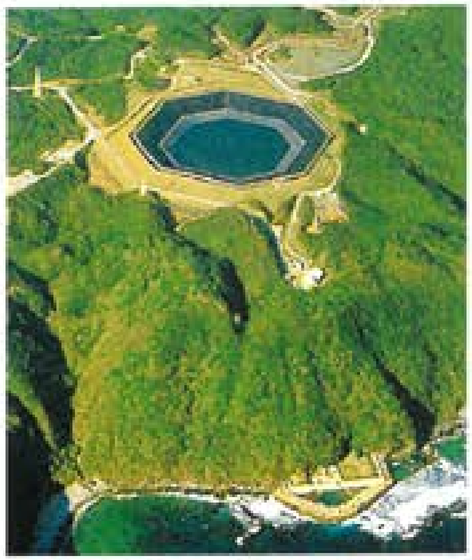

**DC Energy Storage Systems**

# ENERGY STORAGE IN THE GRID

## Electricity Generation

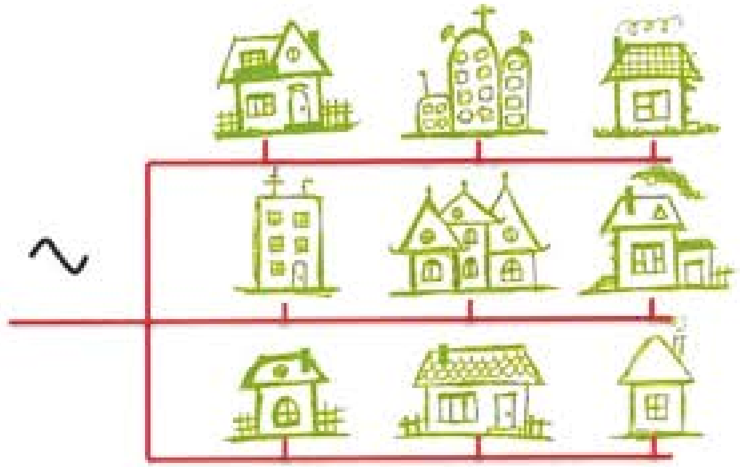
Generators only produce electricity during windy conditions

## Storage of Electricity



Fluctuation in electricity production must be compensated by storage systems

## Power Grid

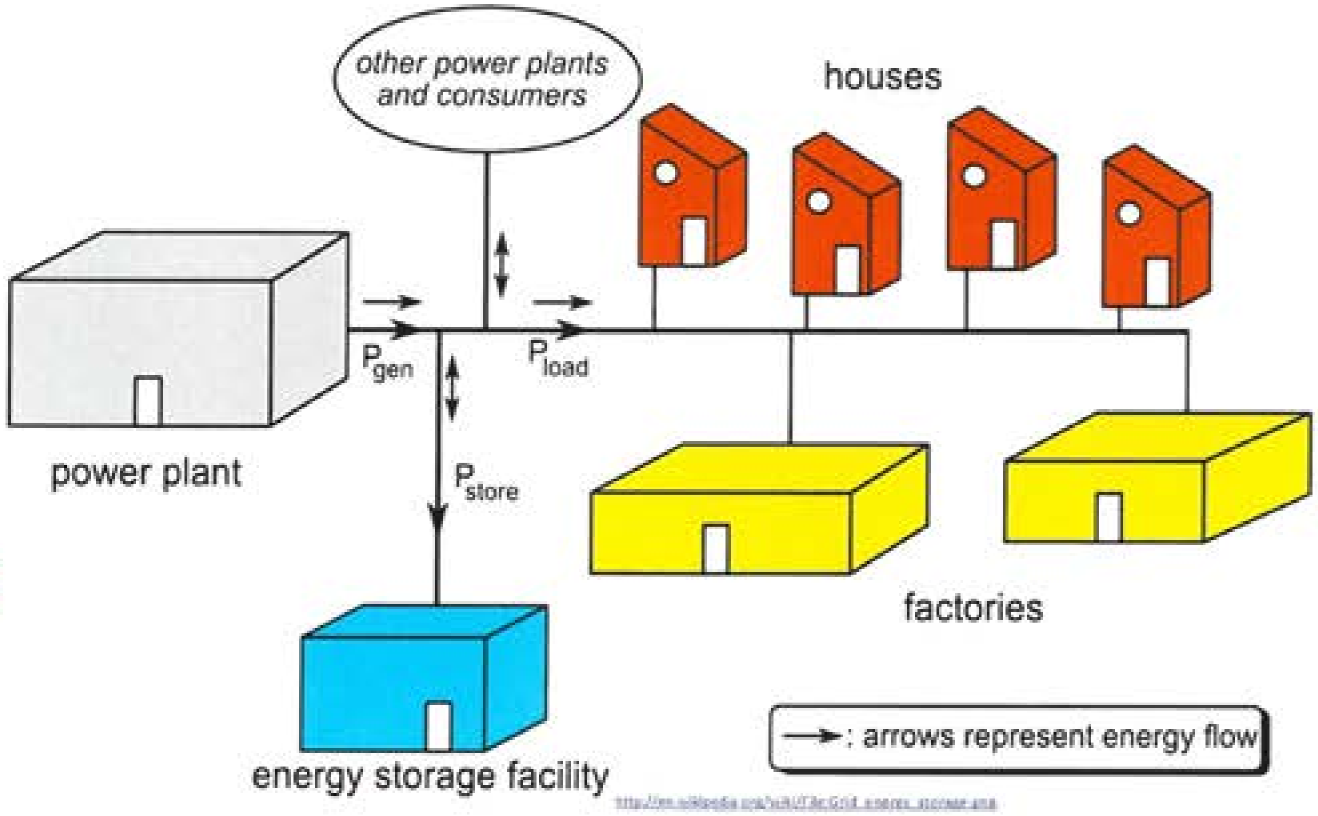


24 hour, sufficient, secured power supply has to be guaranteed

# GRID ENERGY STORAGE

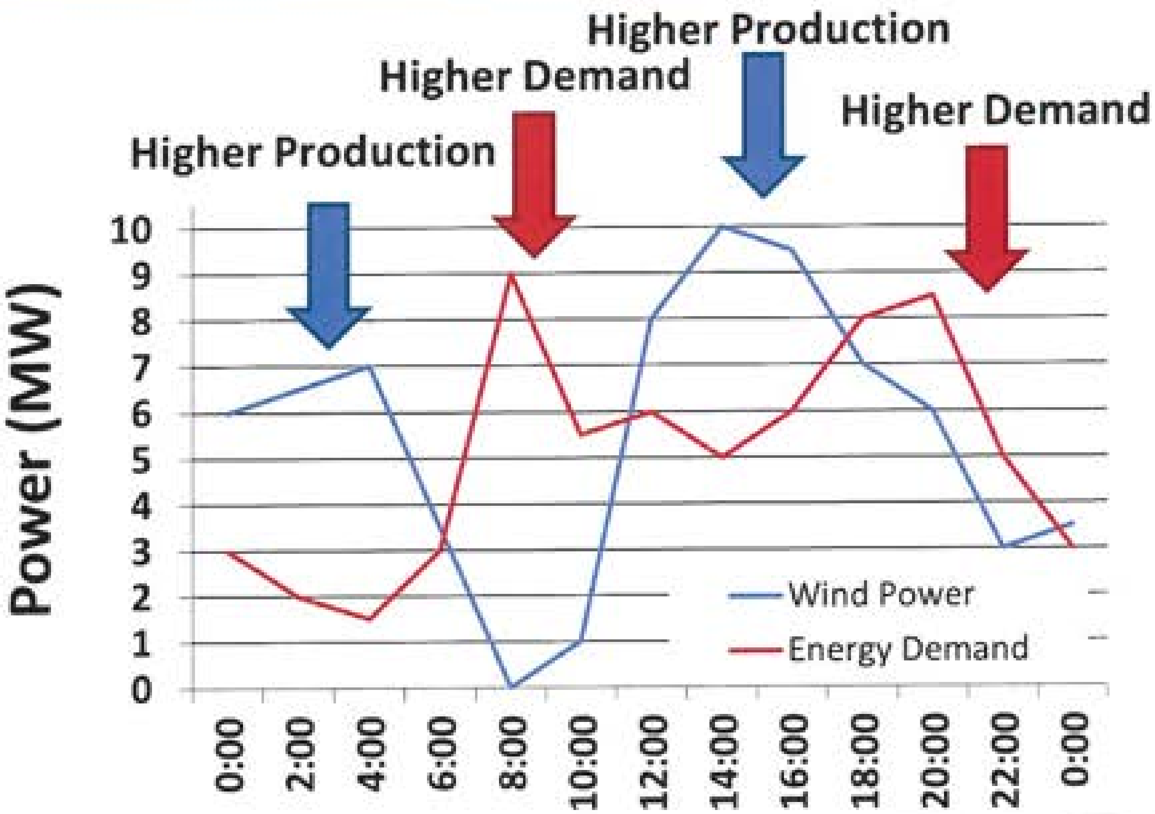
Autonomic power grids are mainly powered by diesel generators which are not environmentally friendly. More and more remote, inhabited places (such as islands, mining towns, ...) are changing their electric energy production to pollution-free systems. Storage of energy is essential for autonomic power grids to balance out power production and demand. Storage systems that are available and in operation include the following:

- Batteries / Capacitor DC
- Compressed air Mechanically
- Flywheel Mechanically
- Hydrogen DC
- Pumped water Mechanically
- Superconducting magnetic energy DC
- Heat storage Thermal




**Electricity can be directly stored only in DC form.**

# POWER MANAGEMENT



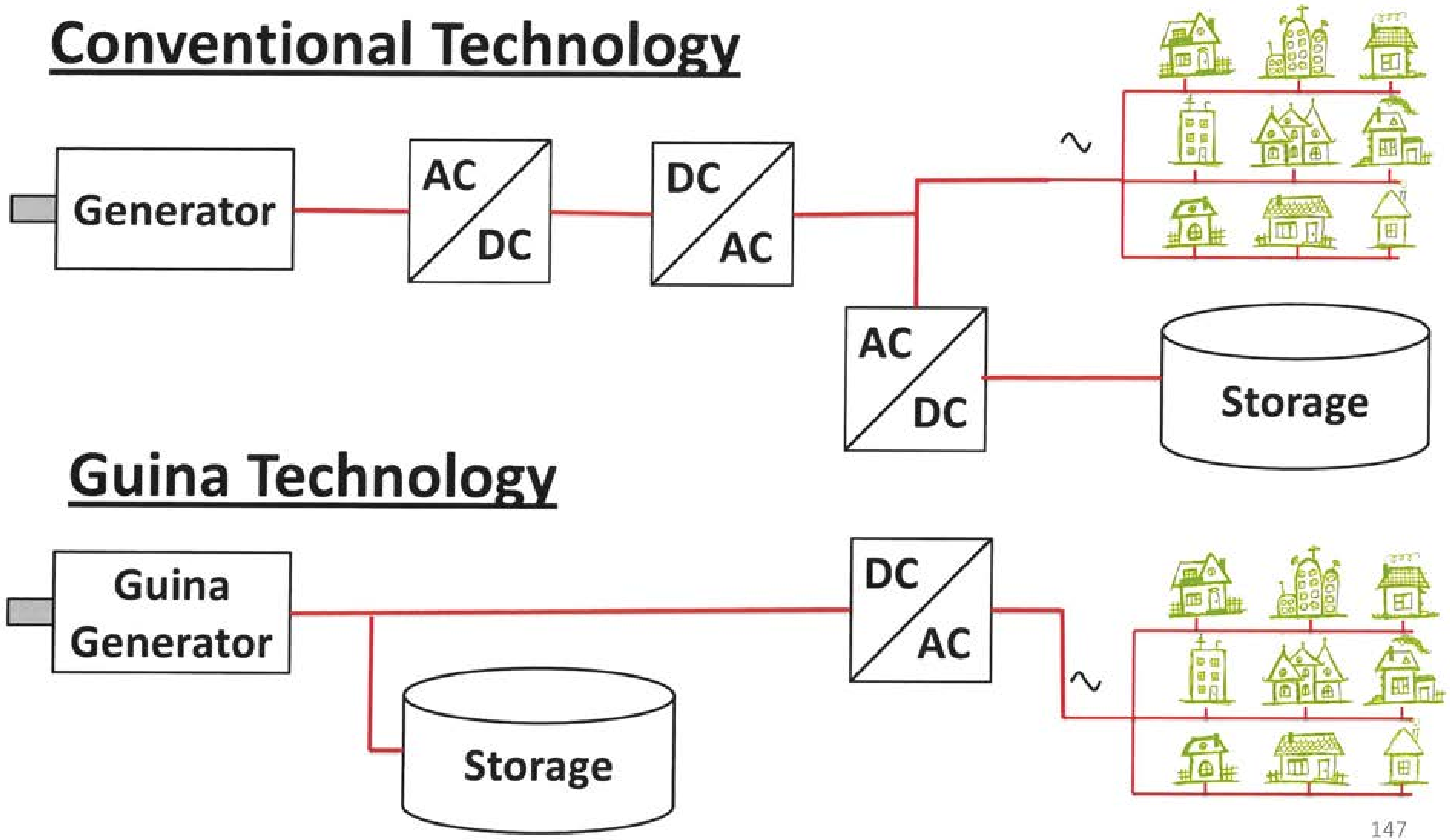

**Required Storage Systems**

- Short term for rapid load changes or gusts
- Medium term for daily demand variations (day / night time)
- Long term during maintenance or prolonged periods without wind (alternative energy source)

**Direct Current (DC) storage systems have higher return efficiencies compared to other technologies.**

| Technology | Power Rating | Discharge Time | Efficiency | Storage Type |
|---|---|---|---|---|
| Pumped hydro | ≥150 MW | 4 – 12 h | 70 – 85 % | Mechanical |
| Flywheels | <20 MW | <1 h | 85 – 90 % | Mechanical |
| Li-Ion batteries | ≤10 MW | <8 h | 85 -95 % | Direct Current |
| Flow batteries | <10 MW | <10 h | 75 – 85 % | Direct Current |
| Superconducting magnetic energy storage | ≤100 MW | 1 - 30 min | ≤98 % | Direct Current |
| Hydrogen | <2 MW | as needed | 30 -45 % | Direct Current |

# AUTONOMIC SMALL GRIDS



# THE IMPACT OF GUINA ENERGY'S TECHNOLOGY

### Smart Energy Utilisation

- Our generators can be directly coupled with DC storage systems and increase the return efficiency of the total system. Systems including Guina Energy's generators coupled with storage systems can be optimised to provide energy independent from the instantaneous production rate.

### Power Electronics

- Reducing several steps of energy conversion in a grid increases the efficiency and reliability. Our electromagnetic power converter can be directly implemented into the generator or function as a stand alone unit to provide convenient voltage and current levels.

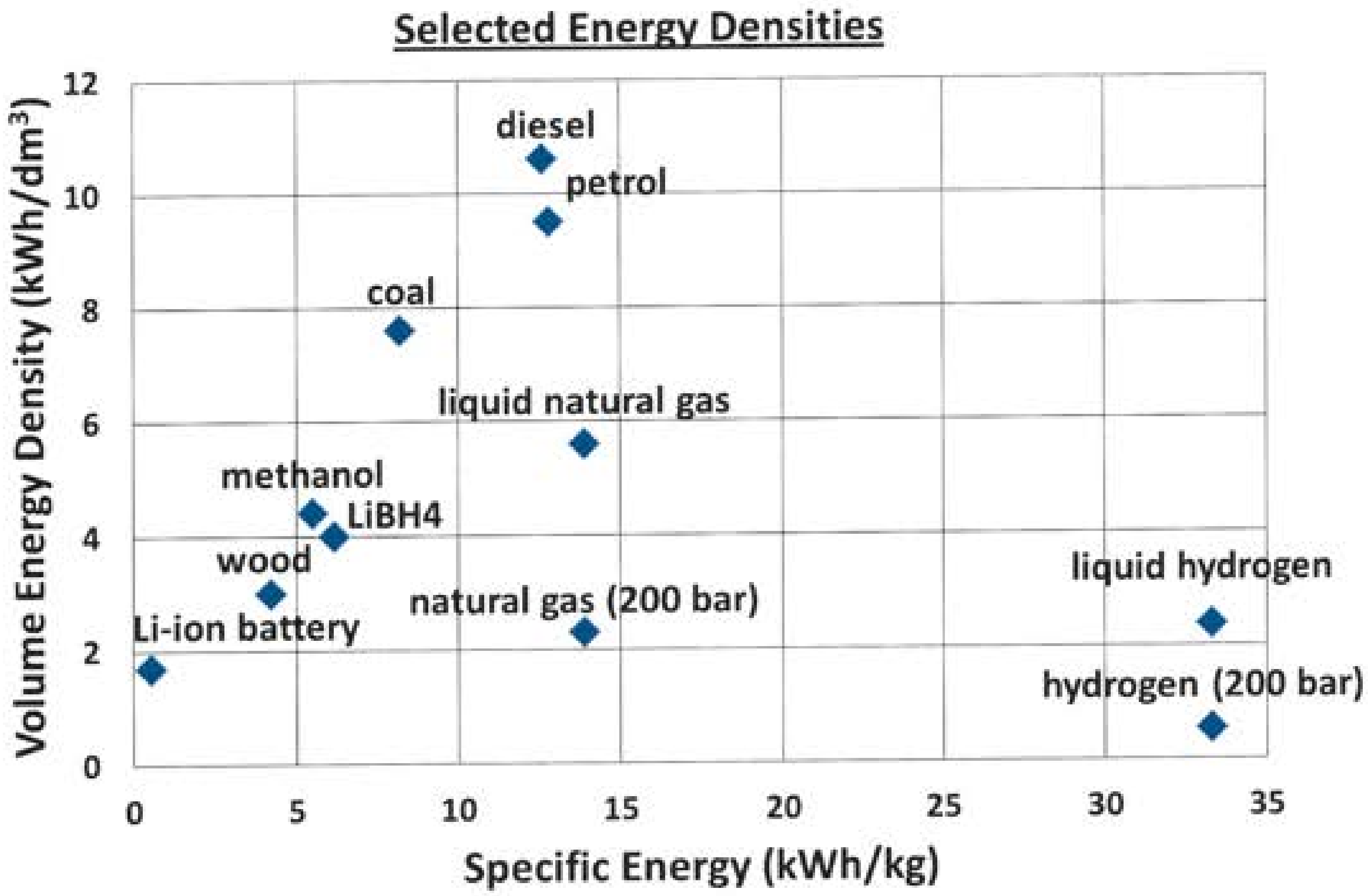
### Power to Size

- Guina Energy's homopolar machines are smaller and have better power to weight ratios than conventional machines. A smaller machine can provide greater flexibility in its implementation.

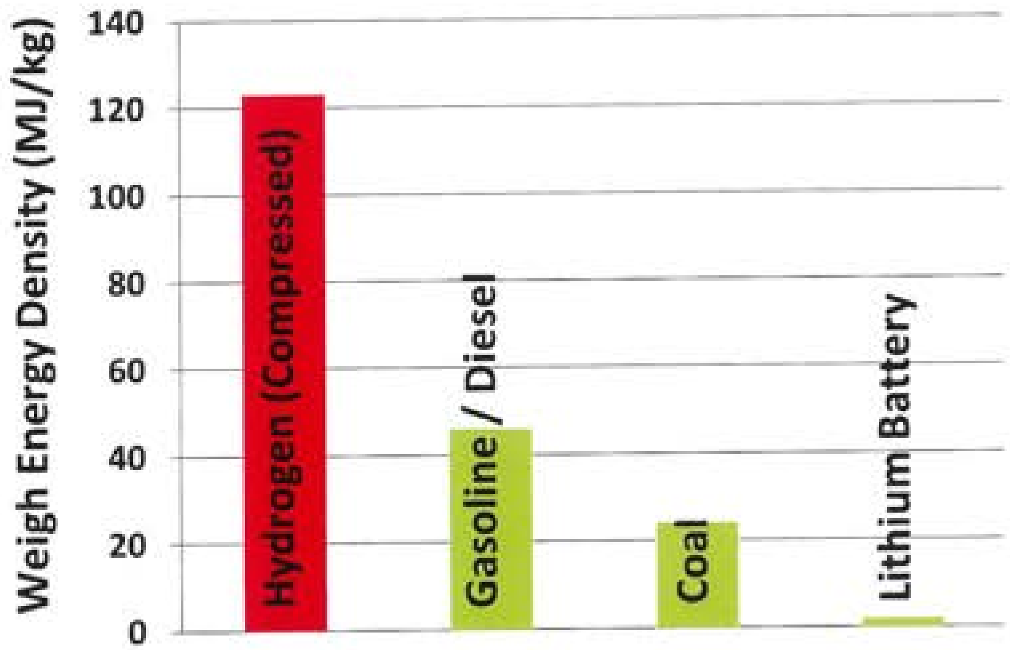
# PRESENTING:
# HYDROGEN ECONOMY

# HYDROGEN

Hydrogen is the simplest and lightest chemical element of the periodic table. Its density as a gas (0.0899 kg/Nm$^3$) is 15 times lighter than that of air. Hydrogen is a fuel with a wide in flammability range both in air and oxygen. It is also the fuel with the highest energy content per mass unit.




| Fuel | Specific Energy (kWh kg$^{-1}$) | Energy Density (kWh dm$^{-3}$) |
|---|---|---|
| Liquid Hydrogen | 33.3 | 2.37 |
| Hydrogen (200 bar) | 33.3 | 0.53 |
| Liquid Natural Gas | 13.9 | 5.6 |
| Natural Gas (200 bar) | 13.9 | 2.3 |
| Petrol | 12.8 | 9.5 |
| Diesel | 12.6 | 10.6 |
| Coal | 8.2 | 7.6 |
| LiBH4 | 6.16 | 4 |
| Methanol | 5.5 | 4.4 |
| Wood | 4.2 | 3 |
| Electricity (Li-ion battery) | 0.55 | 1.69 |




However, the volume energy density is low and hydrogen requires higher storage volumes than other fuels. Hydrogen can be produced by several different processing methods.

# FUEL OF THE FUTURE

## Why Hydrogen?

- Hydrogen is clean and easily available in most parts of the world.
- It can be stored, transported and quickly transferred (refilled).
- It can be used in combustion engines as well as directly in electricity converters (Fuel Cells).

## Why Hydrogen Economy?

With the increasing importance of renewable energy sources and larger variations in the daily energy demand, storage and transportation/transmission of electricity becomes more important in grid systems. Solutions which adapt current infrastructure and equipment are preferable. Hydrogen can replace natural gas in current pipelines, can be easy transformed into electricity, can be transported and is emission free. Energy storage solutions for transport applications have to be light, compact and easy to refill.

## What Our Technology can do?

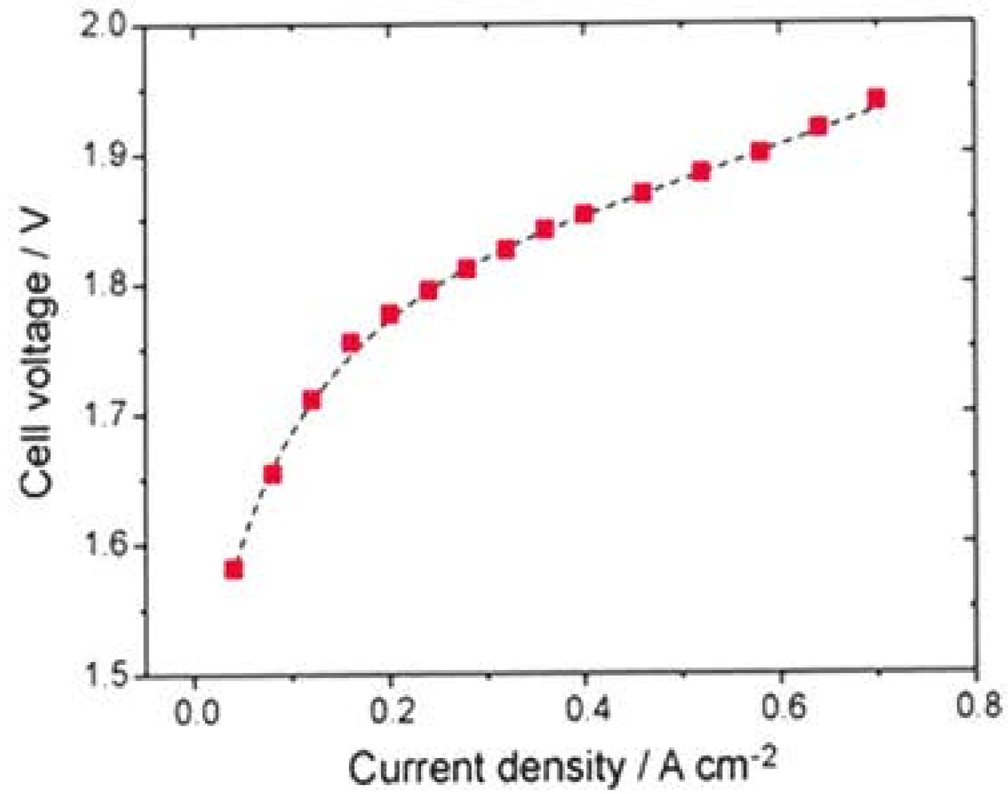
Our generators produce DC power which is required for the electrolysis of water. Electrolysis is the primary method of obtaining hydrogen from water. The hydrogen obtained with this technology has a high purity (99.999 vol.%) which is important for fuel cells. Additionally liquid hydrogen can be used as an excellent cooling medium for our superconducting generators.

# ELECTROLYSIS FROM WATER

A water electrolyser is an electrochemical device that converts electric and thermal energy into chemical energy stored in a fuel (hydrogen).

The global electrolysis reaction taking place is: $H_2O \rightarrow H_2 + \frac{1}{2}O_2$

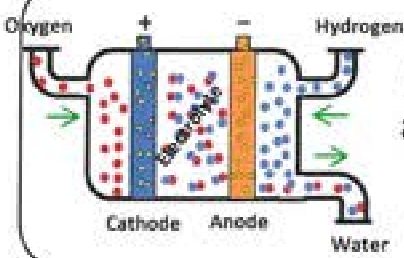
The voltage and current required for an efficient (i.e low heat loss) process can be calculated. Besides a complex relationship between temperature, pressure, materials and others the voltage required for a single cell is normally between 1.9 – 2.5 V. The current depends on the size of the system and is given normally as a current per unit area. To produce a high amount of hydrogen with a monopolar electrolyser the area and therefore the current has to be very high. Homopolar generators can exactly produce these low voltages and high currents without any power electronics.



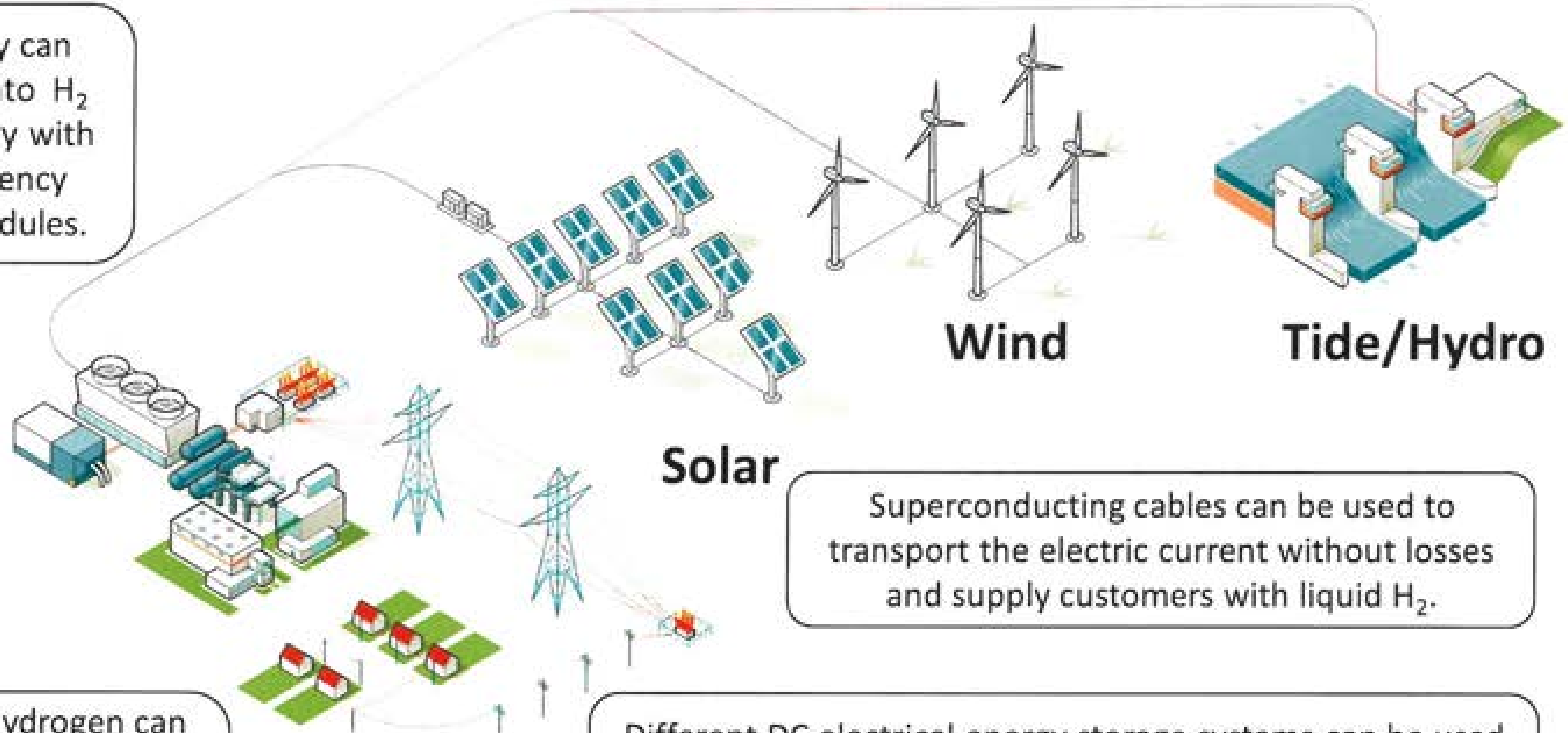
# HYDROGEN GREEN TOWN CONCEPT

Guina Energy's innovative Superconducting DC/DC converter can be used to convert DC power levels to suit load requirements.

Guina Energy's Superconducting Generators produce pure DC power with high currents and low voltages that are ideal for DC energy storage systems and hydrogen production. They can be used in wind turbines as well as all other rotating type generators.




Fuel cell technology can convert electricity into $H_2$ and back to electricity with higher return efficiency than electrolysis modules.




Superconducting cables can be used to transport the electric current without losses and supply customers with liquid $H_2$.

The highest energy storage capacity of hydrogen can be achieved when the hydrogen is liquefied. Hydrogen plants can produce liquid hydrogen during off-peak demand for further use in transportation vehicles, off-grid systems, cooling, etc.

Different DC electrical energy storage systems can be used to regulate the energy demand during periods of peak demand and low electricity production.

# PRESENTING:
# WIND TURBINE GENERATOR TECHNOLOGY

# WIND POWER GENERATOR

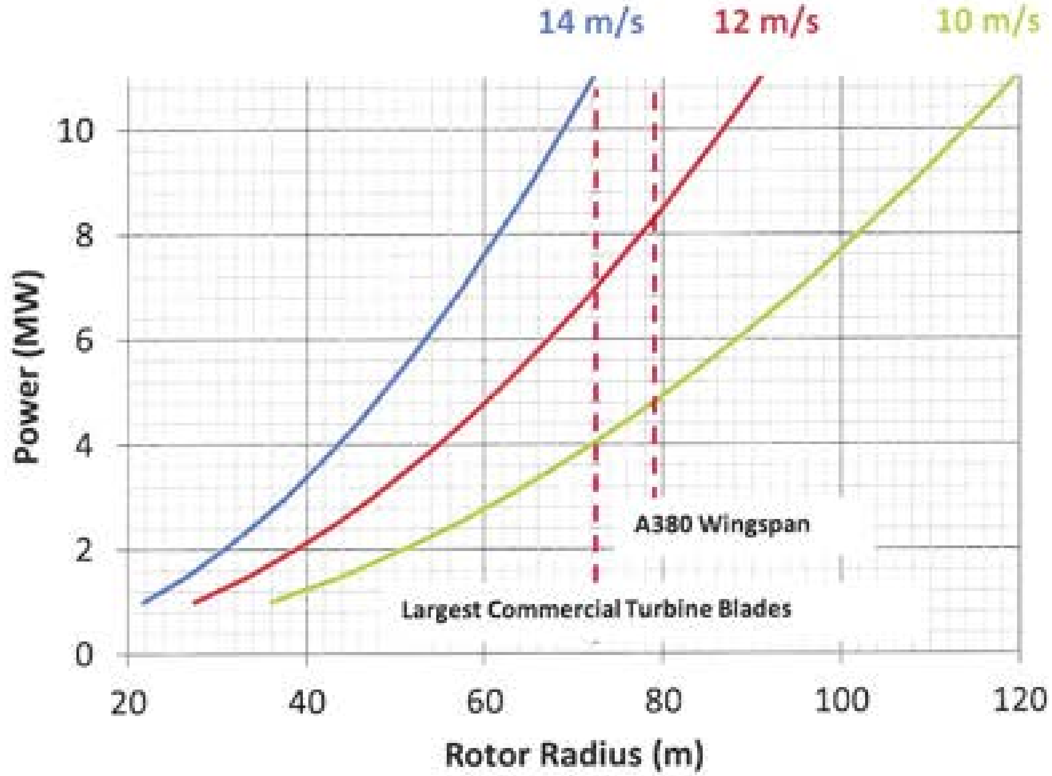
Different types of generators are used in modern wind turbines to convert the mechanical energy into electricity – including:

- Synchronous Generators
- Induction Generators
- Asynchronous Generators
- Permanent Magnet Generators
- ...

But traditional techniques with conventional generators and gearboxes rapidly reach their practical limits because of the special requirements of wind turbines. Wind turbines have low rotation speeds with high torques and they have to be mounted on top of a tower where weight and size issues become crucial. The limit of rated power for conventional systems appears to be around 8 MW.

# WIND TURBINE THEORY (1/4)

The power which can be extracted from the wind by a wind turbine depends on the swept area, wind speed, the density of air and the coefficient of performance of the wind turbine. After optimizing all other parameters the only way to increase the power output further is to increase the rotor diameter.




## *Captured Wind Power*

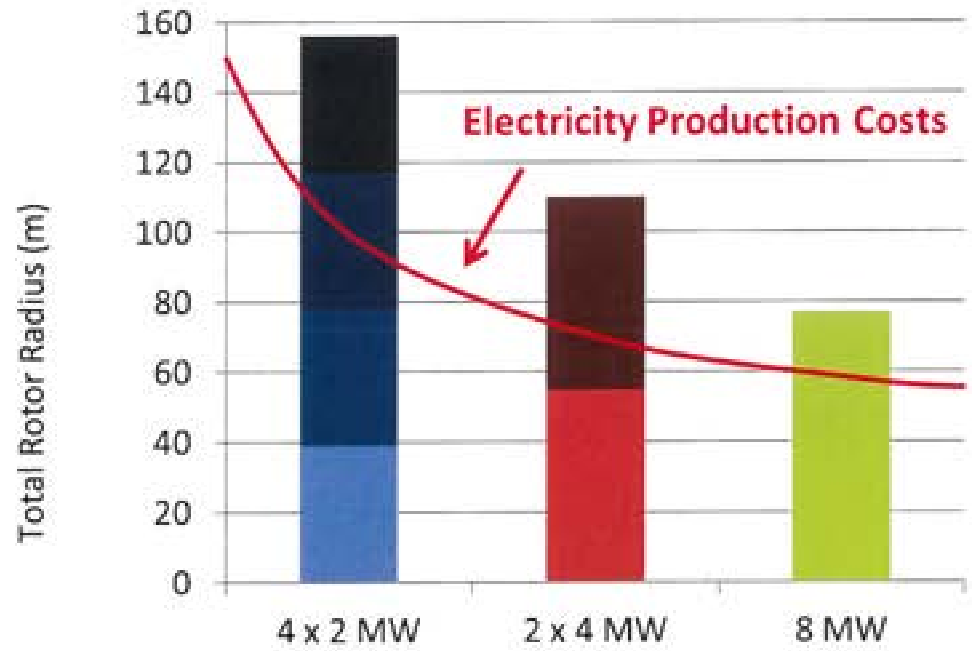
$$P = \frac{A\rho v^3 C_p}{2}$$

A ... swept area
$\rho$ ... density of air
v ... wind speed
$C_p$ ... coefficient of performance

$$R = \sqrt{\frac{P \times 2}{\rho \times v^3 \times C_p \times \pi}}$$

## Coefficient of performance ($C_p$)

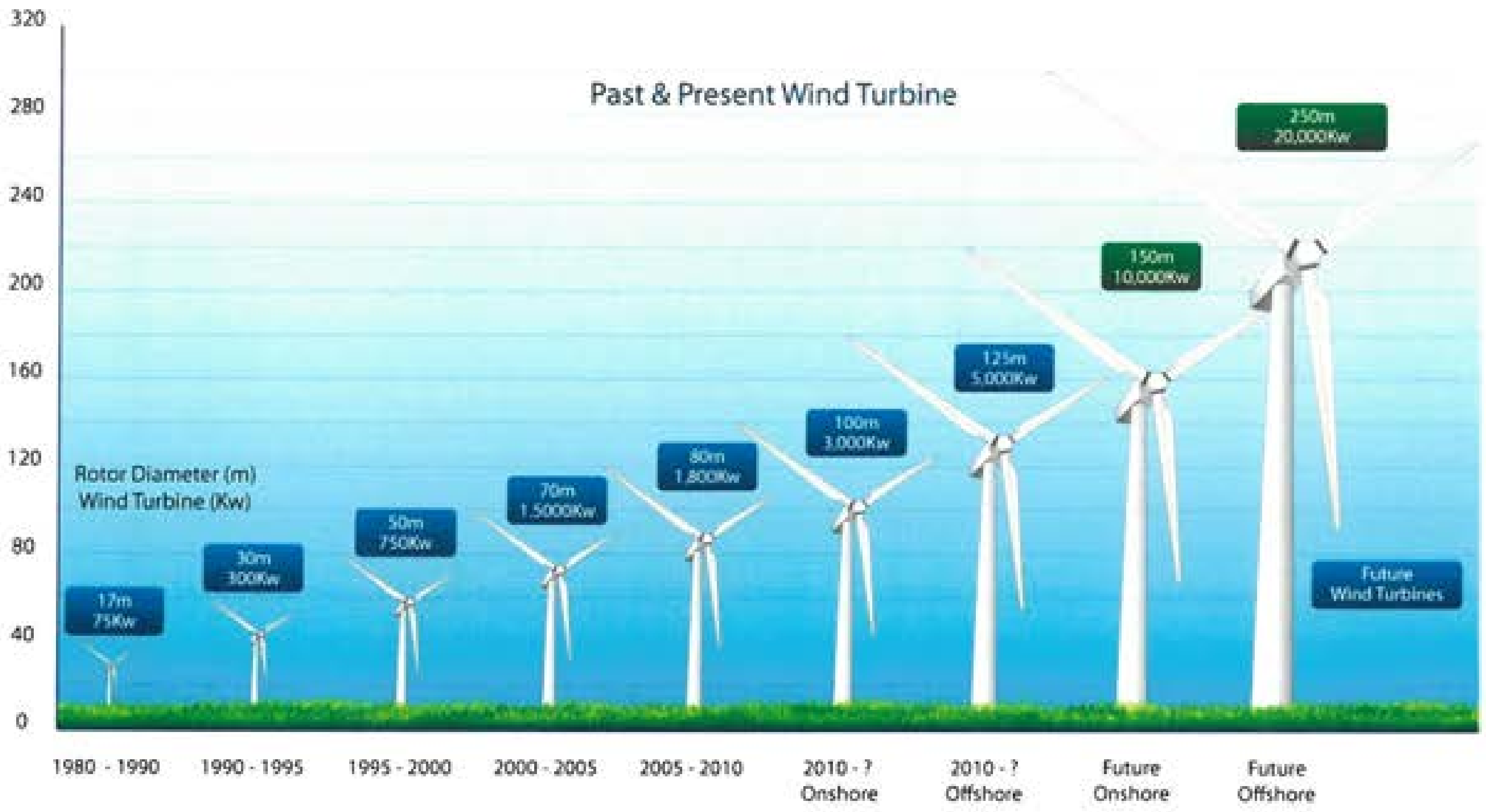
A maximum theoretical limit for the $C_p$ is given by the Betz Limit which can't be higher than 59%. The latest wind turbine designs reach a $C_p$ of 0.45 for their rated wind speed.




**Larger wind turbines can capture more power but have to be designed carefully.**

# WIND TURBINE THEORY (2/4)

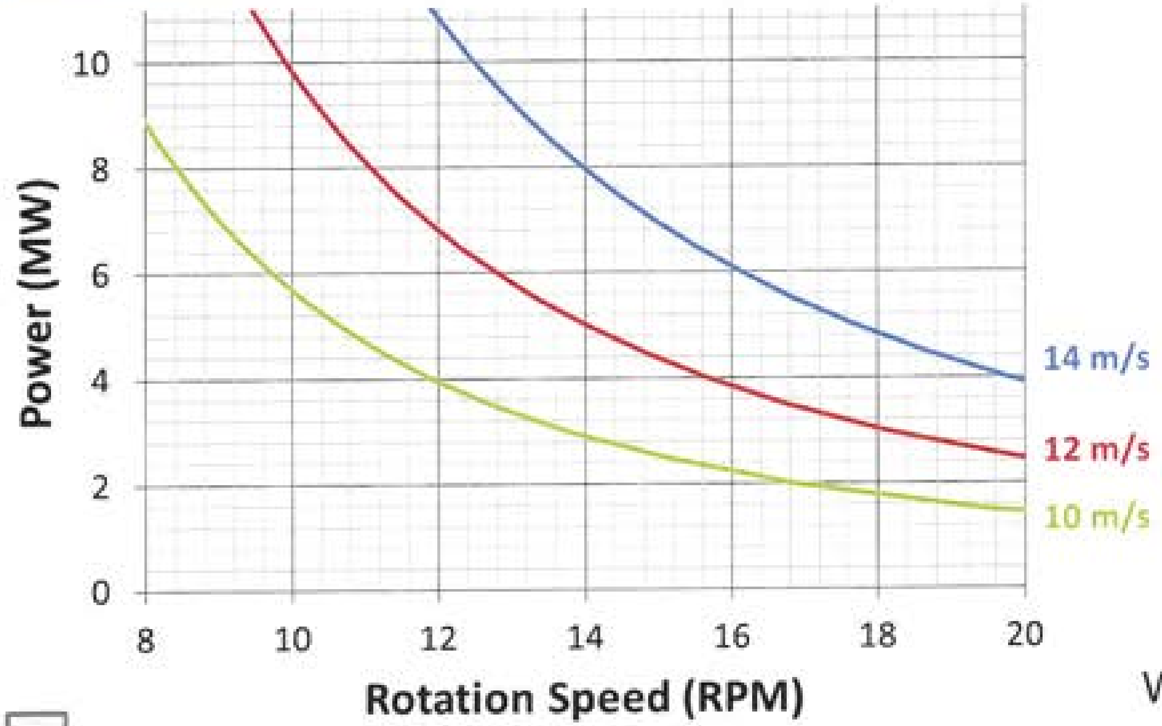
## History of Wind Turbine Size Development




**Wind turbines become more efficient with increasing turbine size due to the larger captured wind power.**

The equation on the previous slide also shows that two turbines with the same rotor diameter produce less power than one turbine with double the rotor diameter. This makes larger wind turbines more efficient and lowers the production cost of the electricity. Additionally two turbines require more area than one turbine for the same total power. Larger bladed turbines decrease the total size of a wind farm. This explains the trend towards larger turbines.

# WIND TURBINE THEORY (3/4)

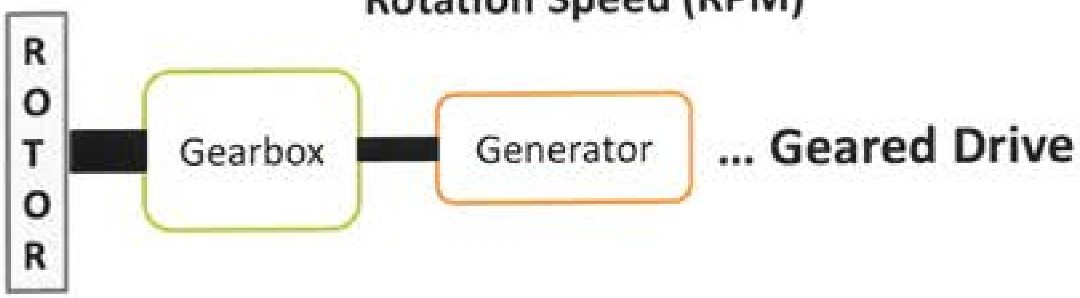



Wind turbines have a narrow range of rotation speeds to keep the coefficient of performance (efficiency) high. Type of turbine, blade shape and size are the main parameters to obtain the best Tip-Speed-Ratio and maximum efficiency. In general, the rotation speed decreases with lower average wind speed and larger rotor diameter.

<u>Tip-Speed-Ratio</u>

$$\lambda = \frac{\omega R}{v}$$

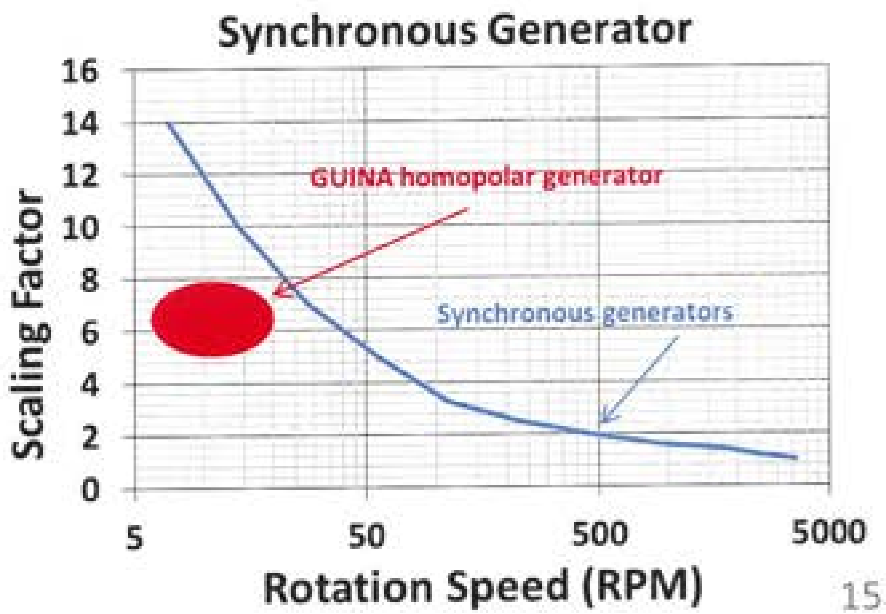
$\omega$ ... angular velocity
R ... rotor radius
v ... wind speed





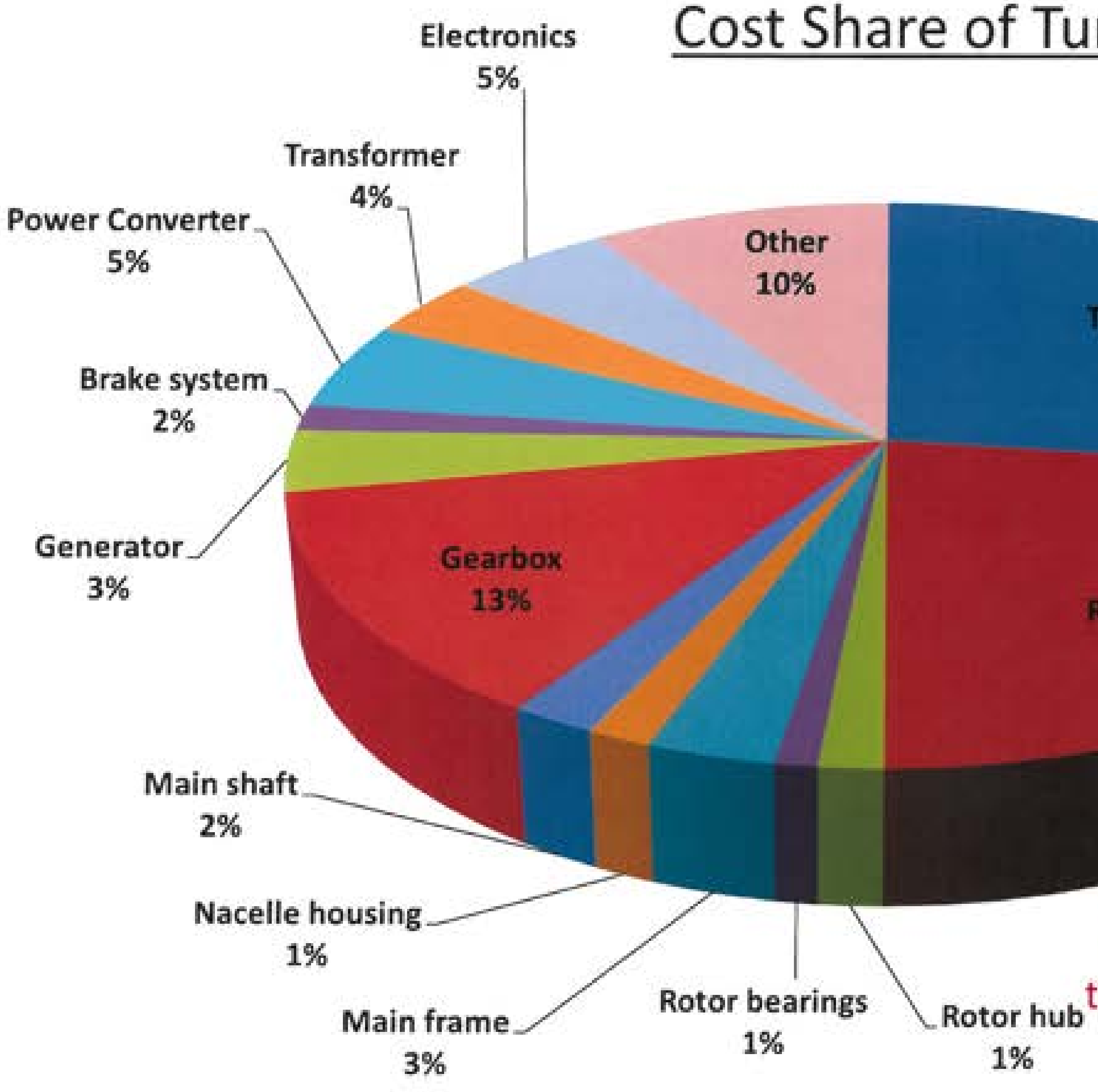
With increasing torque and higher gear ratios the gearboxes become very heavy and unreliable. Therefore direct drive systems are preferred for larger wind turbines. However conventional direct drive generators are significantly larger and heavier than geared generators.

**Guina Energy's direct drive generators are significantly smaller and lighter compared to direct drive synchronous generators.**



# WIND TURBINE THEORY (4/4)

## Cost Share of Turbine Components




50% of total costs

| Component | Cost Percentage |
|---|---|
| Tower | 27% |
| Rotor blades | 23% |
| Rotor hub | 1.5% |
| Rotor bearings | 1% |
| Main frame | 3% |
| Nacelle housing | 1.5% |
| Main shaft | 2% |
| Gearbox | 13% |
| Generator | 3.5% |
| Brake system | 1.5% |
| Power Converter | 5% |
| Transformer | 3.5% |
| Electronics | 5% |
| Other | 9.5% |

Structure

Drivetrain

More than three times the cost of the generator

More than two times the cost of the generator

**Lighter drivetrains can reduce the overall building cost and reduces the loads on structural components.**

**The 10 MW direct drive generator proposed by Guina Energy is expected to be approximately 100 tons lighter than the nearest competitor.**

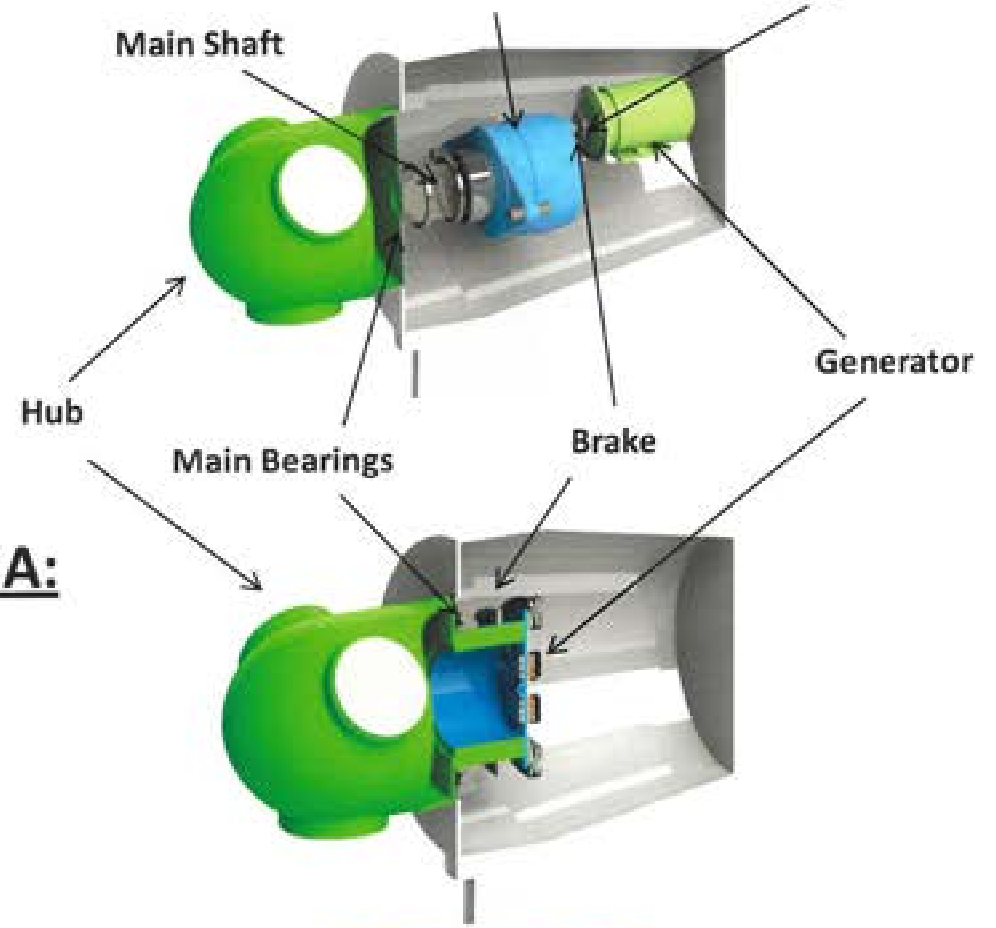
# DRIVETRAIN SIMPLIFICATION (1/2)

GUINA ENERGY GROUP

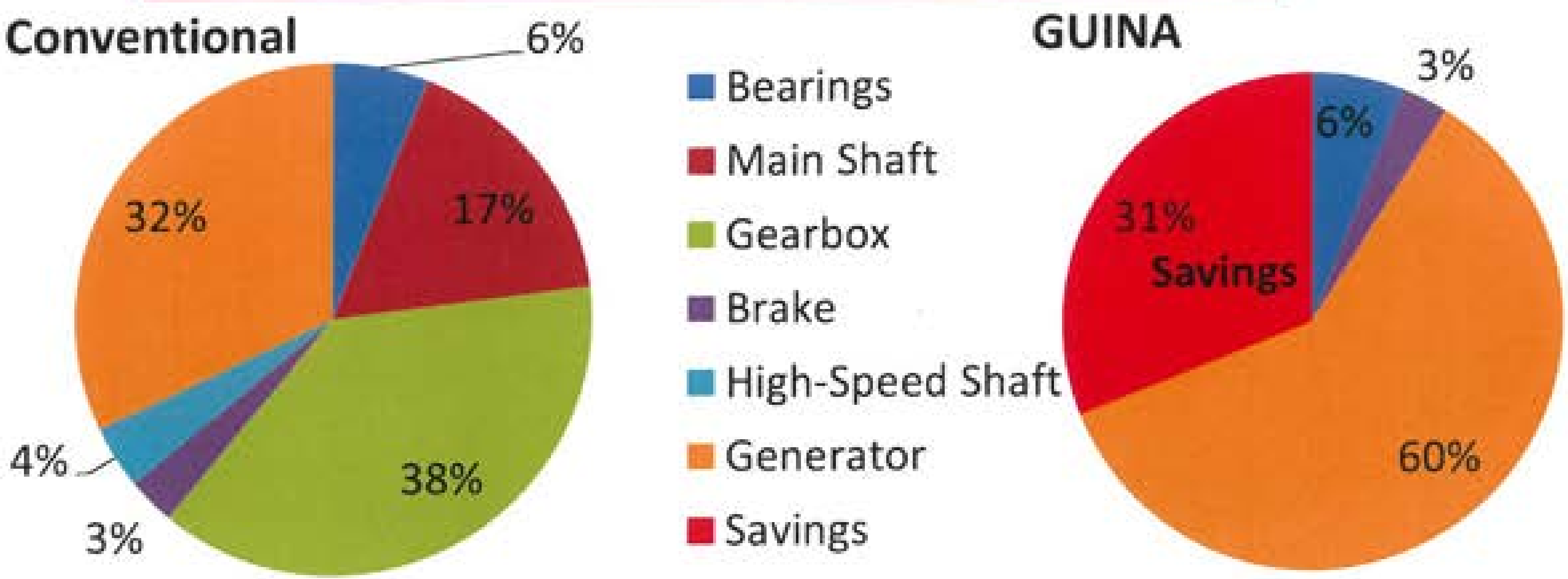
| | Conventional | GUINA |
|---|---|---|
| Main Bearings | ✓ | ✓ |
| Main Shaft | ✓ | × (if directly coupled to Hub) |
| Gearbox | ✓ | × |
| Brake | ✓ | ✓ |
| High Speed Shaft | ✓ | × |
| Generator | ✓ | ✓ |

**Conventional:**

**GUINA:**




**Weight Percentage for the Different Parts**

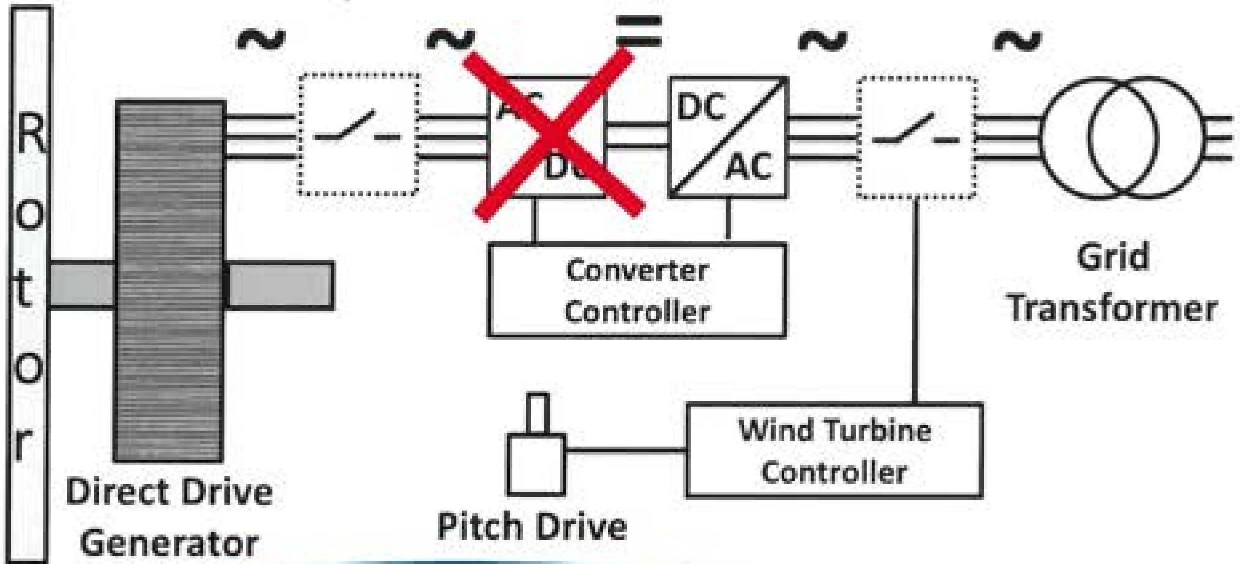


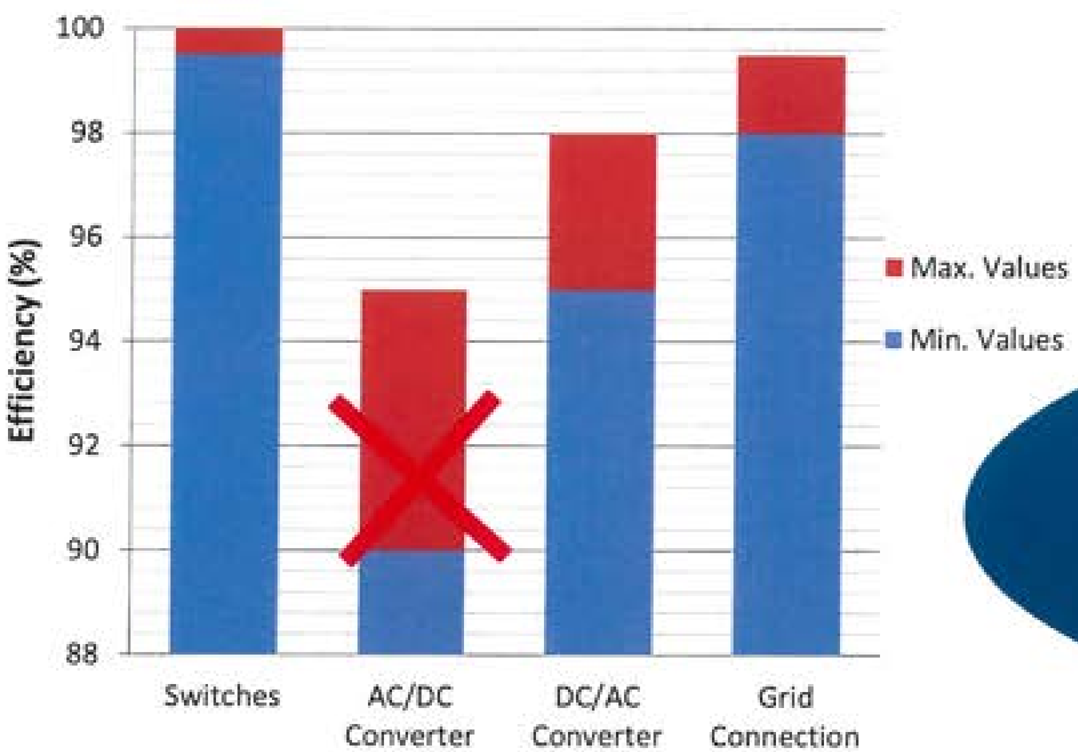

**The result is an overall reduction in weight, fewer components and higher efficiency of Guina Energy's Concept.**

# DRIVETRAIN SIMPLIFICATION (2/2)

| | Conventional Direct Drive | GUINA |
|---|---|---|
| Main Switch | ✓ | ✓ |
| AC/DC Converter | ✓ | × |
| Converter Controller | ✓ | O (simplified) |
| DC/AC Converter | ✓ | ✓ |
| Grid Connection | ✓ | ✓ |

Modern Direct Drive generators face the problem that their generator frequency is not compatible with the grid frequency. Therefore they have to convert the generator output first into a DC current and then back to AC while matching the grid frequency. Our generators have the advantage of producing pure DC power which can be than converted into the grid AC power without a rectifier.

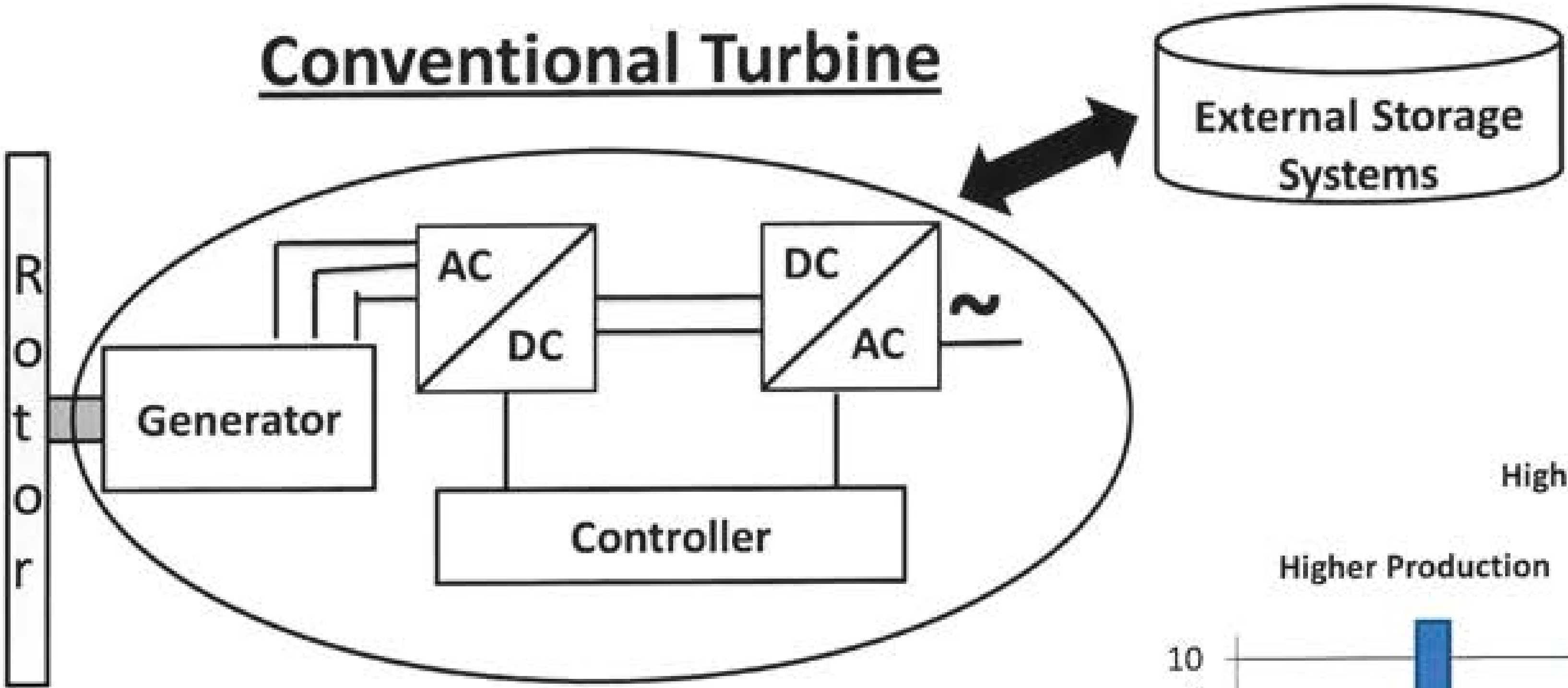



**Guina Energy's DC generator simplifies the power electronics required to connect the wind turbine to the power grid which results in higher efficiency and better reliability.**

# DC Wind Turbine Generator

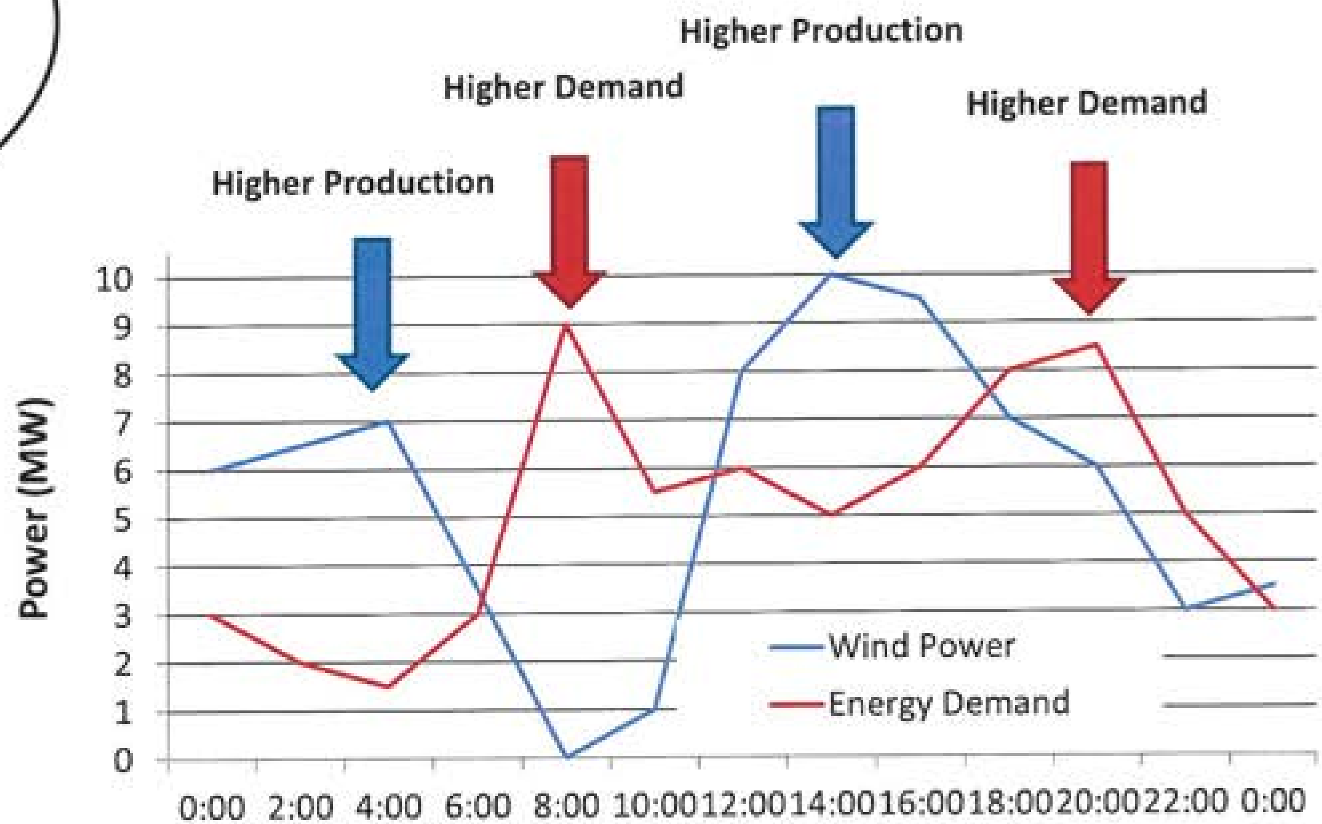
## Conventional Turbine




- DC storage systems are most efficient
- Different storage times are required

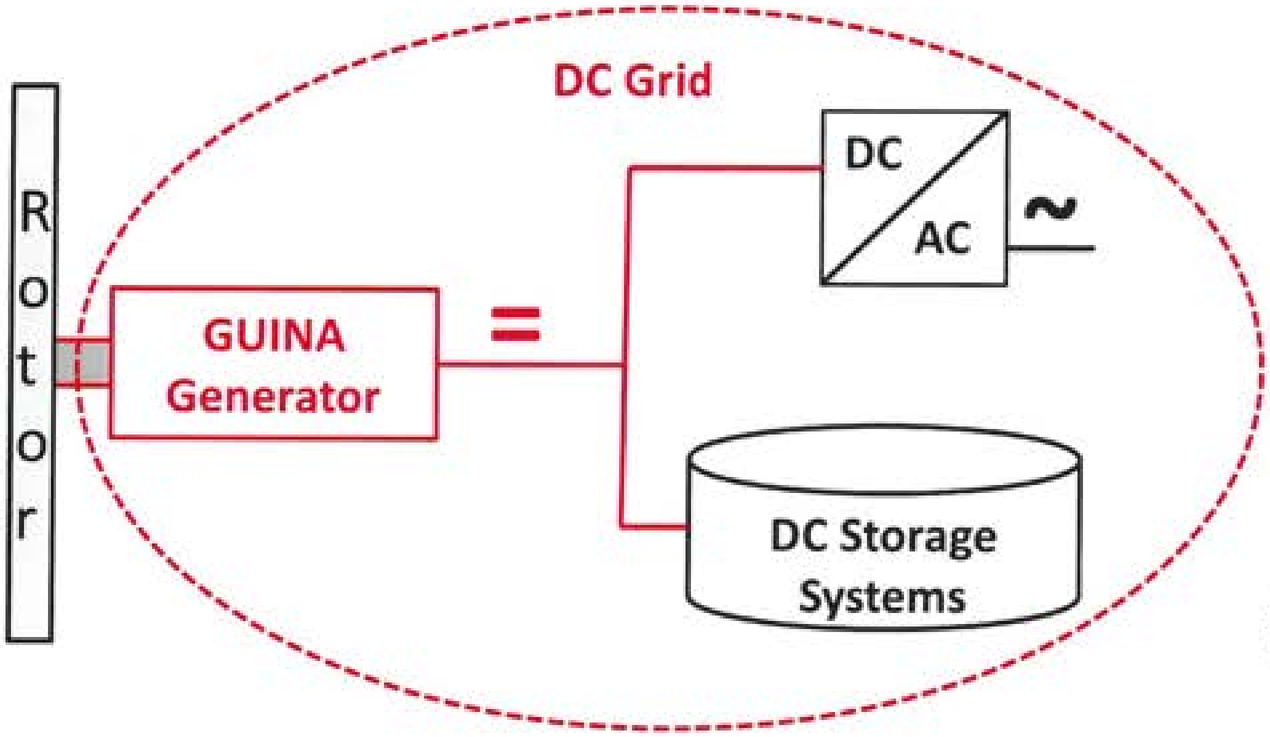
DC connections in conventional wind turbines:

- Two stage converter to reach grid compatibility
- Long distance DC cables

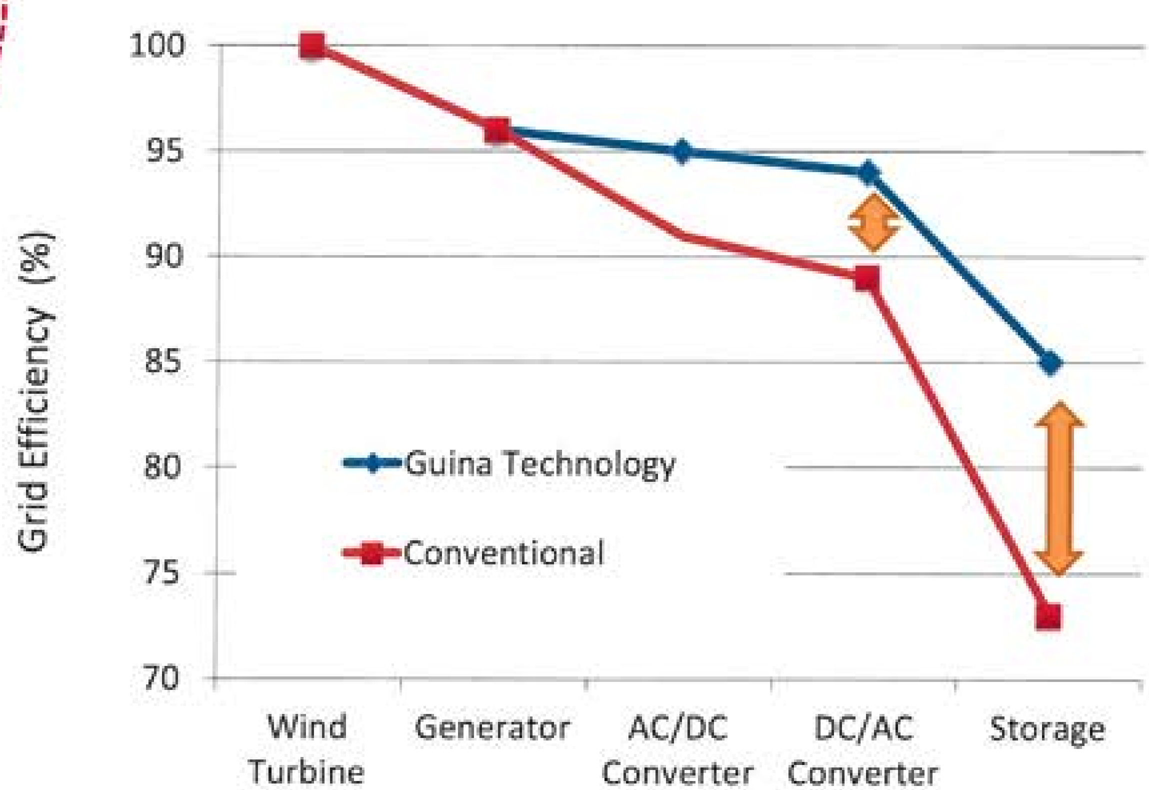


# DC Wind Turbine Generator

## Guina Electromagnetic Turbine

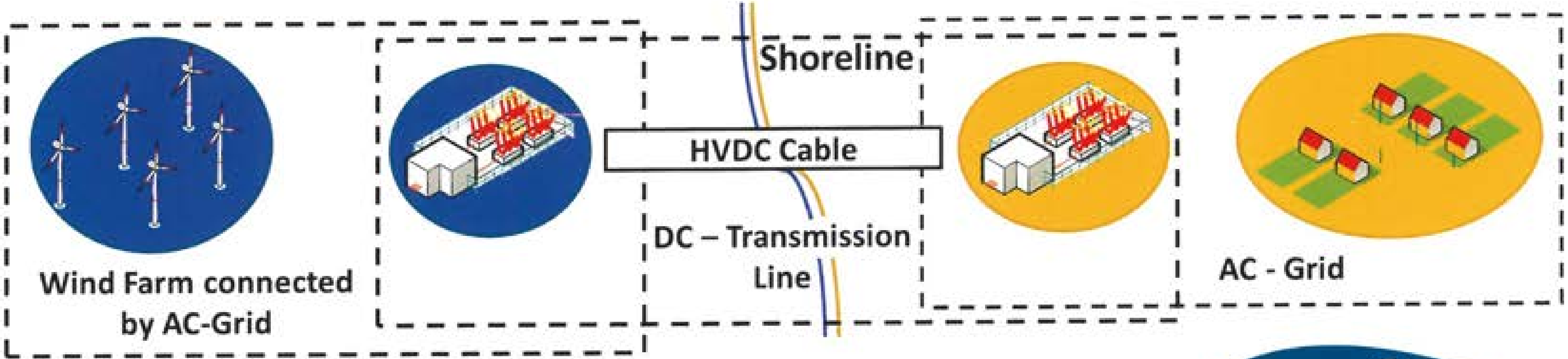



Short and long term DC storage system can be directly connected to the generator




The efficiency of the converter stage can be improved and reliability increased

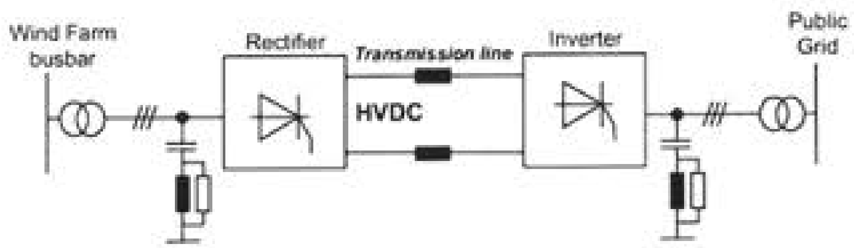
# OFFSHORE WIND FARMS



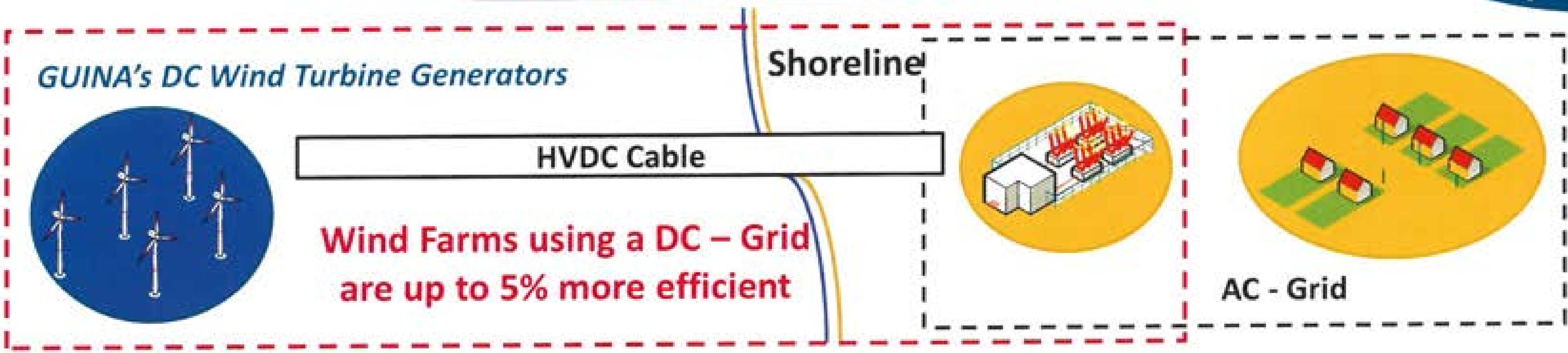

DC wind farm grid advantages:

- reduces the initial costs
- requires **no offshore rectifier**
- requires less maintenance

High-Voltage DC Transmission Line for over ~100 km underwater cable lengths.




**Guina Energy's wind turbine generators simplify offshore wind farm infrastructure.**

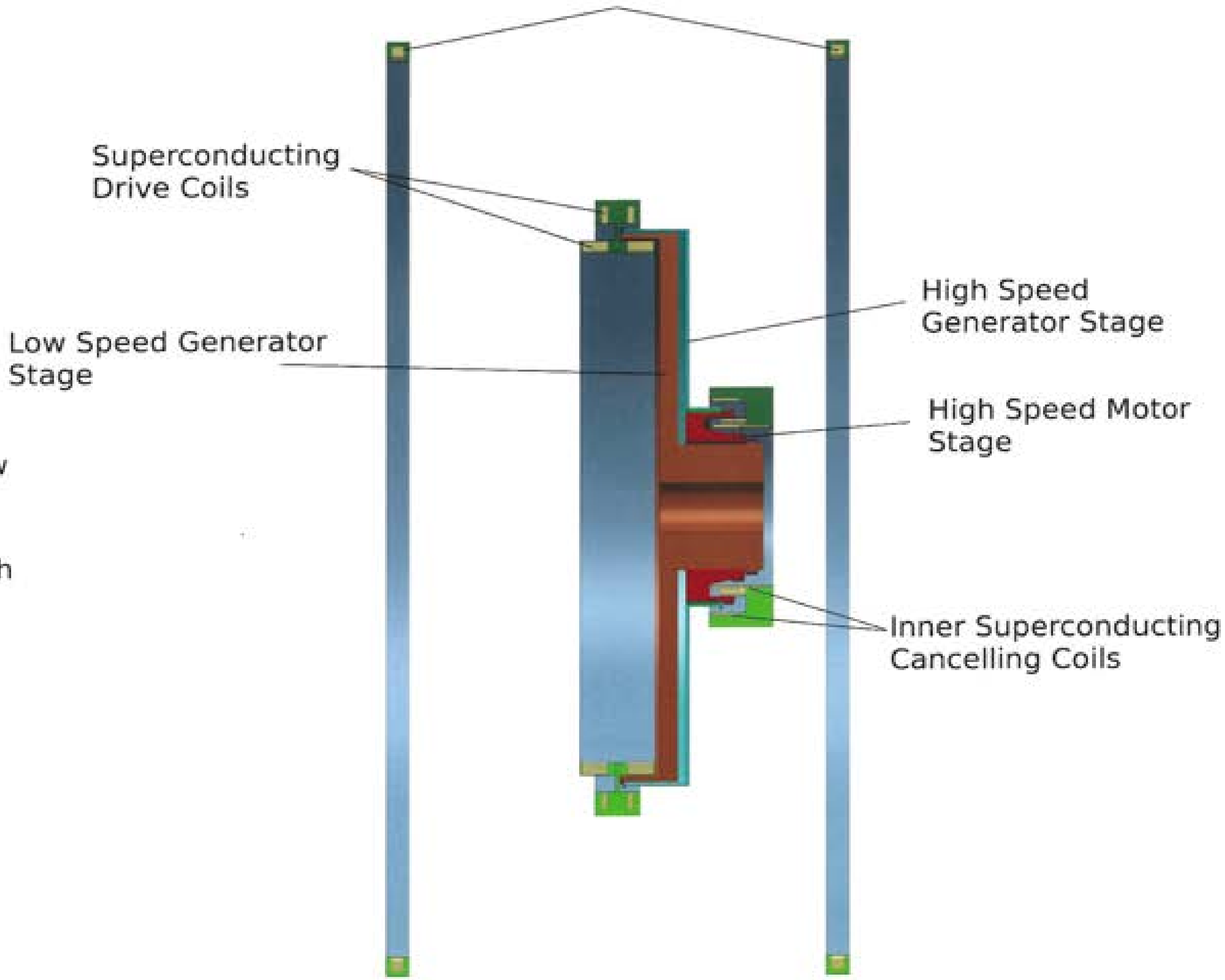


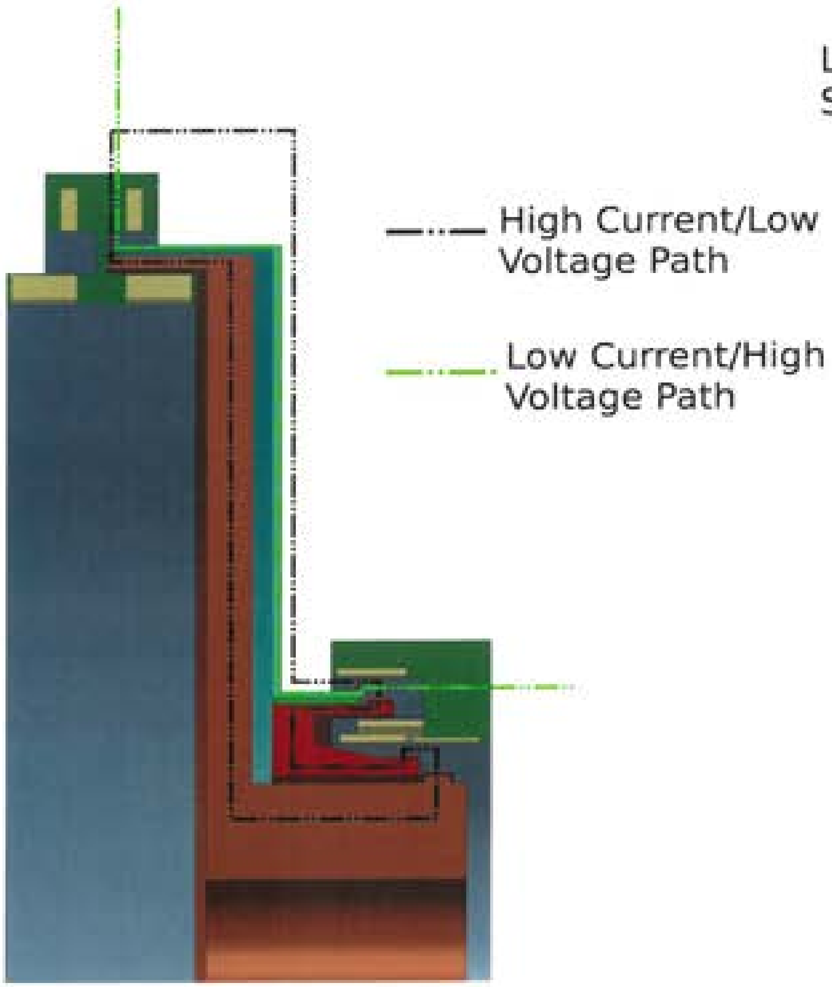
# INTRODUCTION TO OUR TECHNOLOGY

Guina Energy Group has developed a range of generator solutions for the Wind Turbine industry.

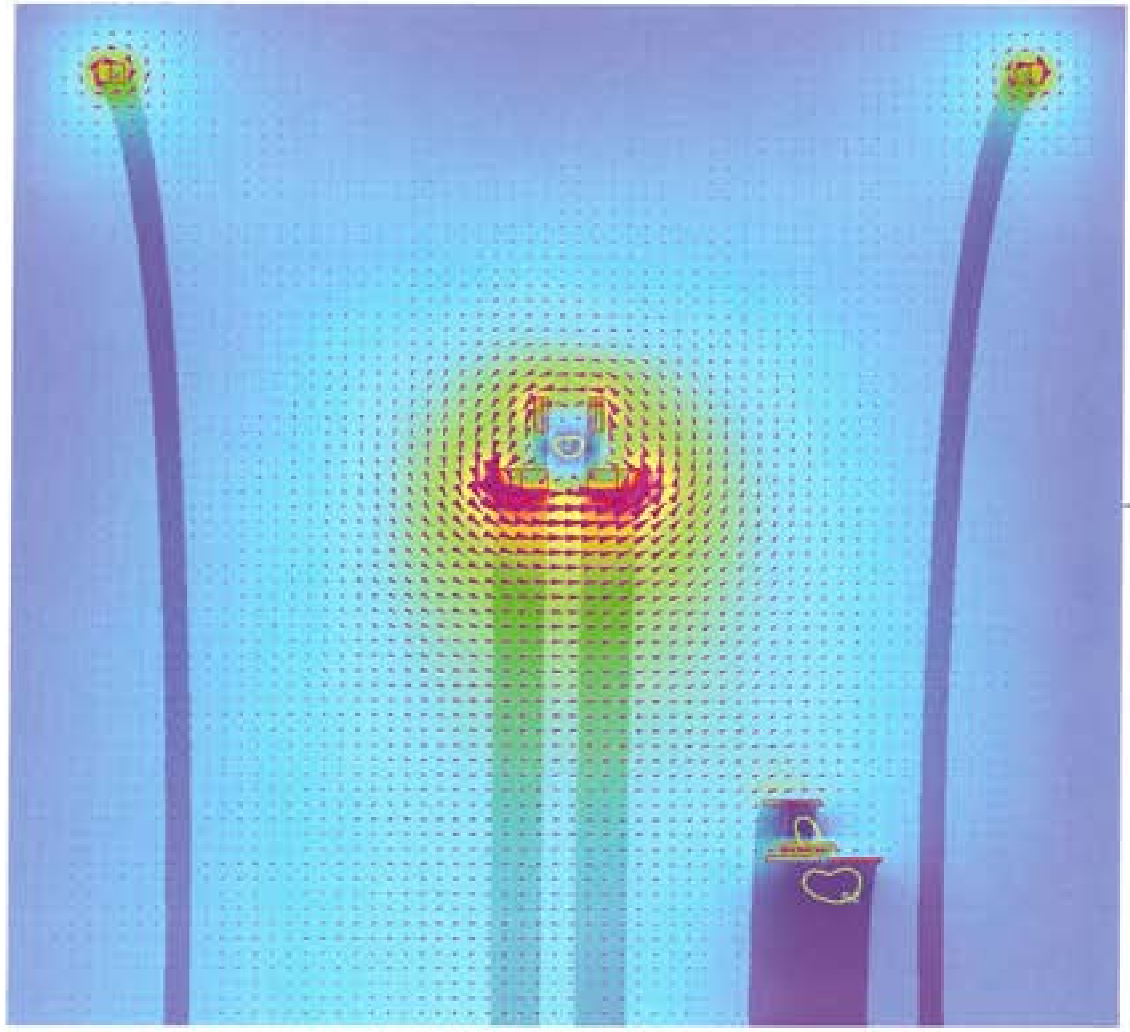
All of our designs focus on high power, lightweight solutions that do not use steel or iron shielding and flux guides. Minimising the tower mass results in lower manufacturing and installation costs. The technology shown has been extensively modelled and simulated using Vector Fields and SolidWorks modelling software.

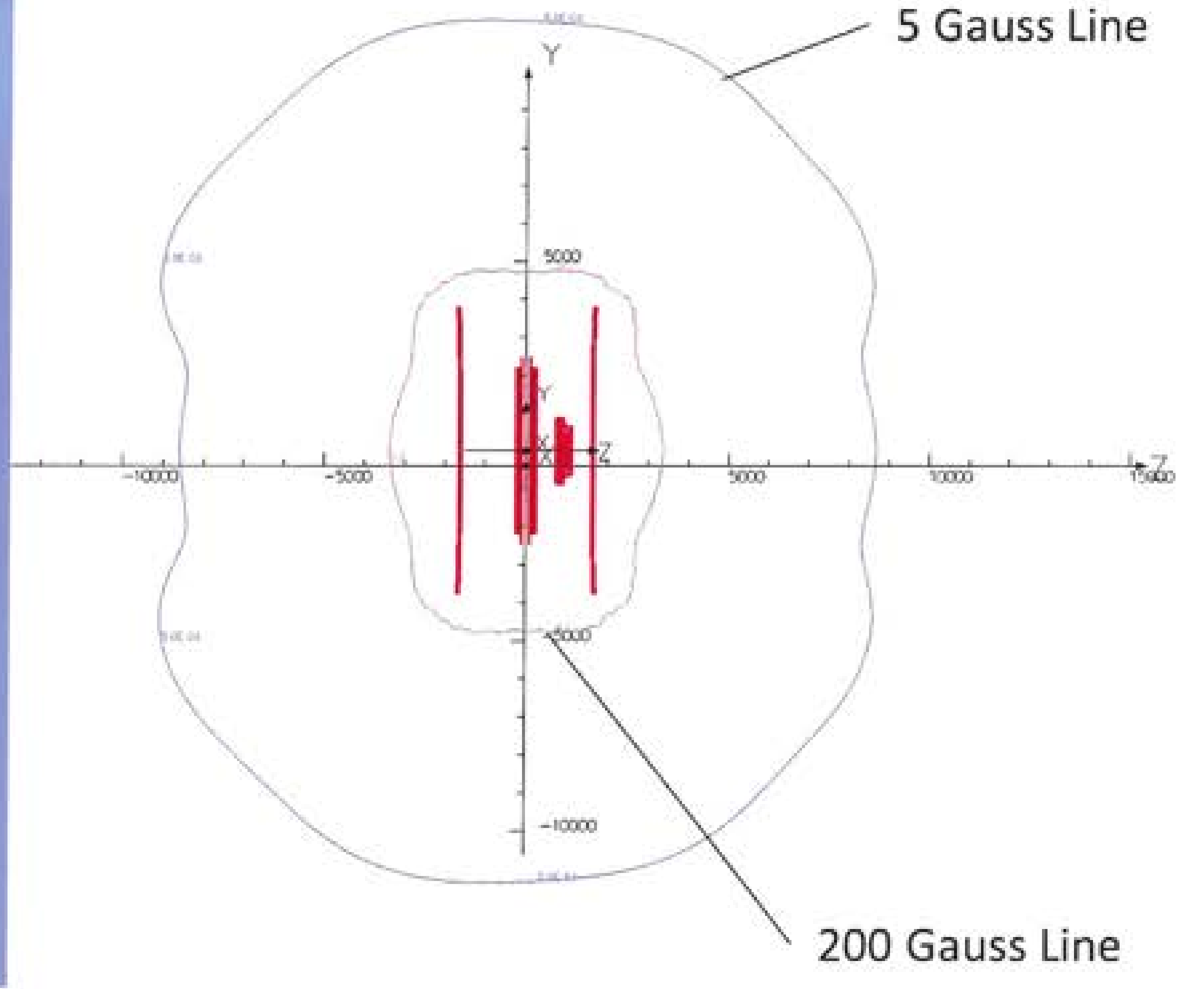
# 10 MW WIND TURBINE – HOMOPOLAR DIRECT DRIVE



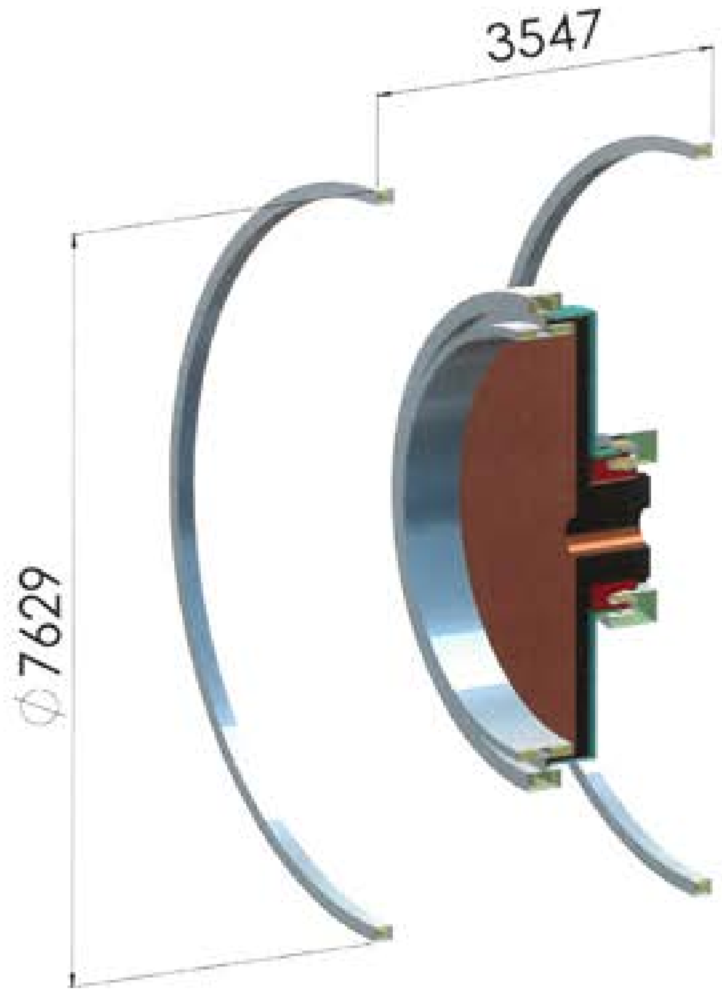



# Magnetic Field Plots





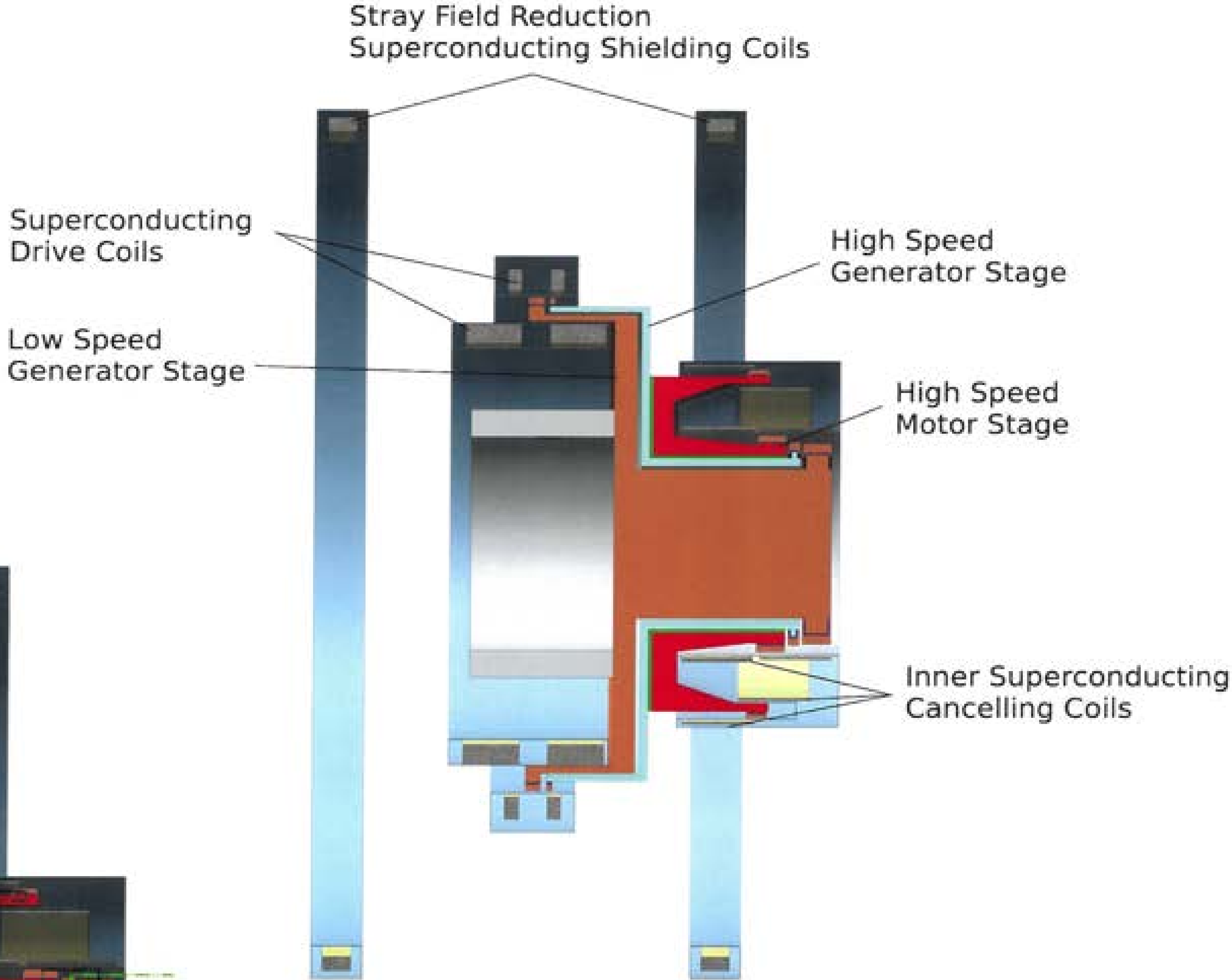
# 10 MW WIND TURBINE – HOMOPOLAR DIRECT DRIVE

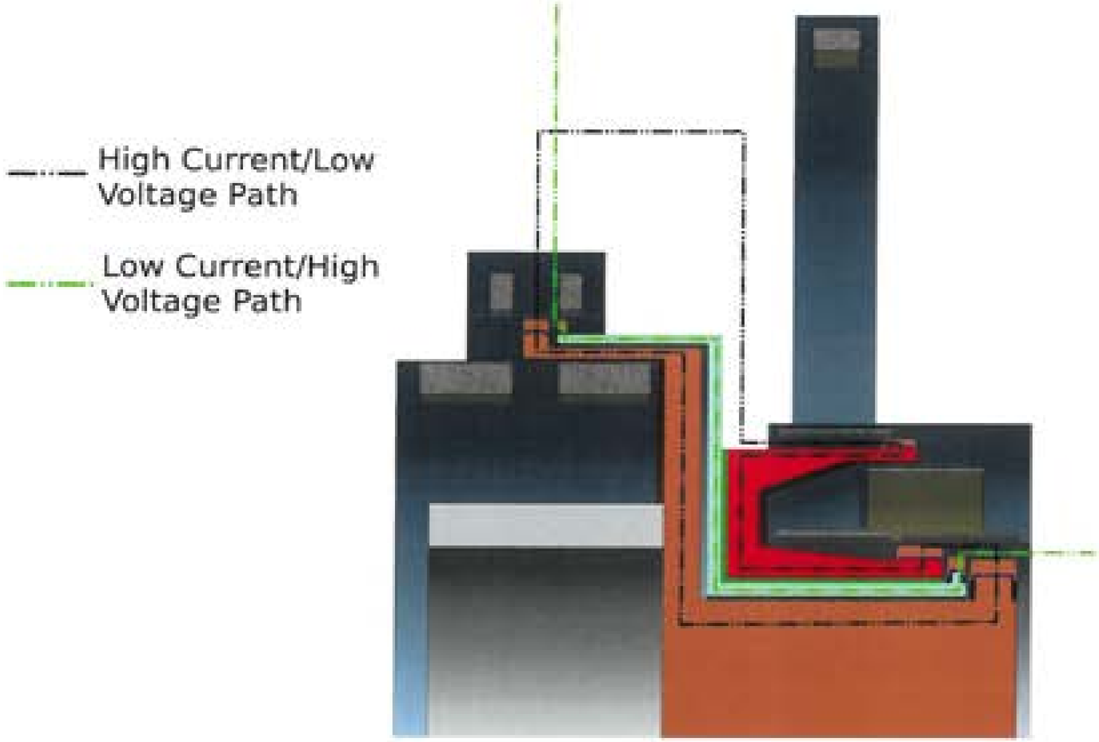



| | |
|---|---|
| Power (MW) | 10 |
| Speed (RPM) | 6 to 12 |
| Total Current (A) | 760052 |
| LMB Current Density A/cm$^2$ | 500 |
| Max Rotor Tip Speed (m/s) | 158 |
| Max Coil Diameter (mm) | 7629 |
| Rotor Radius (mm) | 2240 |
| Rotor Material | Aluminium |
| Super Conductive Wire | $Nb_3Sn$ |
| SC Wire Length (km) based on $\phi$ 0.85 mm wire | 1124 |
| SC Wire Weight (kg) | 4465 |
| SC Wire Packing Factor | 0.6 |
| SC Wire current density (A/mm$^2$) | 240 |
| Peak Field on wire (T) | 13.2 |
| Cryogenic Temperature (K) | 4 |
| Low speed Stage Speed (RPM) | 12 |
| High Speed Stage Speed (RPM) | 673 |
| Low speed Stage Current (A) | 760052 |
| Low Speed Stage Voltage (V) | 13.16 |
| High speed Stage Current (A) | 13553 |
| High Speed Stage Voltage (V) | 738 |

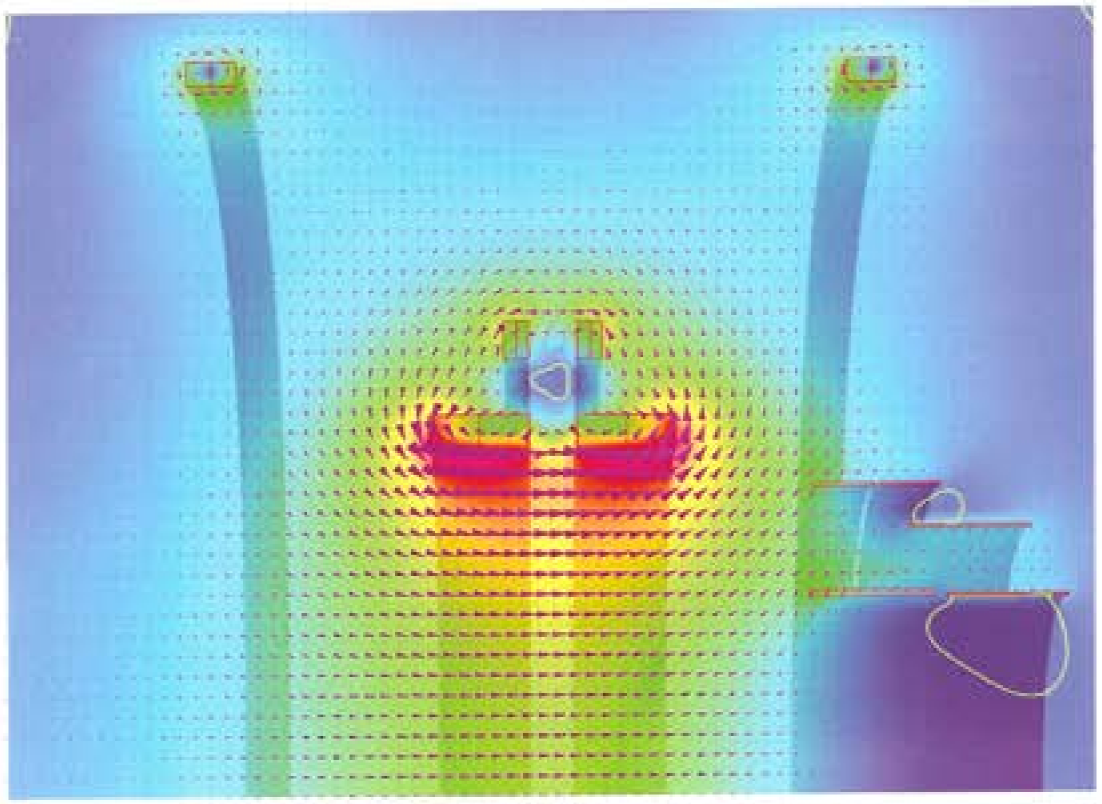
**All weights listed exclude Cryostat, support structures and return busses. Weights are approximate and could be reduced further with optimisation.**

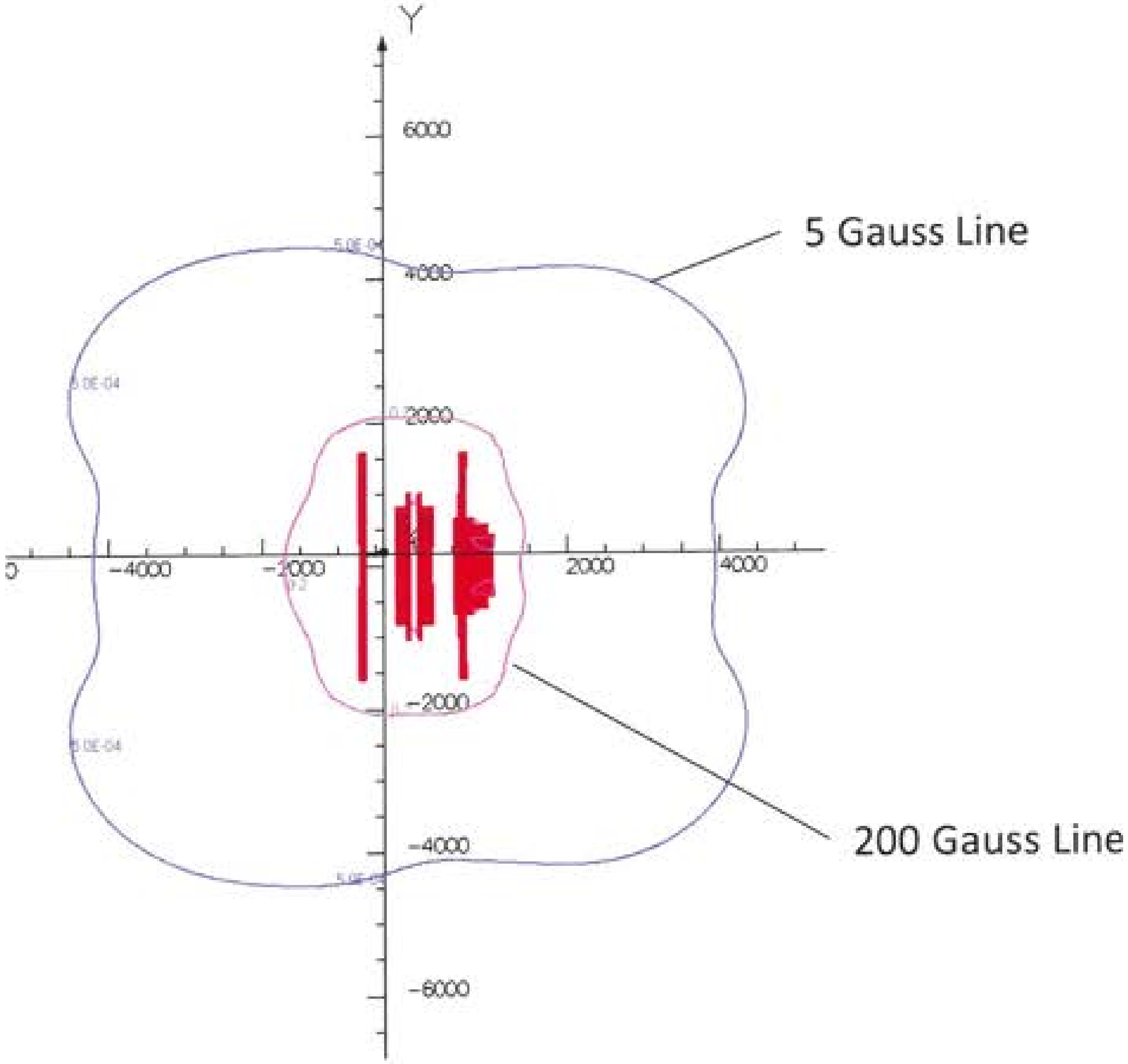
# 10 MW WIND TURBINE – HOMOPOLAR INTERMEDIATE SPEED



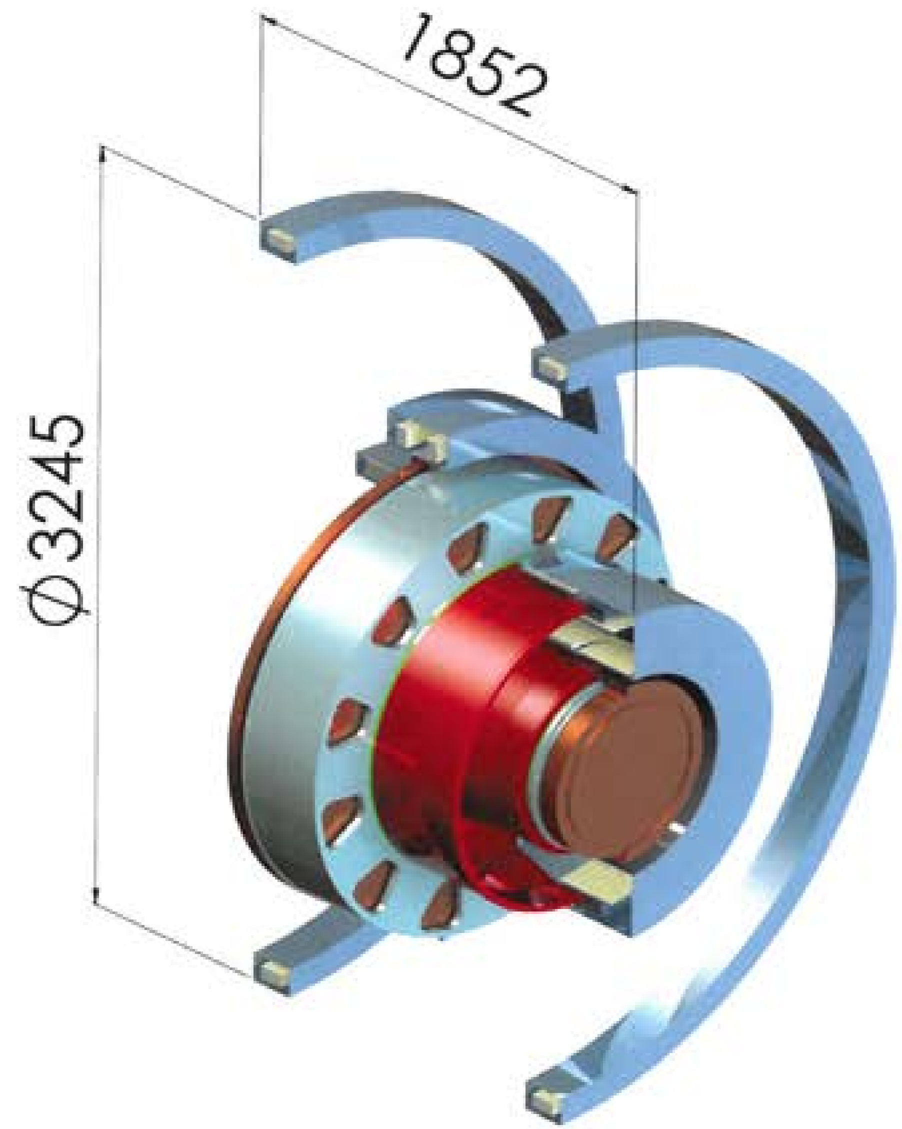



## Magnetic Field Plots





# 10 MW WIND TURBINE – HOMOPOLAR INTERMEDIATE SPEED




| | |
|---|---|
| Power (MW) | 10 |
| Speed (RPM) | 60-100 |
| Total Current (A) | 511780 |
| LMB Current Density A/cm² | 500 |
| Max Rotor Tip Speed (m/s) | 102 |
| Max Coil Diameter (mm) | 3245 |
| Rotor Radius (mm) | 900 |
| Rotor Material | Aluminium |
| Super Conductive Wire | $Nb_3Sn$ |
| SC Wire Length (km) based on $\phi$ 0.85 mm wire | 354 |
| SC Wire Weight (kg) | 1406 |
| SC Wire Packing Factor | 0.6 |
| SC Wire current density (A/mm²) | 240 |
| Peak Field on wire (T) | 13.2 |
| Cryogenic Temperature (K) | 4 |
| Low speed Stage Speed (RPM) | 100 |
| High Speed Stage Speed (RPM) | 1087 |
| Low speed Stage Current (A) | 511780 |
| Low Speed Stage Voltage (V) | 19.54 |
| High speed Stage Current (A) | 47094 |
| High Speed Stage Voltage (V) | 212 |

**All weights listed exclude Cryostat, support structures and return busses. Weights are approximate and could be reduced further with optimisation.**

# 10 MW HOMOPOLAR WIND TURBINE GENERATOR

Wind farm efficiencies increase with larger sized wind turbines and therefore industry is aiming for light-weight 10 MW-class wind turbines. Guina Energy has developed a range of 10 MW Wind Turbine generator solutions. All the devices will be lightweight, compact, power dense and relatively simple when compared with current concepts and offerings.

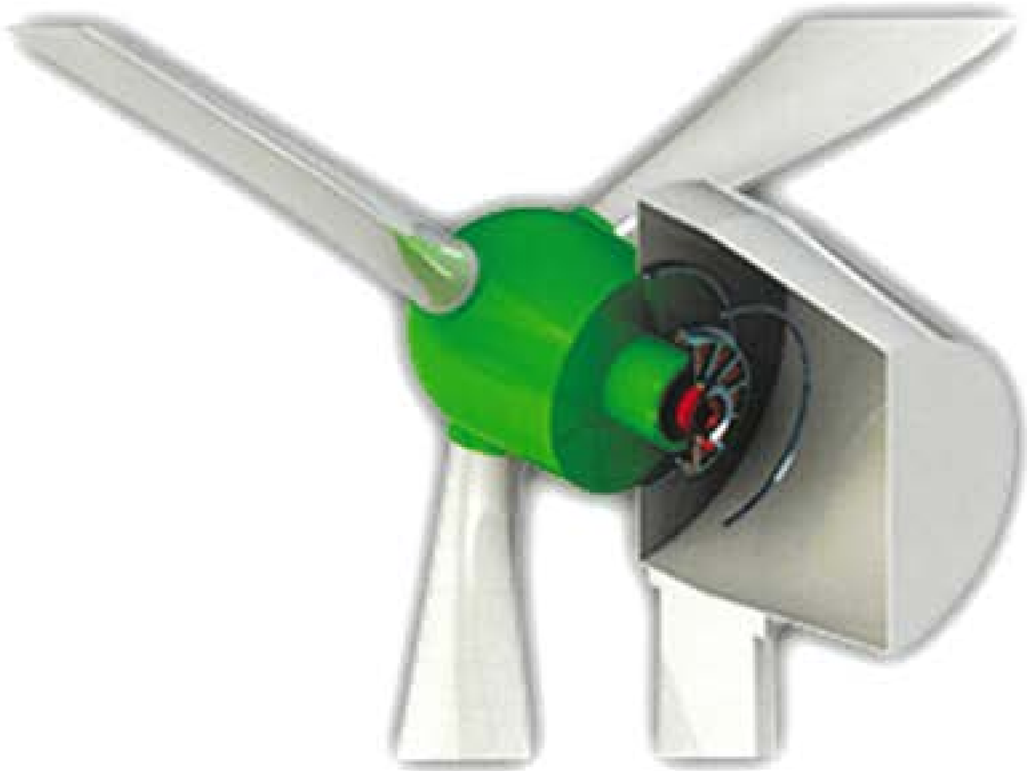
Guina Energy's wind turbine technology...

... reduces the overall weight of wind turbines.

... increases the energy production efficiency.

... simplifies and improves grid integration of wind turbines.

... is perfectly suited to offshore wind farms that are grid connected via DC transmission lines.



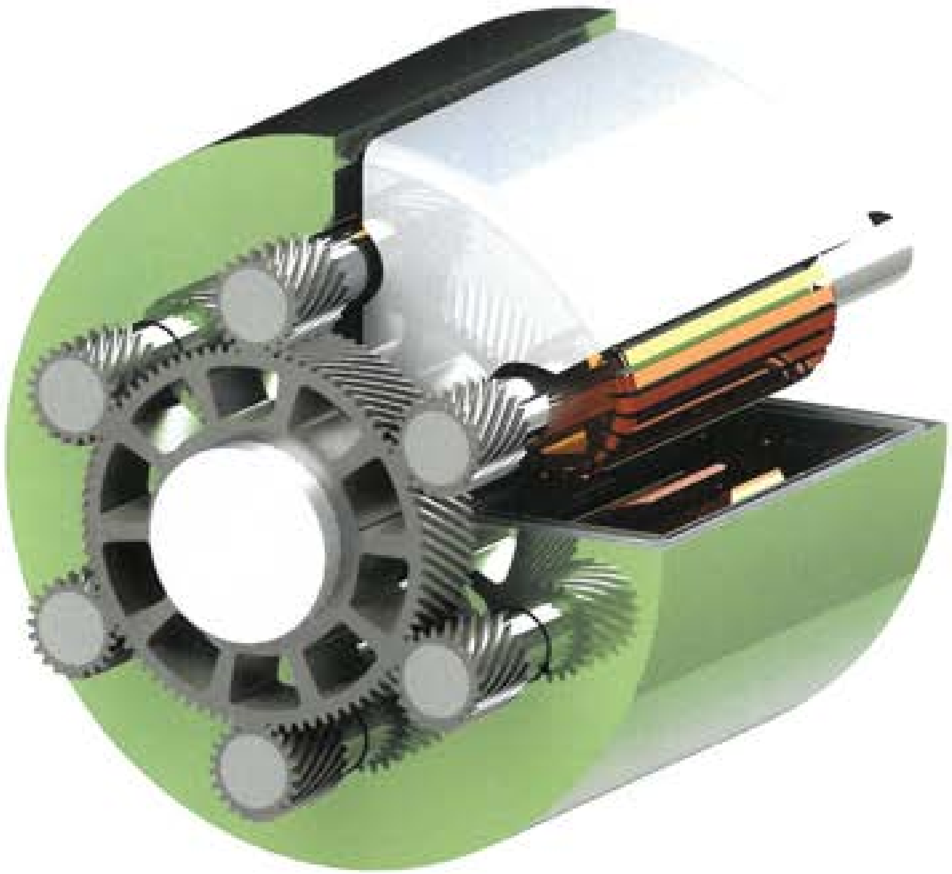
**All of these advantages contribute to smaller, more efficient wind farms with lower construction and electricity production costs**

# PRESENTING:
# SUPERCONDUCTING TOROIDAL TECHNOLOGY

# SUPERCONDUCTING TOROIDAL TECHNOLOGY

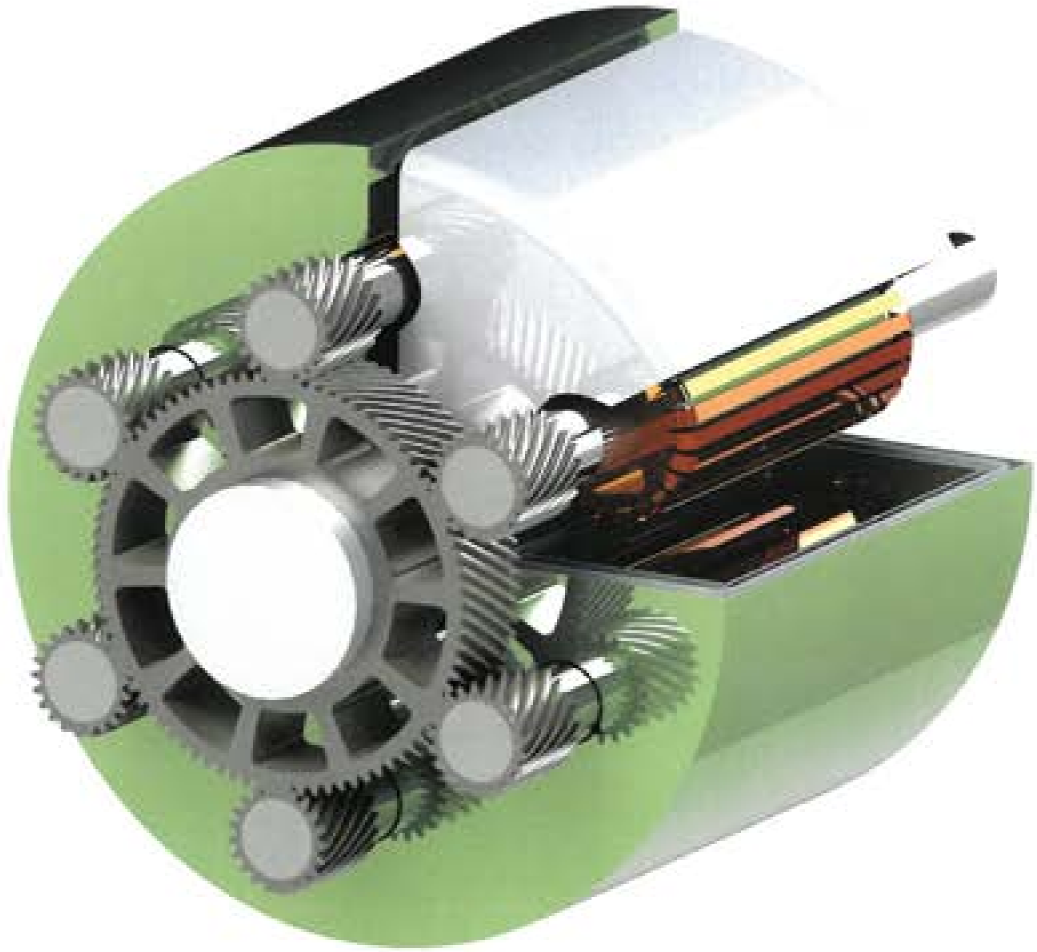
Guina Energy's Toroidal Drive system is the first electromagnetic motor and generator technology that inherently contains the magnetic field within the device without heavy iron flux guides. This contained magnetic field is used multiple times to create a power dense, lightweight motor/generator solution. The technology shown has been extensively modelled and simulated using Vector Fields and Solidworks modelling software.

In production these will be the most power dense electrical machines on the planet. The quoted power figures are based on a 10 A/mm$^2$ RMS AC sine wave current waveform.

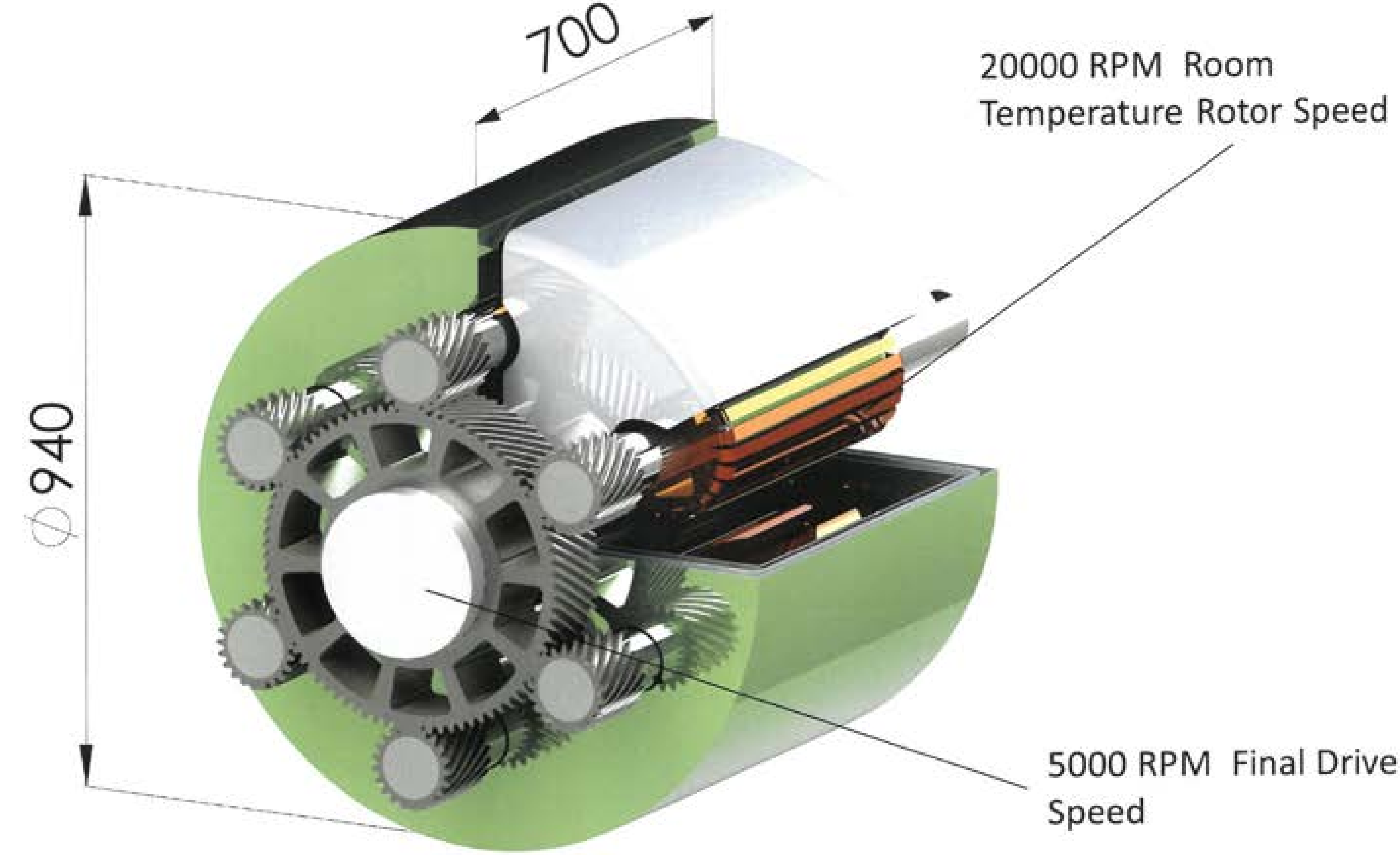


# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

- Our High Speed Superconducting Toroidal Drive consists of a stationary toroidal coil body, made from superconducting wire encased in a cryostat, which produces a toroidal DC magnet field.
- The rotor assemblies are made from copper and operate at room temperature outside of the cryogenic compartment.
- The rotor windings consist of multiple independent windings which can be operated in 3 or more phases. The current waveform in the windings can be sinusoidal or a square wave.



# Superconducting DC Toroidal Drive
# 40 MW – 4:1 Gearing

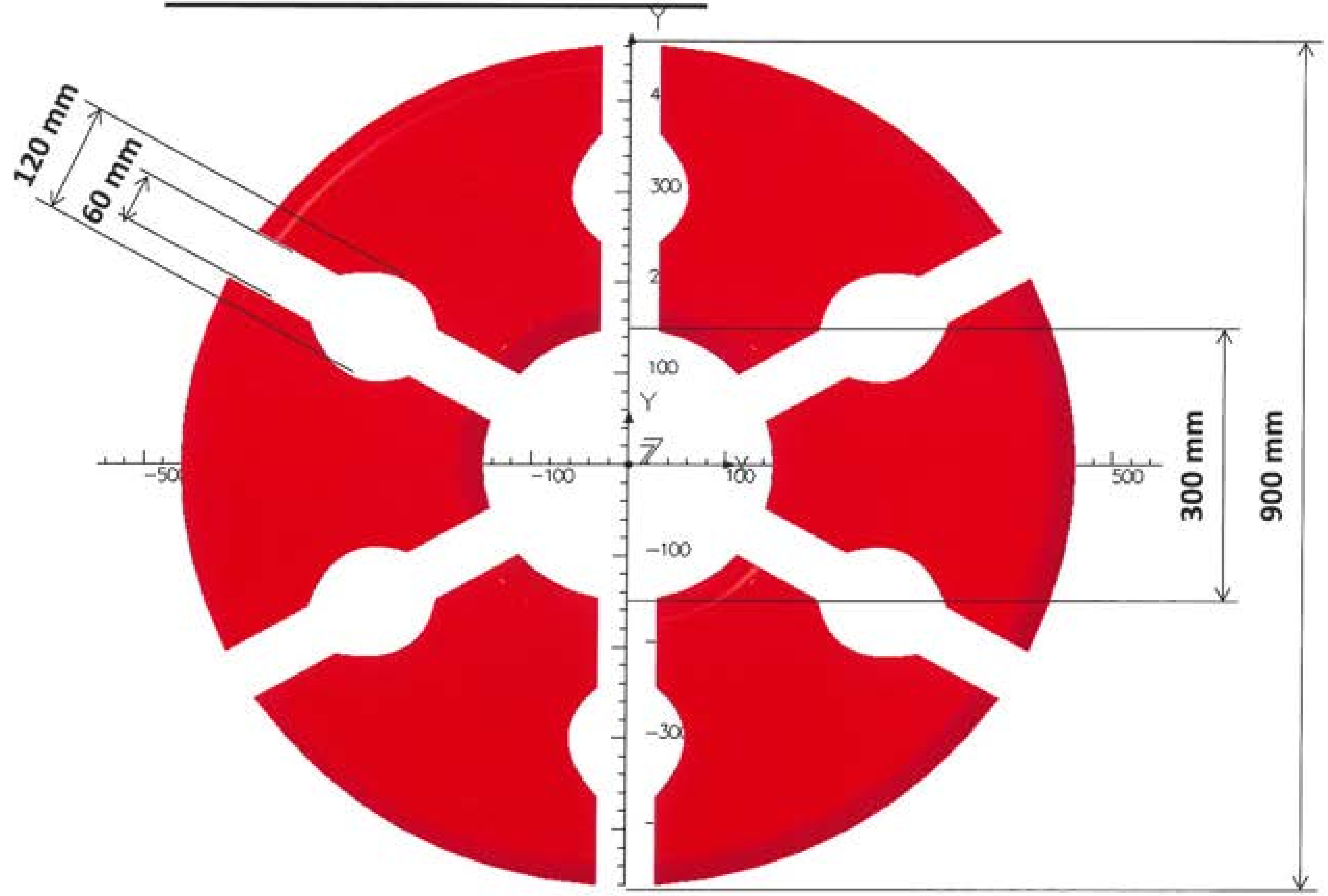


# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

## Proposed method of Superconducting Toroid construction

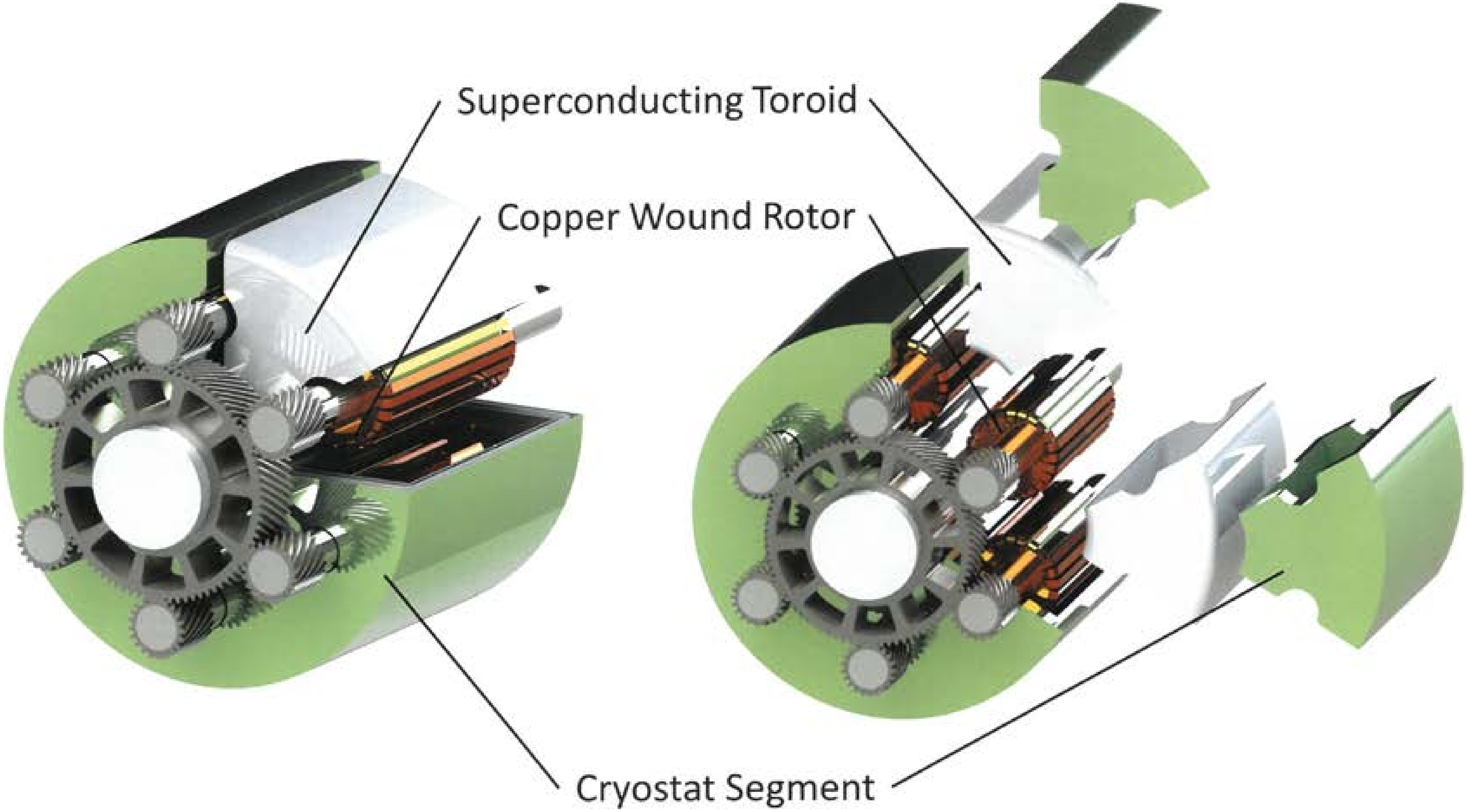
The Superconducting Toroid could be constructed from multiple arc segments each housed in a separate cryostat.

The individual cryostats are assembled around the rotors to complete the Superconducting Toroid

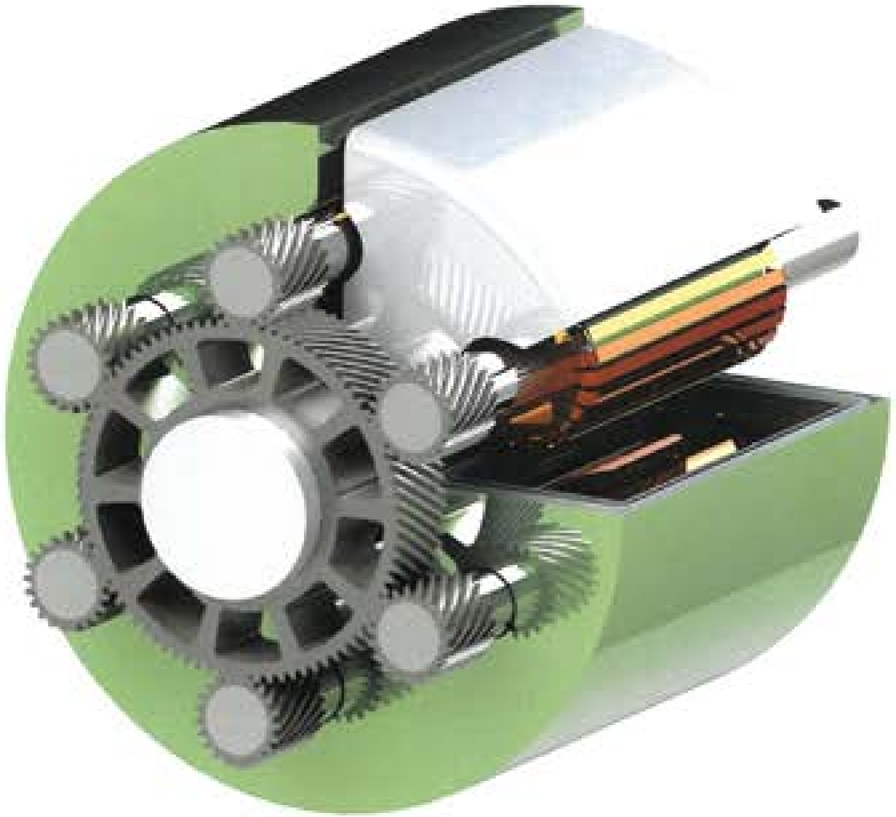


# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

## Proposed method of Superconducting Toroid construction



# Why Toroids?



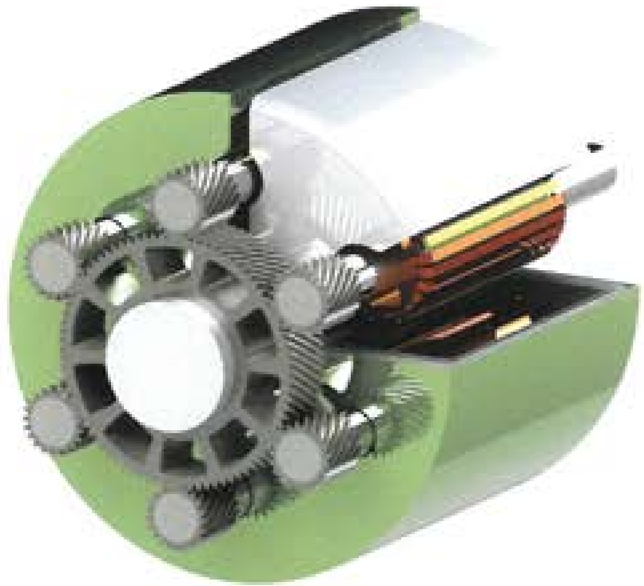
Superconducting Toroidal Technology

Permanent Magnet Toroidal Technology

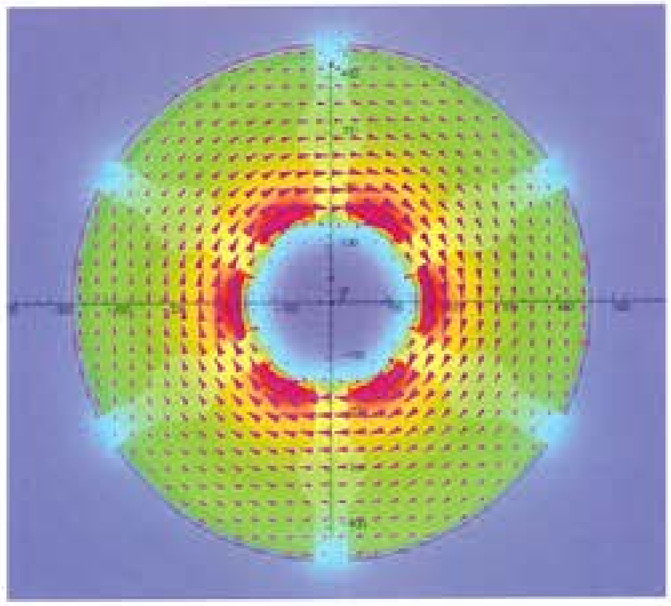
# OUR TECHNOLOGY

## Toroidal Technology

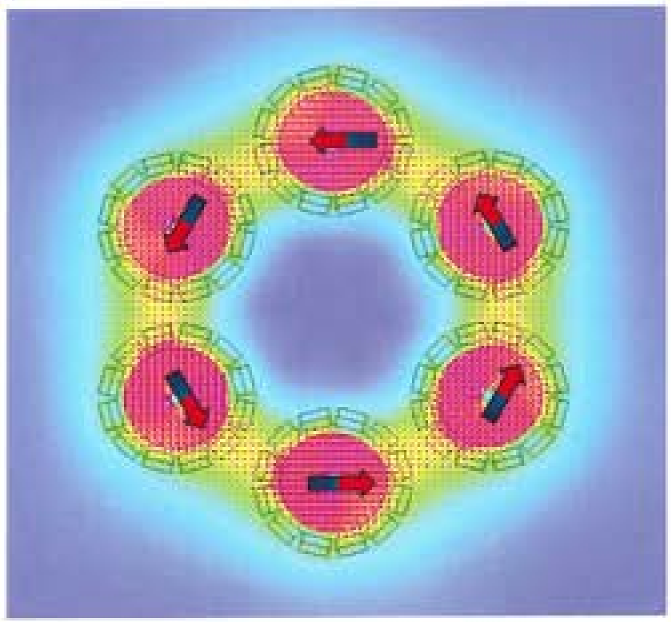
## Containment of Stray Magnetic Field



Superconducting Toroidal Technology



Permanent Magnet Toroidal Technology

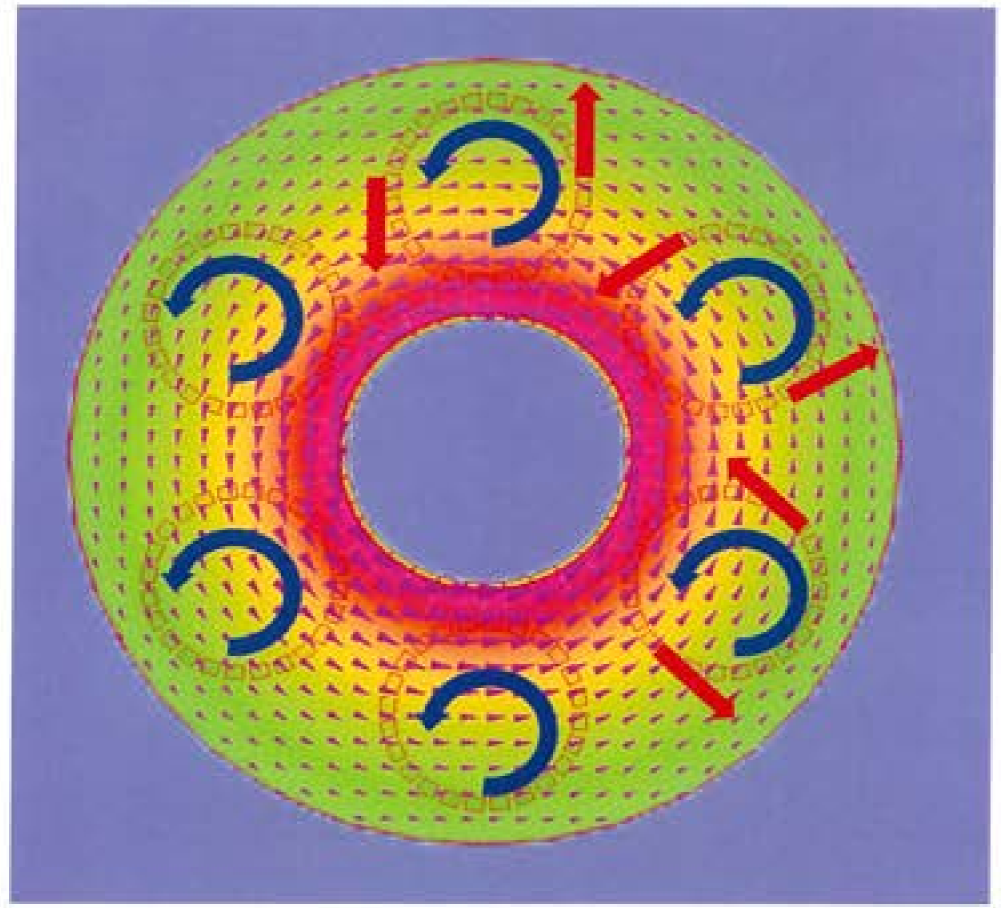


# OUR TECHNOLOGY

GUINA ENERGY GROUP

**Toroidal Technology** = **Fully utilising the contained magnetic field path through multiple rotors**

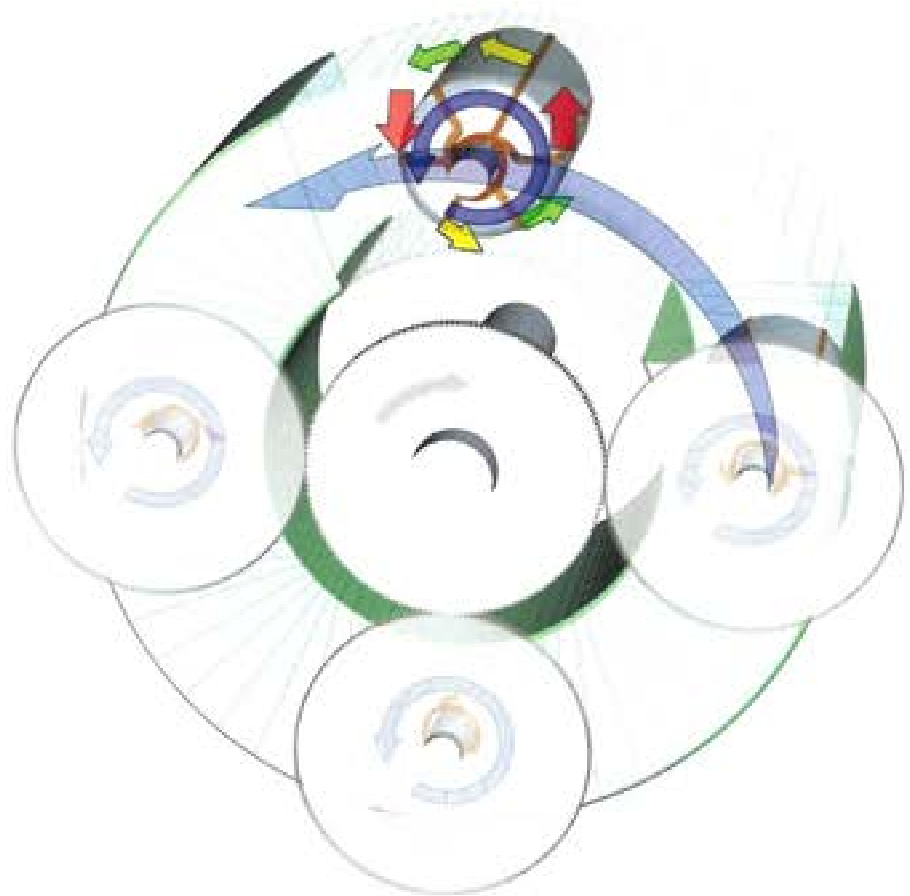
=



# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

## Key Technology Advantages

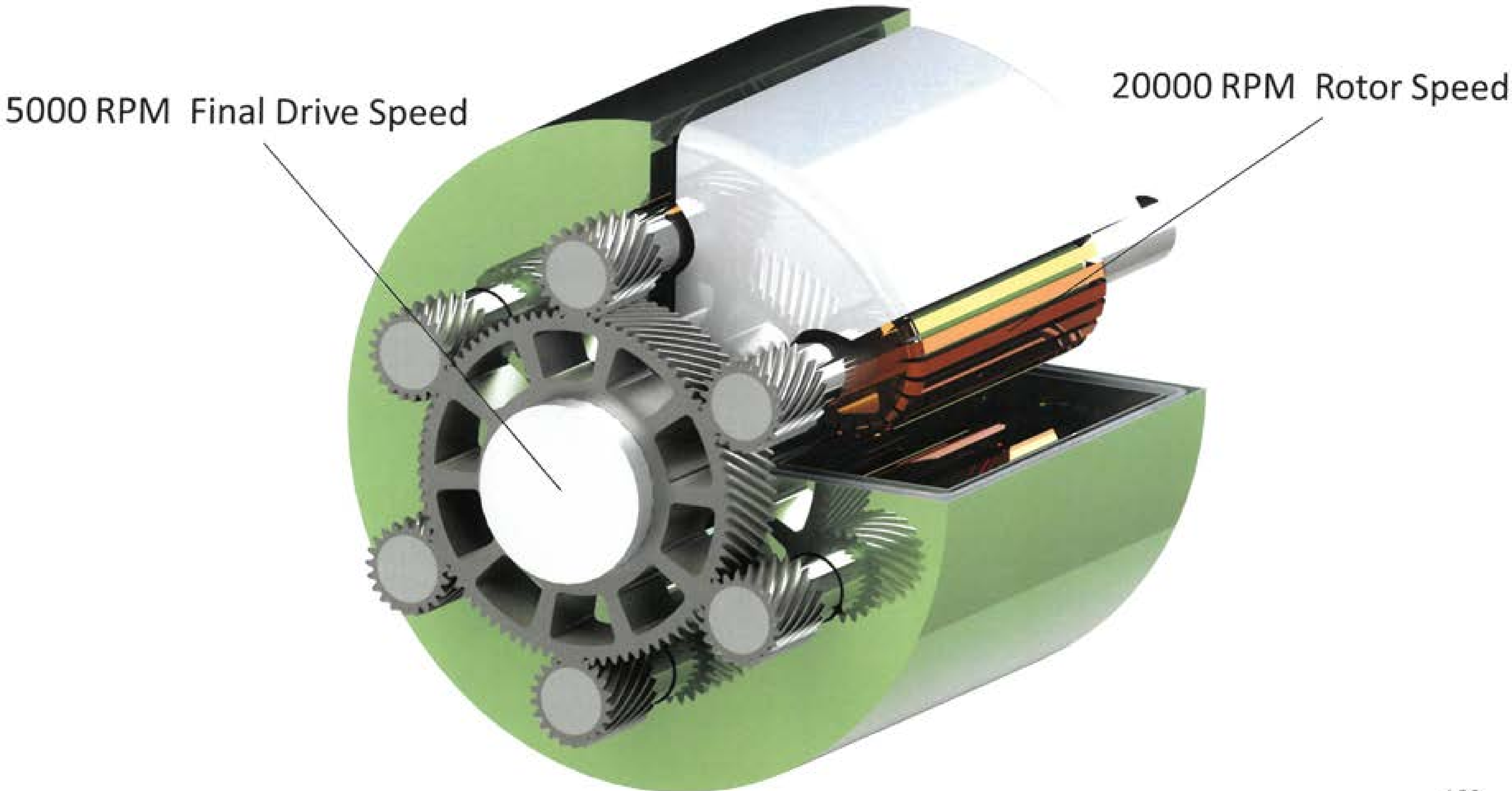
- Stray field is contained by a toroidal stator winding
- All rotors utilise the same toroidal background field
- Iron-free design removes iron hysteresis loss and reduces eddy current formation
- Low torque ripple
- Configurable number of independent rotor windings
- Superconducting Toroid produces a much more **powerful background field** resulting in superior power to weight



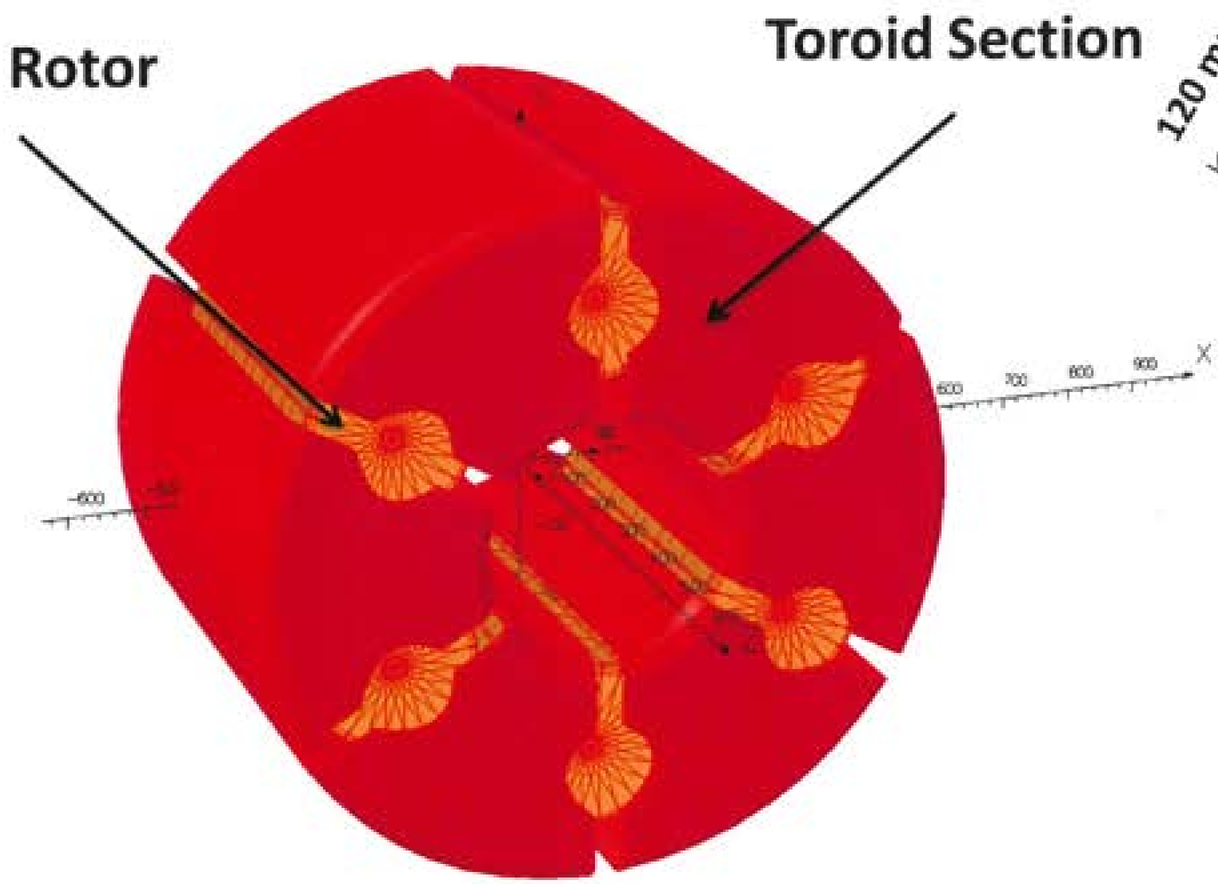
The output torque from multiple rotors is combined into a single output shaft via gears

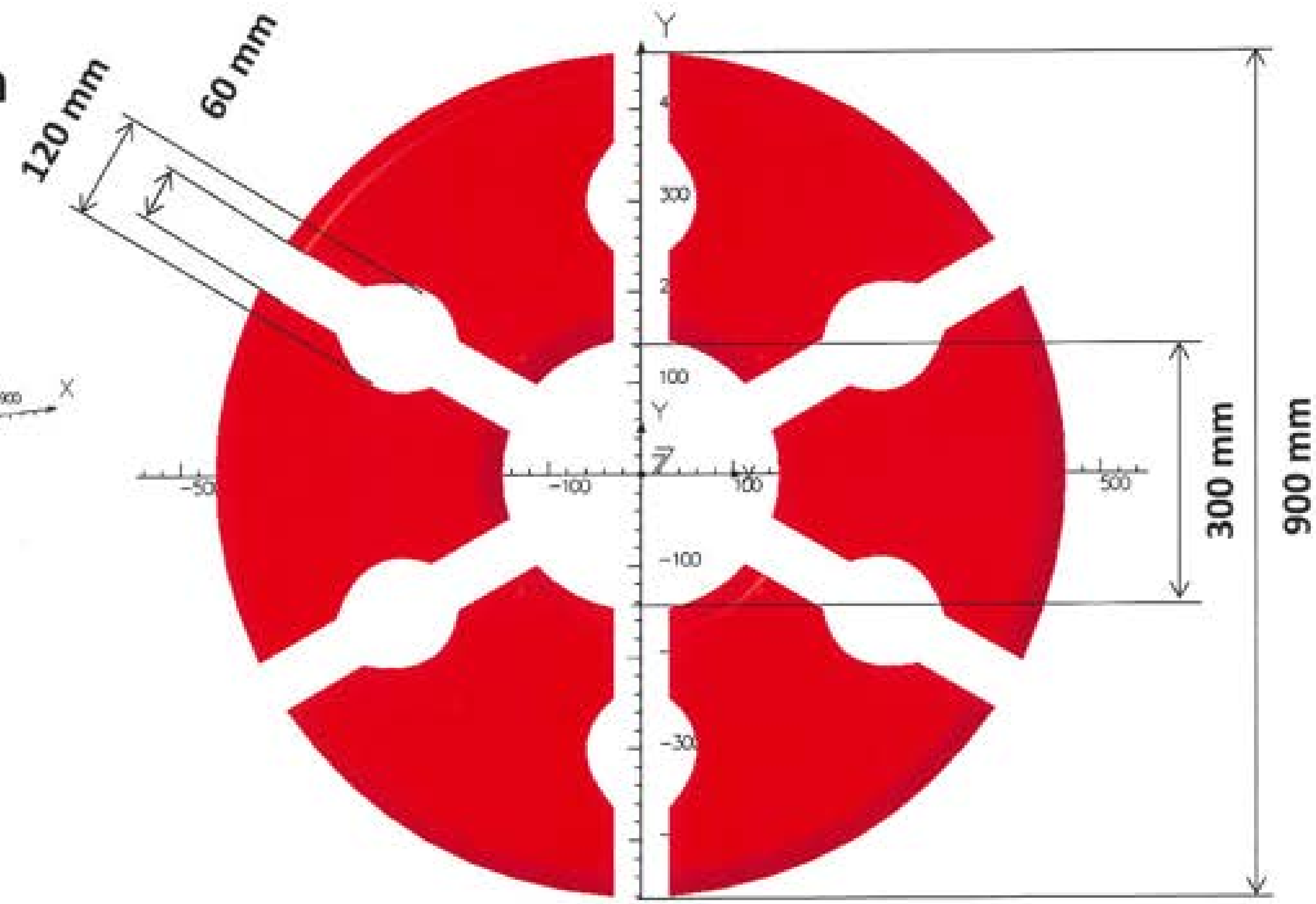
# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

## 40 MW – 4:1 Gearing



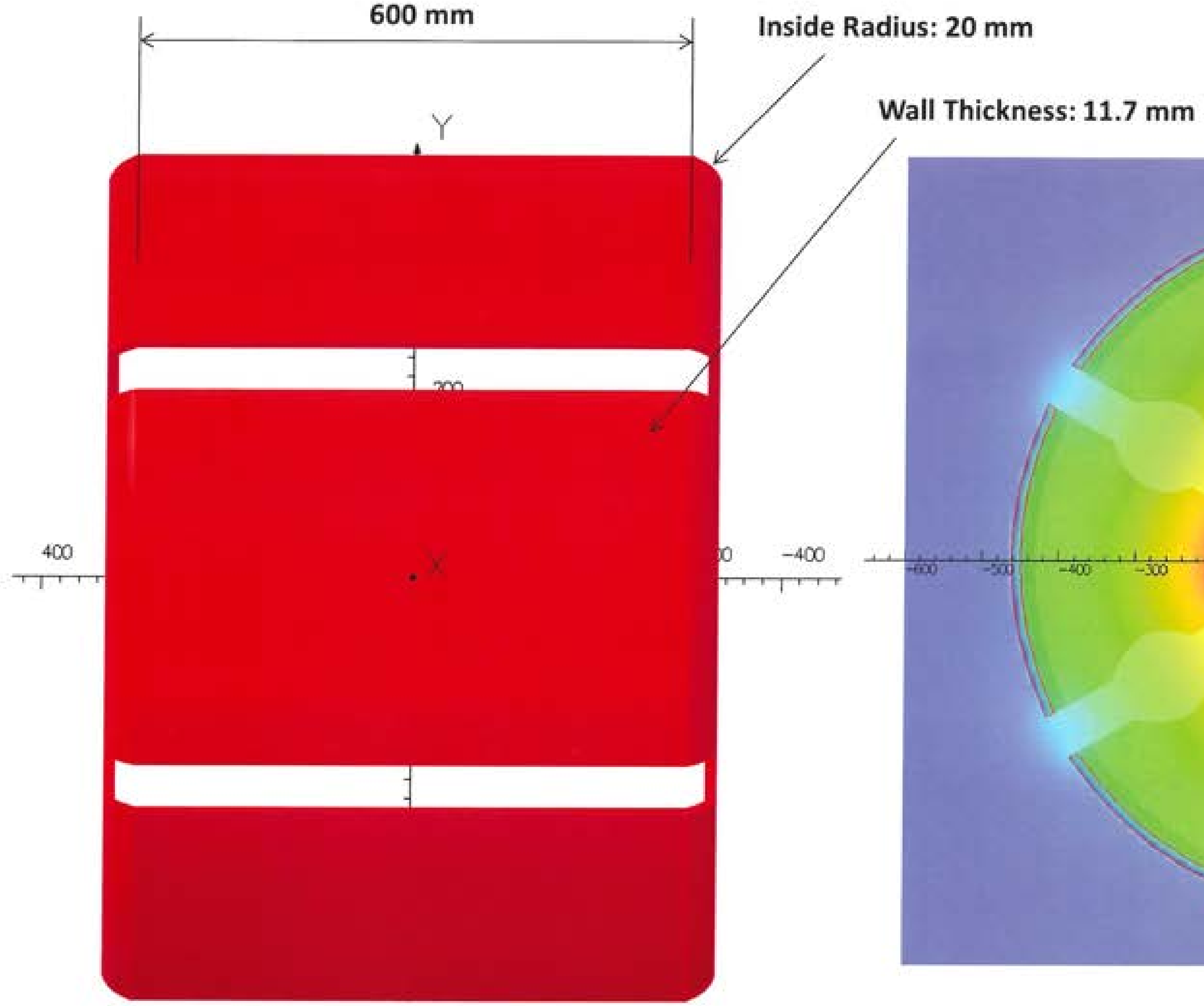
# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

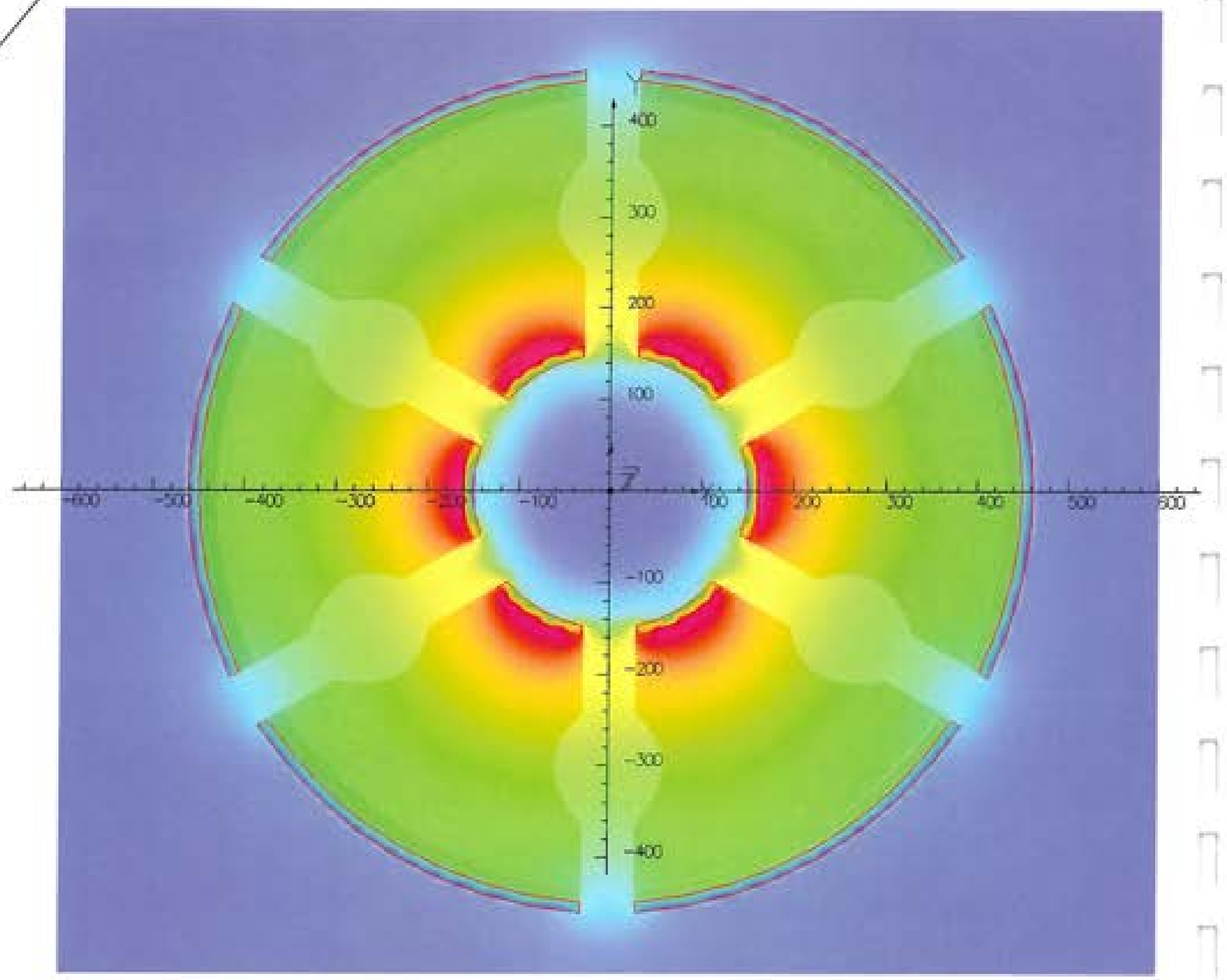



Proposed method of construction

# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

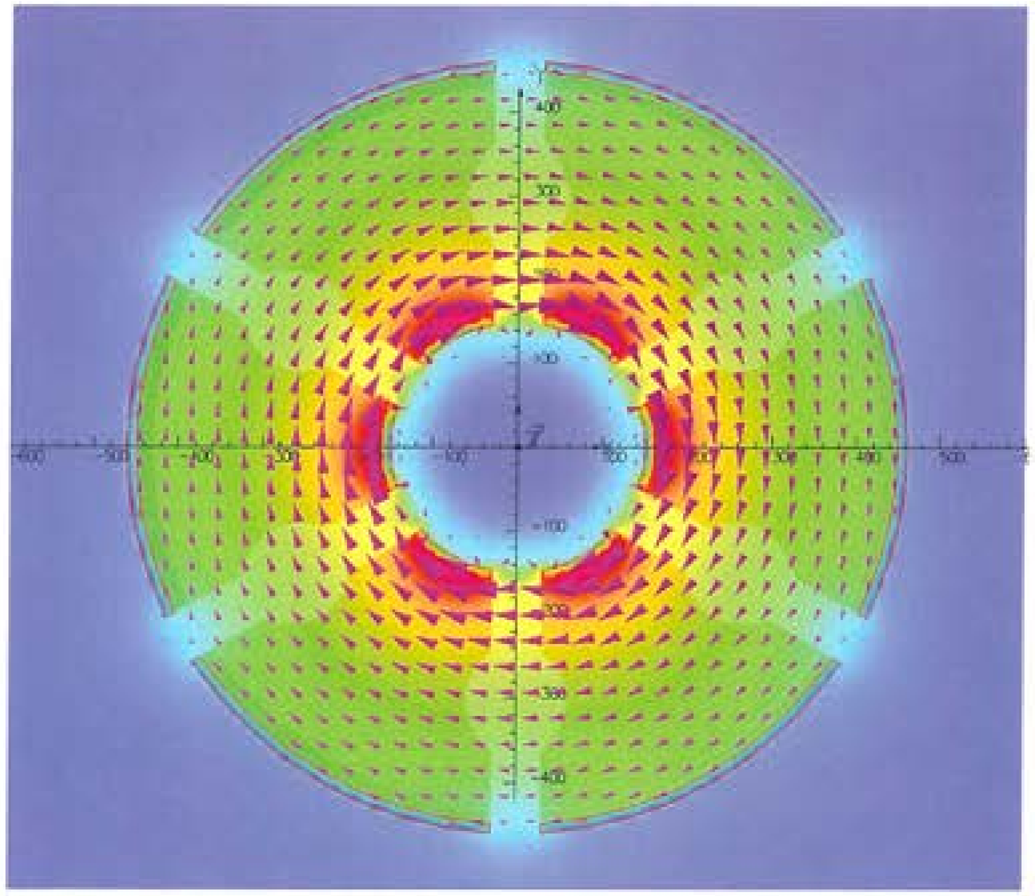


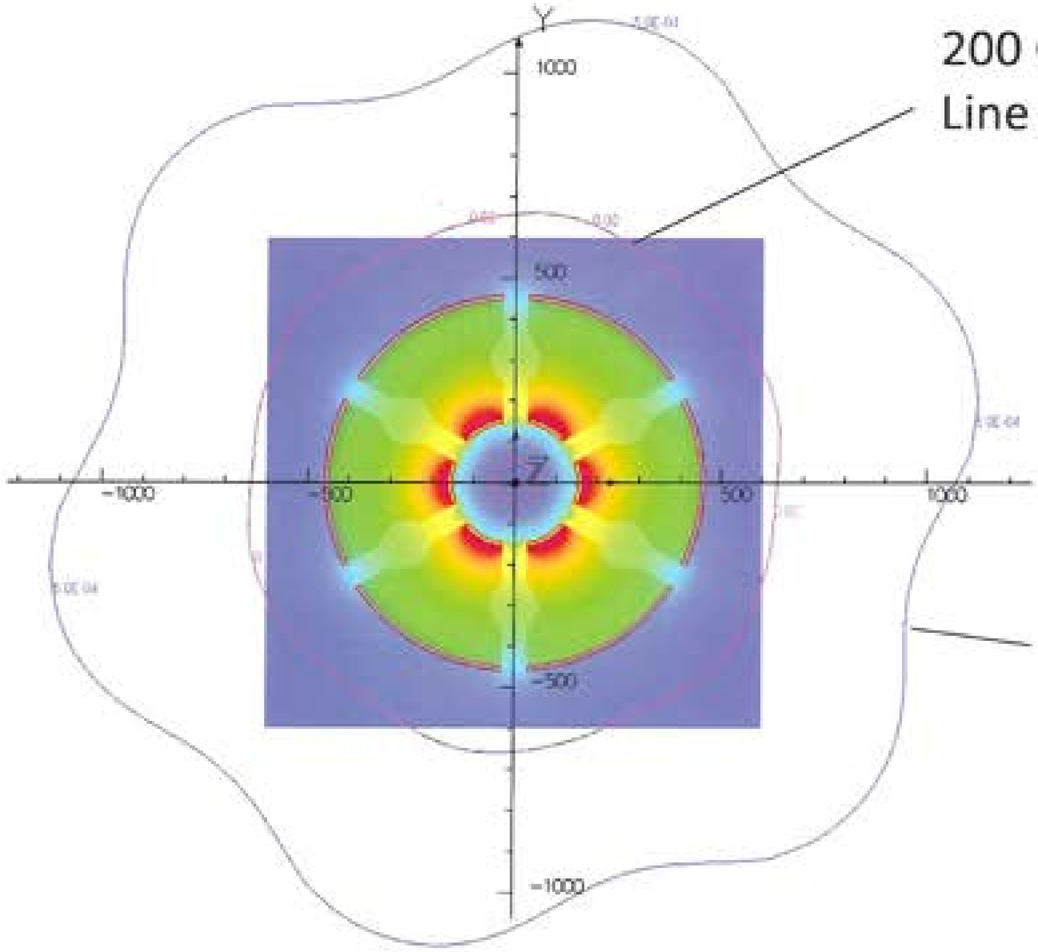




Proposed method of construction

# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

## Magnetic Field Plots

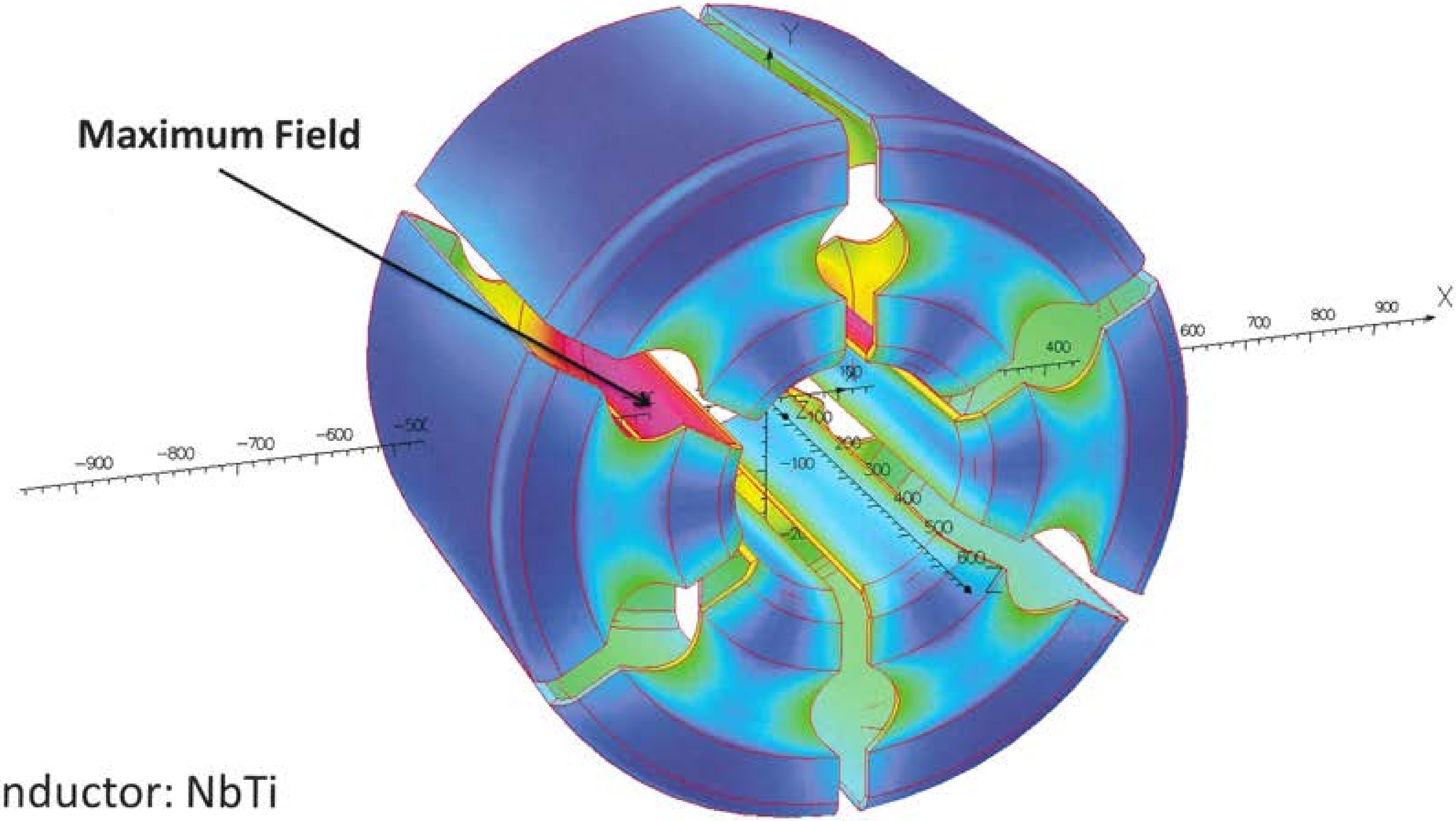





## Proposed method of construction

# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

## Magnetic Field Distribution

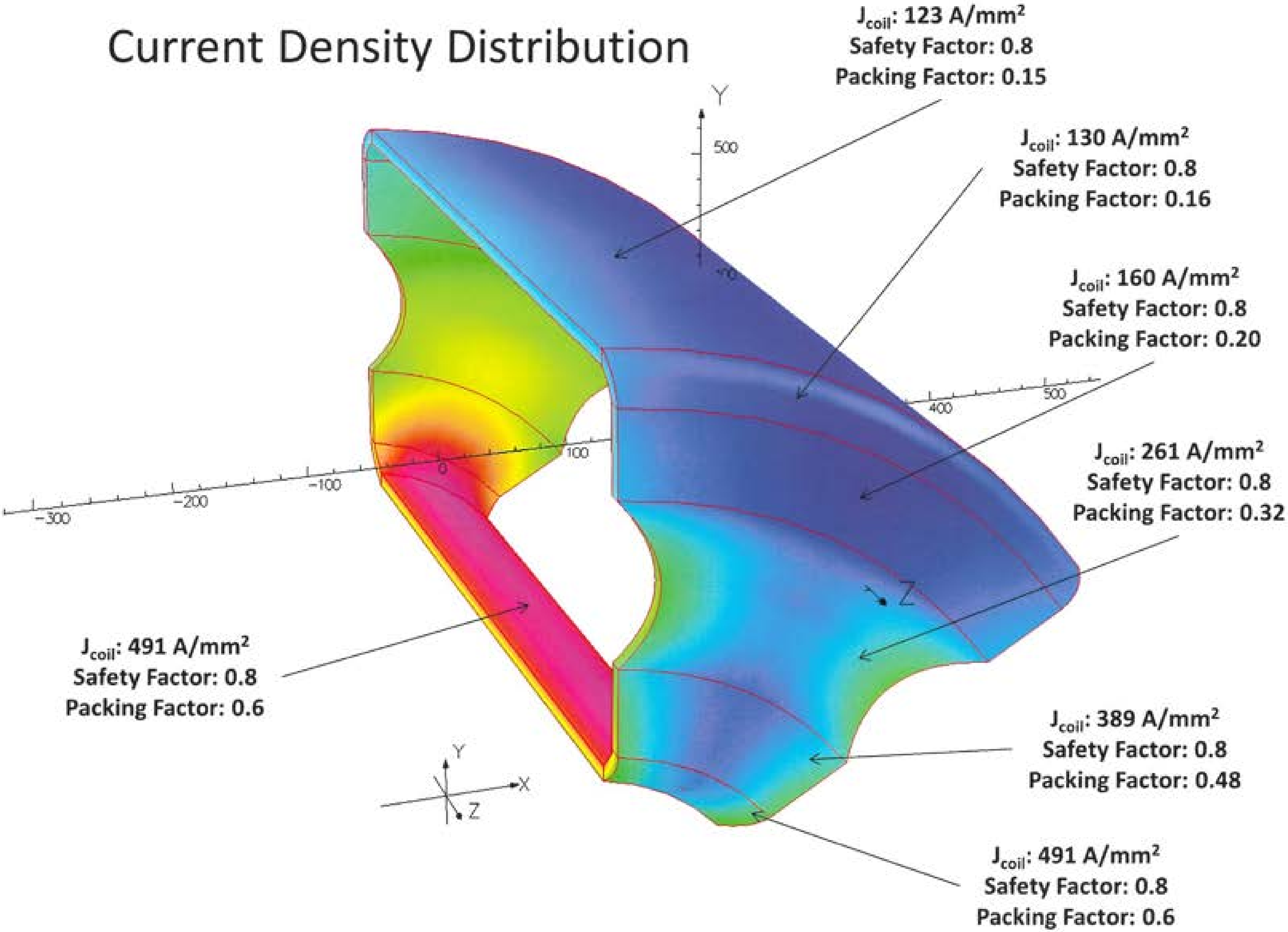



Conductor: NbTi
Maximum Field: ~6 Tesla
Maximum Current Density: 475 A/mm$^2$

# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

GUINA ENERGY GROUP

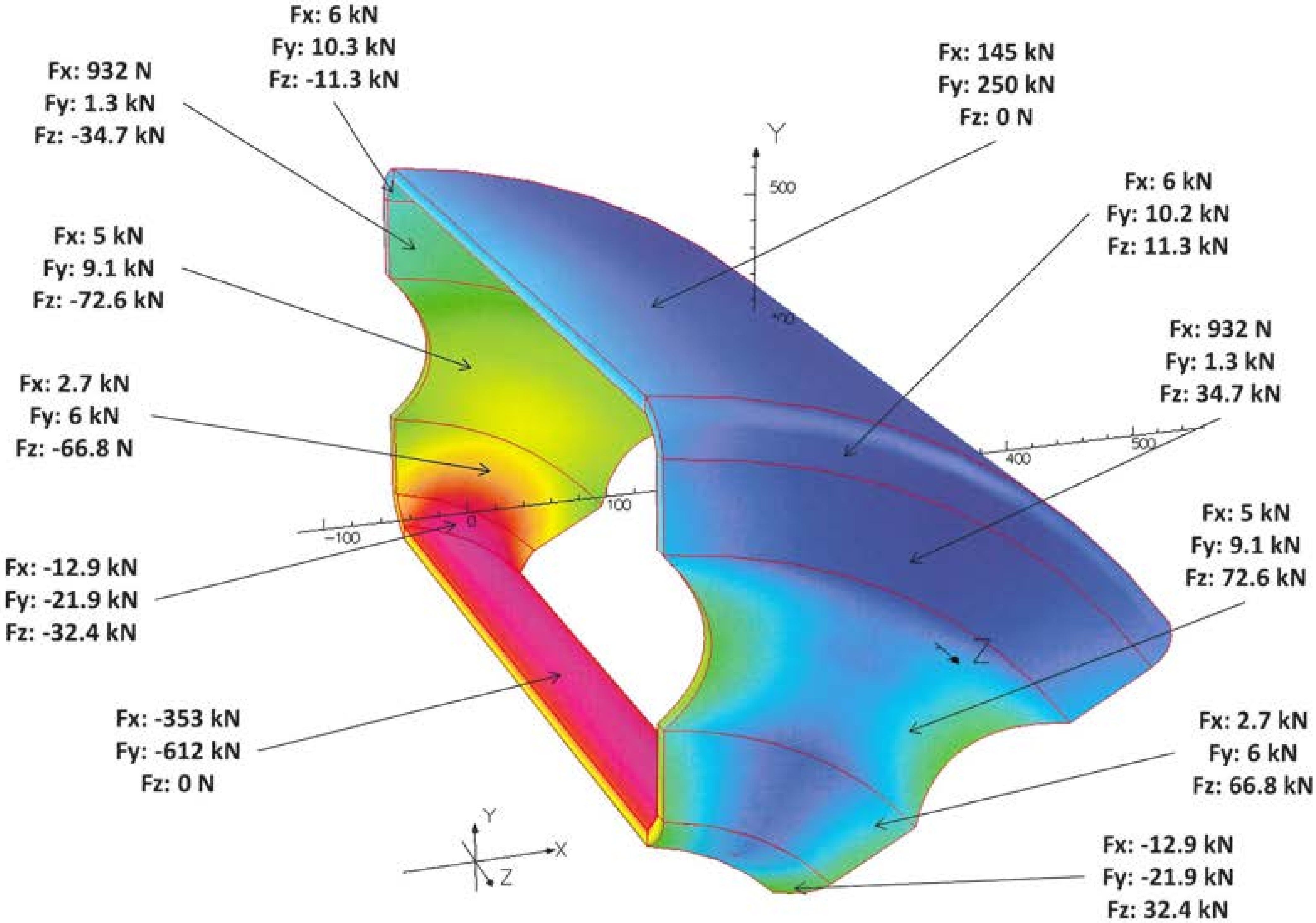
## Current Density Distribution



# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

GUINA ENERGY GROUP

## Forces



# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

No. of Rotors: 6

Material: Oxygen Free Copper

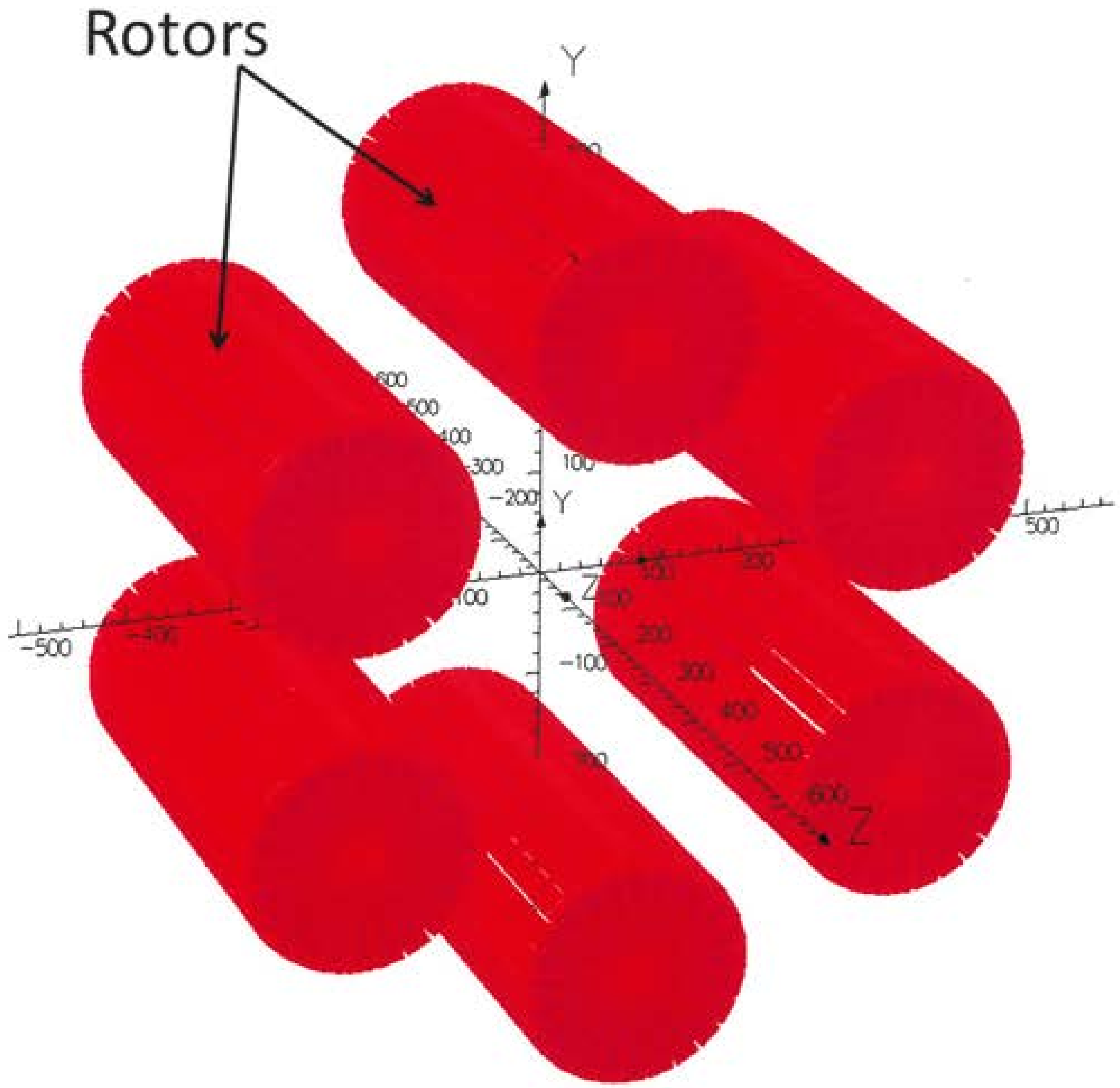
Current Density: 10 A/mm$^2$

Coils per Rotor: 12 (24 Phases)

Rotor Diameter: ~210 mm

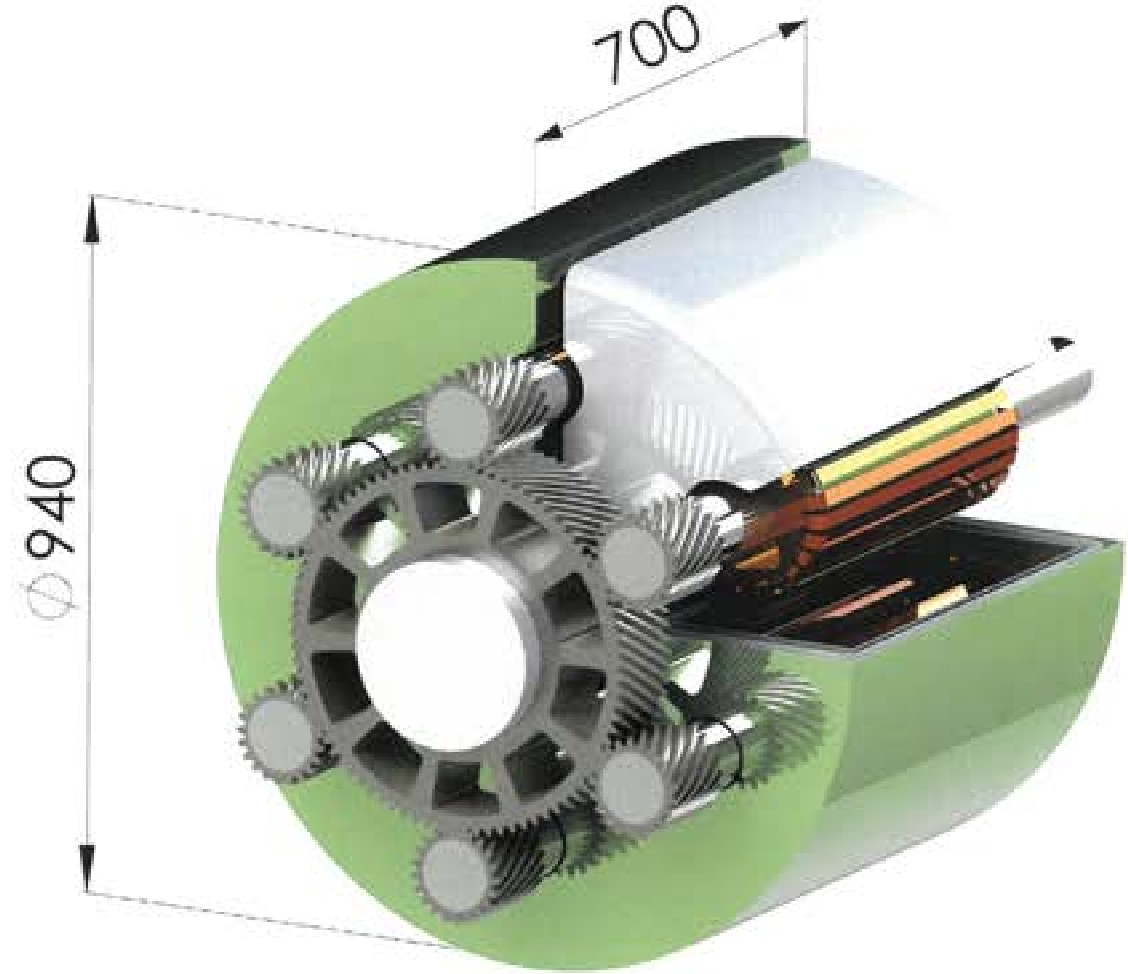
Rotor Length: ~500 mm

Bar Size: 23 x 7 mm



# SUPERCONDUCTING DC TOROIDAL TECHNOLOGY

| | |
|---|---|
| Maximum Power per Rotor (MW) | 1.79 |
| Torque per Rotor (Nm) | 3433 |
| Rated Rotor Speed (RPM) @ 4:1 Gearing | 20000 |
| Power Total (MW) | 40 |
| Rated Rotor Speed (RPM) @ 1:1 Gearing | 5000 |
| Power Total (MW) | 10 |
| **Rotor** | |
| No. of Rotor Assemblies | 6 |
| Rotor Current Density (A/mm$^2$) | 10 |
| Rotor Tip Speed (m/s) | 58.3 |
| Rotor Diameter (mm) | 222.6 |
| No. of Independent Rotor Windings | 12 |
| Rotor Material | Oxygen Free Copper Wire |
| Rotor Weight – Copper (kg) | 106 |
| **Toroid Coils** | |
| Super Conducting Wire | NbTi |
| SC Wire Length based on Ø 0.76 mm wire (km) | 18 |
| SC Wire Weight (kg) | 63 |
| SC Packing Factor | 0.6 – 0.17 |
| SC Wire Current Density (A/mm$^2$) | 792 |
| Maximum Coil Current Density (A/mm$^2$) | 491 |
| Peak Field on Wire (T) | 5.94 |
| Operating Temperature (K) | 4 |

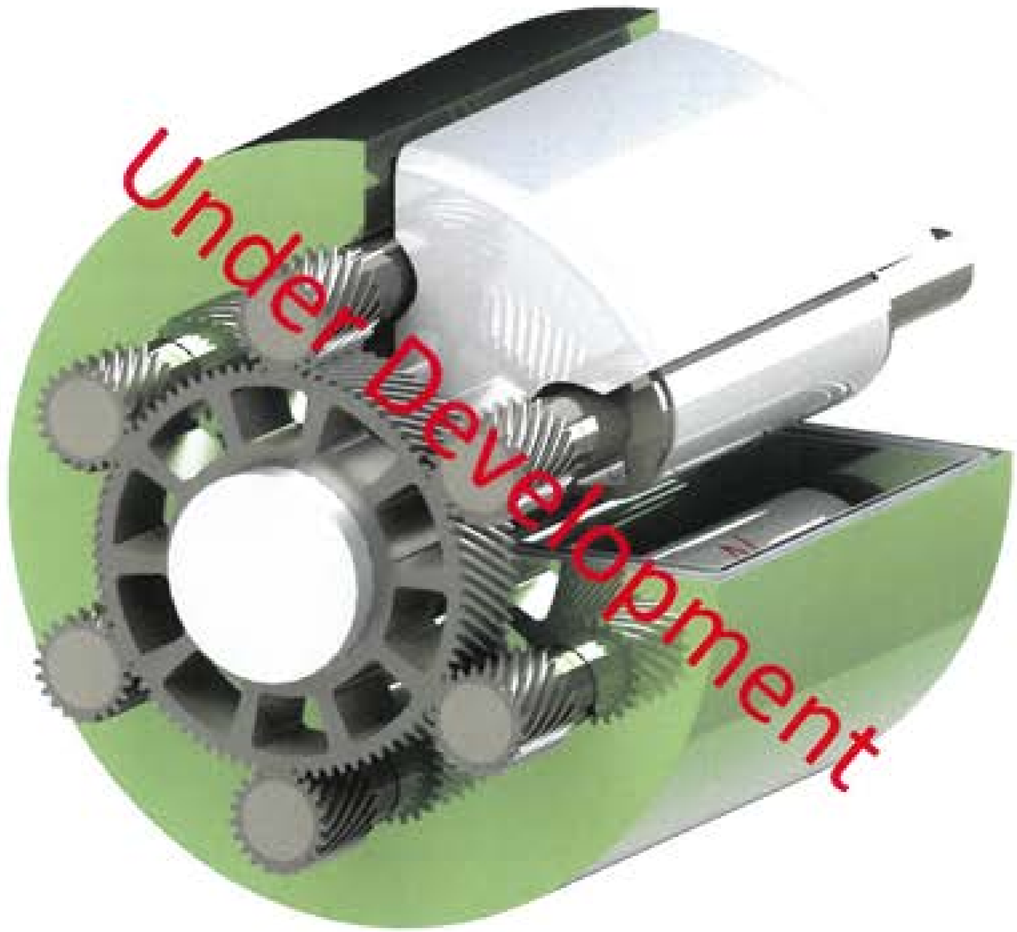


# SUPERCONDUCTING AC TOROIDAL TECHNOLOGY

Our Superconducting AC Toroidal Drive consists of a stationary toroidal body, made from superconducting wire encased in a cryostat, which operates in AC mode producing an AC toroidal magnetic field.

The rotor assemblies are made from permanent magnets and operate at room temperature outside of the cryogenic compartment.

Our Superconducting AC Toroidal Drive will be well suited to the next generation of low-AC loss superconducting wires and tapes.



# PRESENTING:
# ALTERNATIVE WIND TURBINE GENERATORS

# SECTION OUTLINE

- Toroidal Wind Turbine Generator

- All Pole Wind Turbine Generator

# INTRODUCTION TO OUR TECHNOLOGY

Guina Energy has developed a range of generator solutions for the Wind Turbine industry. All of our designs focus on high power, lightweight solutions that do not use steel or iron shielding and flux guides.

Minimising the tower mass results in lower manufacturing and installation costs. The technology shown has been extensively modelled and simulated using Vector Fields and Solidworks modelling software.

Our Toroidal and Homopolar Wind Turbine Generators are the only generators in the world that can be constructed entirely from low temperature superconducting wire while still having low AC/DC loss.

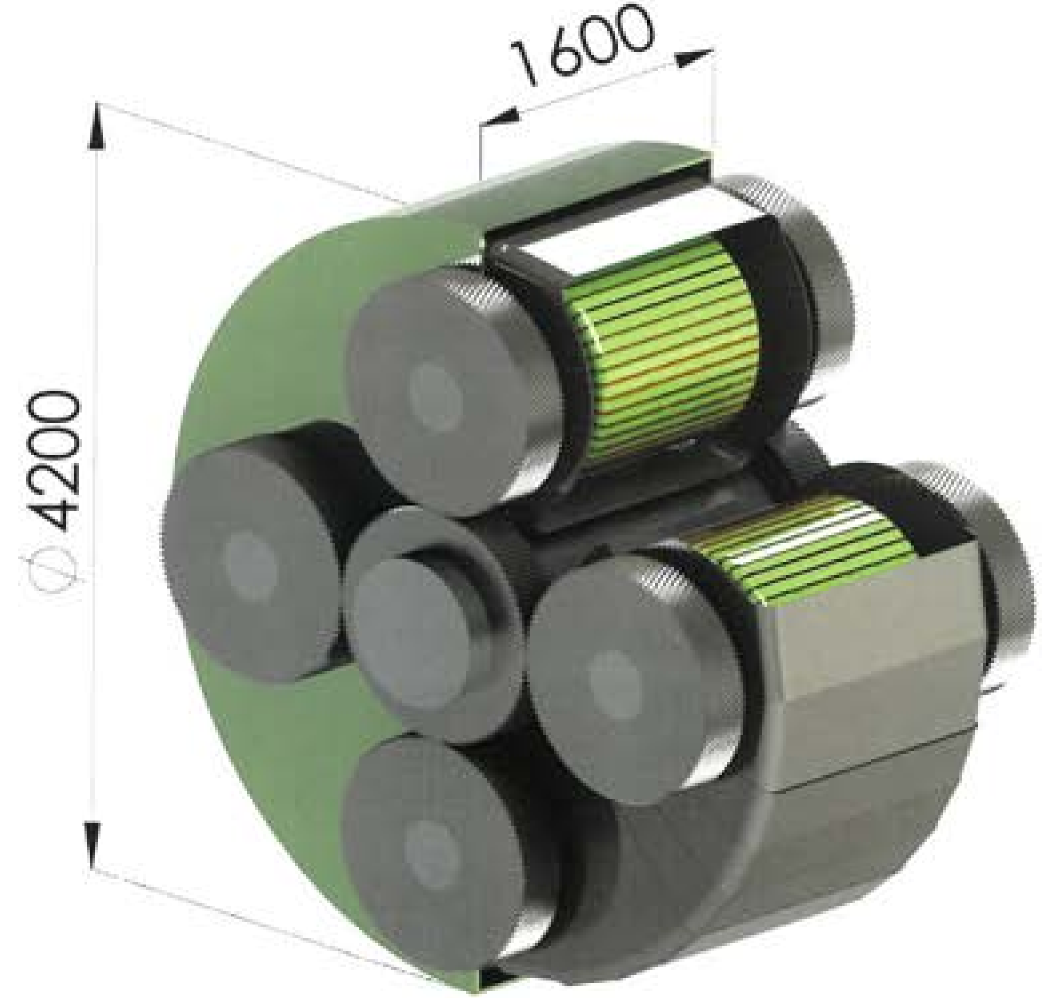
# TOROIDAL WIND TURBINE GENERATOR

This concept encompasses four generator assemblies within a Toroidal System creating a 10MW generator. The advantages of Guina Energy's Toroidal Wind Turbine generators include:

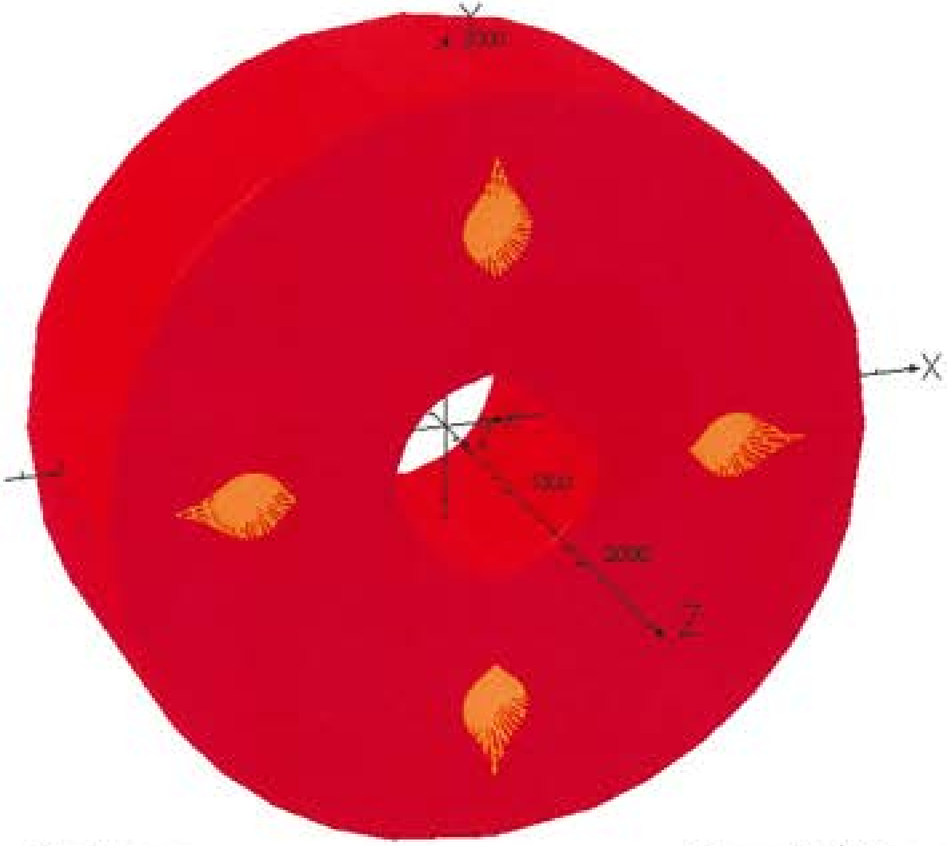
- Each individual generator can be progressively engaged allowing effective generation across a wider range of wind speeds and operating conditions.
- The Toroidal design encapsulates the magnetic field within the device removing the need for heavy iron shielding or flux guides.
- This generator can be constructed fully out of low temperature superconducting materials while maintaining low AC losses.
- Our Toroidal generators have the lowest operating frequency (1/6 Hz) for a 10MW direct drive generator.

Our Toroidal Wind Turbine generator consists of a stationary toroidal body made from superconducting wire encased in a cryostat. This cryostat consists of a number of interlocking modular sections to allow assembly around the rotor assemblies. The rotor assemblies are also made from superconducting wire and operate inside a rotating cryogenic compartment.

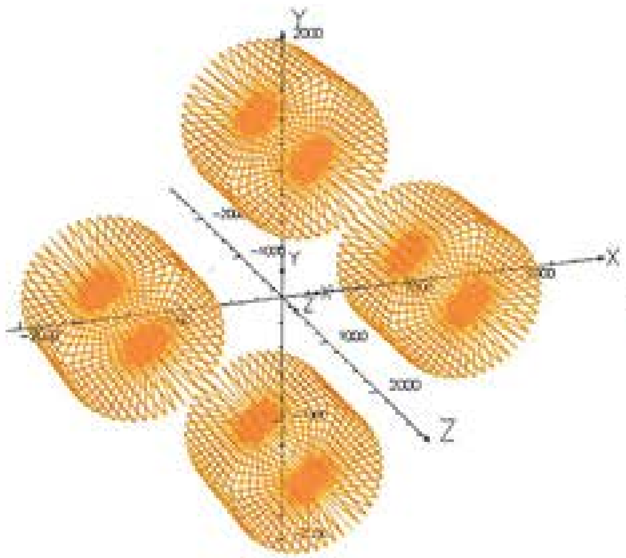
# 4 Rotor/24 Independent Rotor Windings



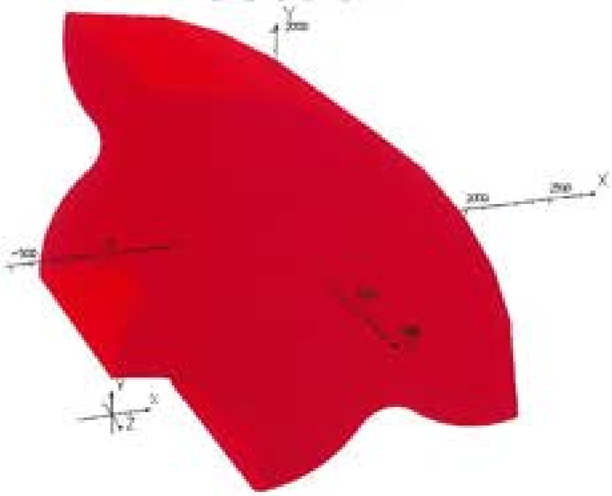
# TOROIDAL WIND TURBINE NbTi GENERATOR



Rotors



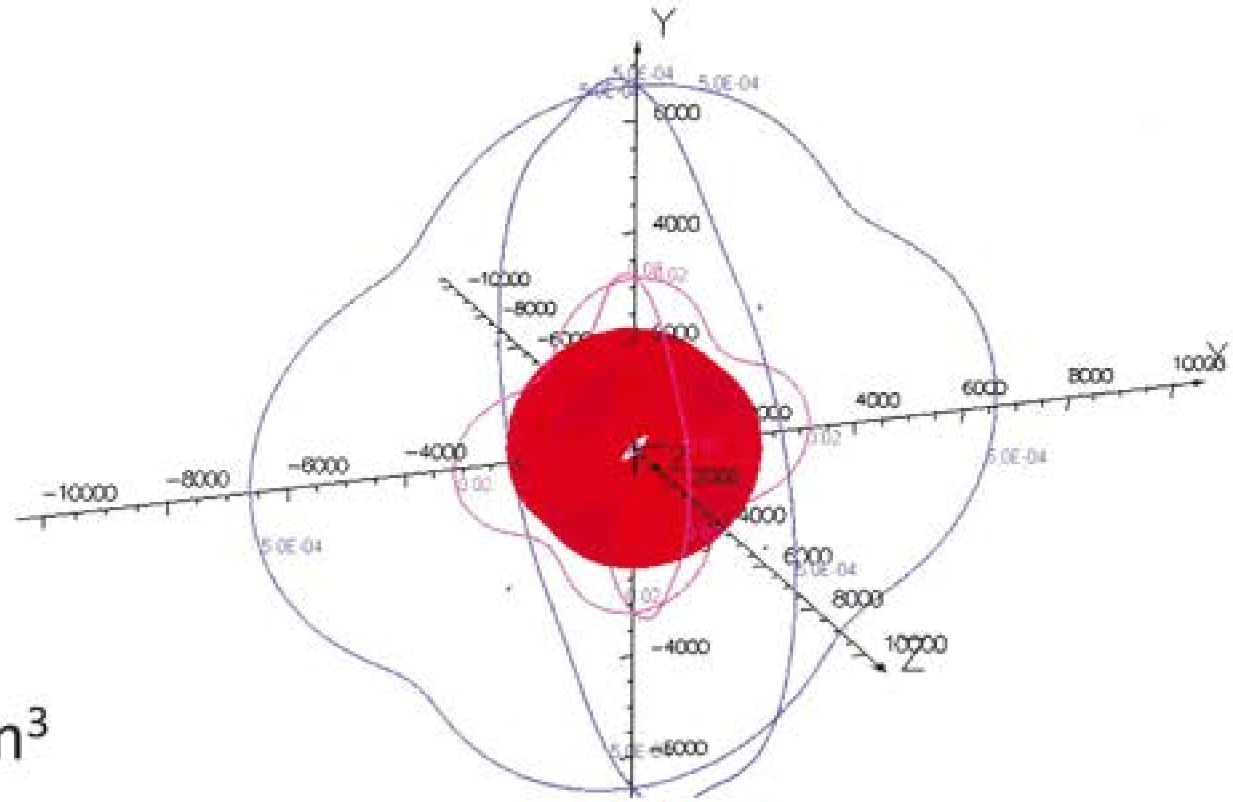
Toroid Construction Section

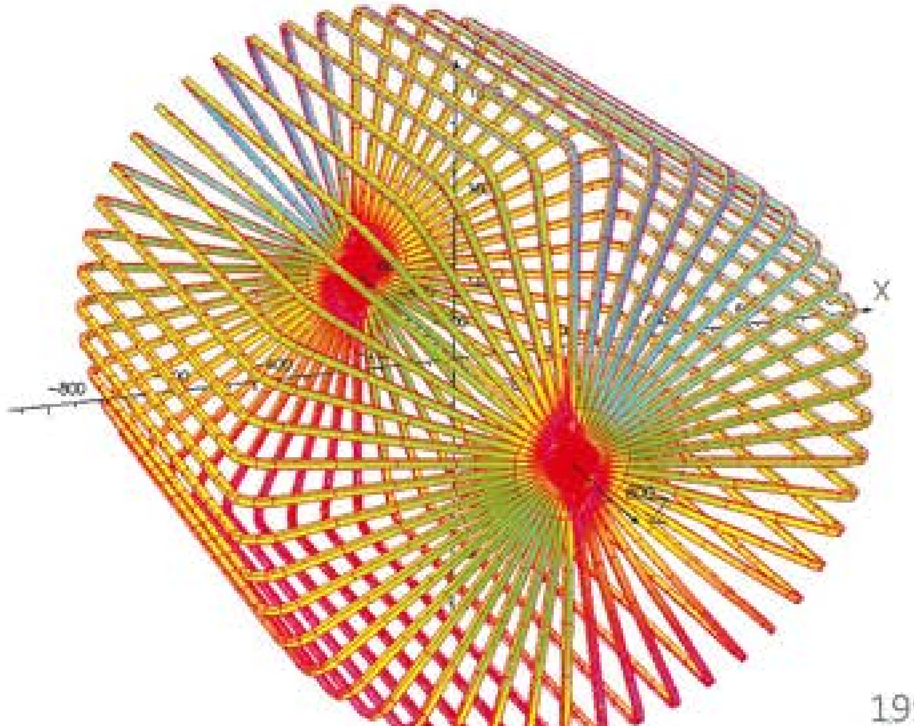


- External Dimensions
  - Toroid
    - Inner Diameter: 1 m
    - Outer Diameter: 4 m
    - Length: 2 m
  - Rotors
    - Diameter: 1.2 m
    - Length: 1.2 m
- DC Toroidal Coils (NbTi)
  - Winding Thickness: 5.55 mm
  - Wire Length: 379 km
  - Operating Temperature: 4.2 K
  - Engineering Current Density: 224 ~ 448 $A/mm^2$
- AC Rotor Coils (NbTi)
  - Number of Coils: 4 x 24
  - Width/Thickness: 13.8/13.8 mm
  - Operating Temperature: 4.2 K
  - Wire Length: 73 km
  - Engineering Current Density: 224 $A/mm^2$

# TOROIDAL WIND TURBINE NbTi GENERATOR

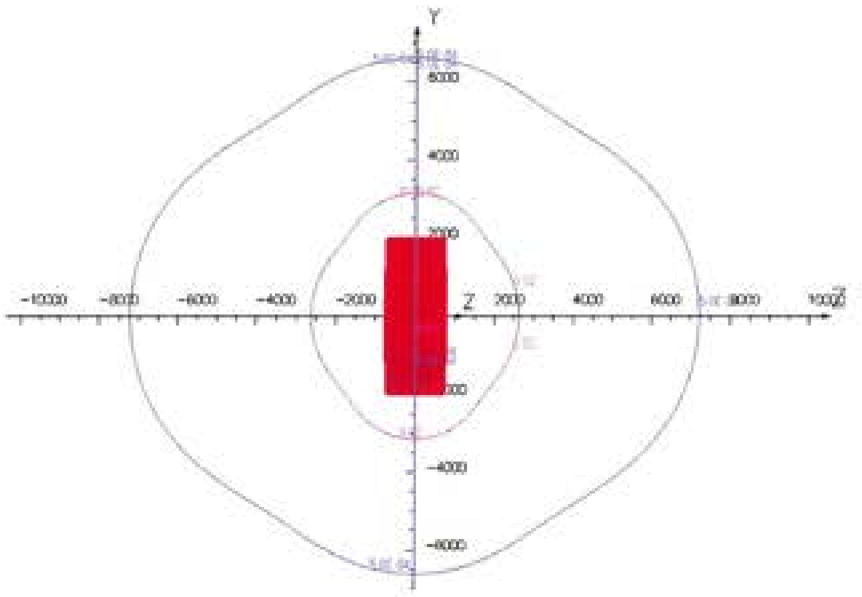
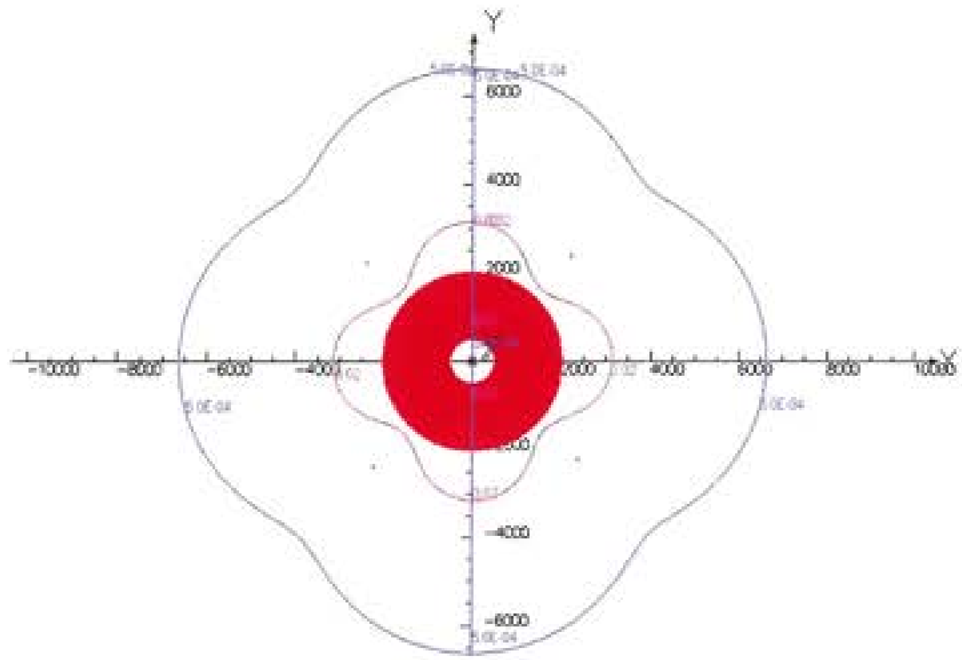
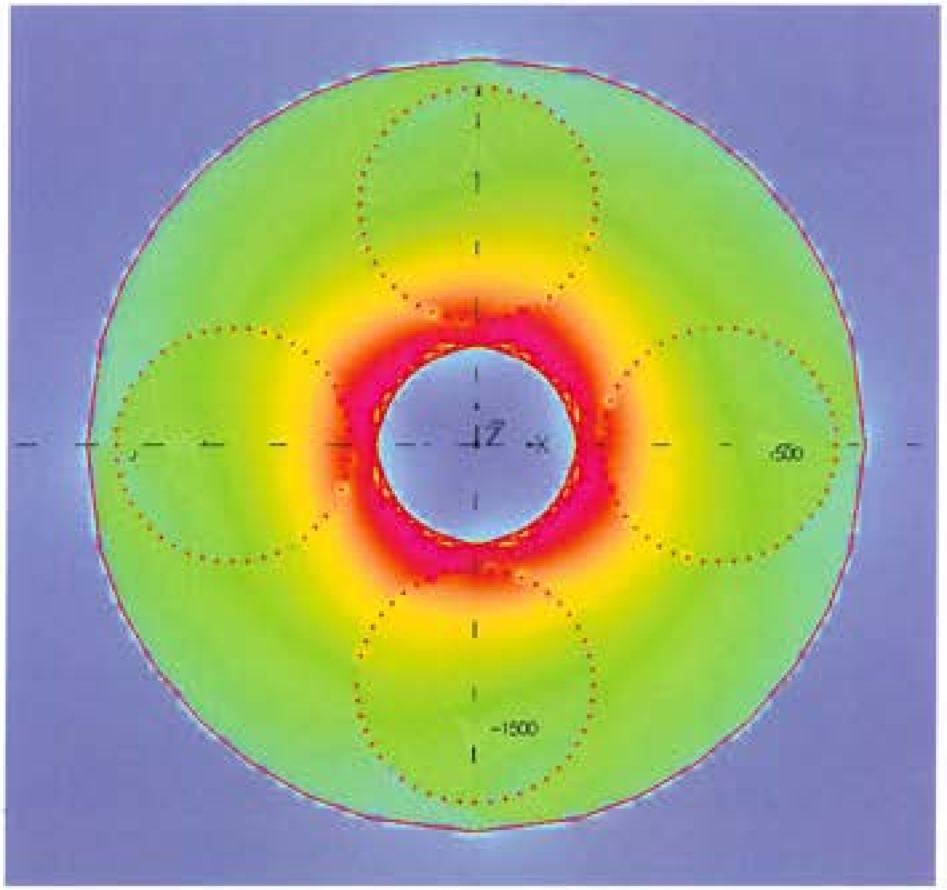
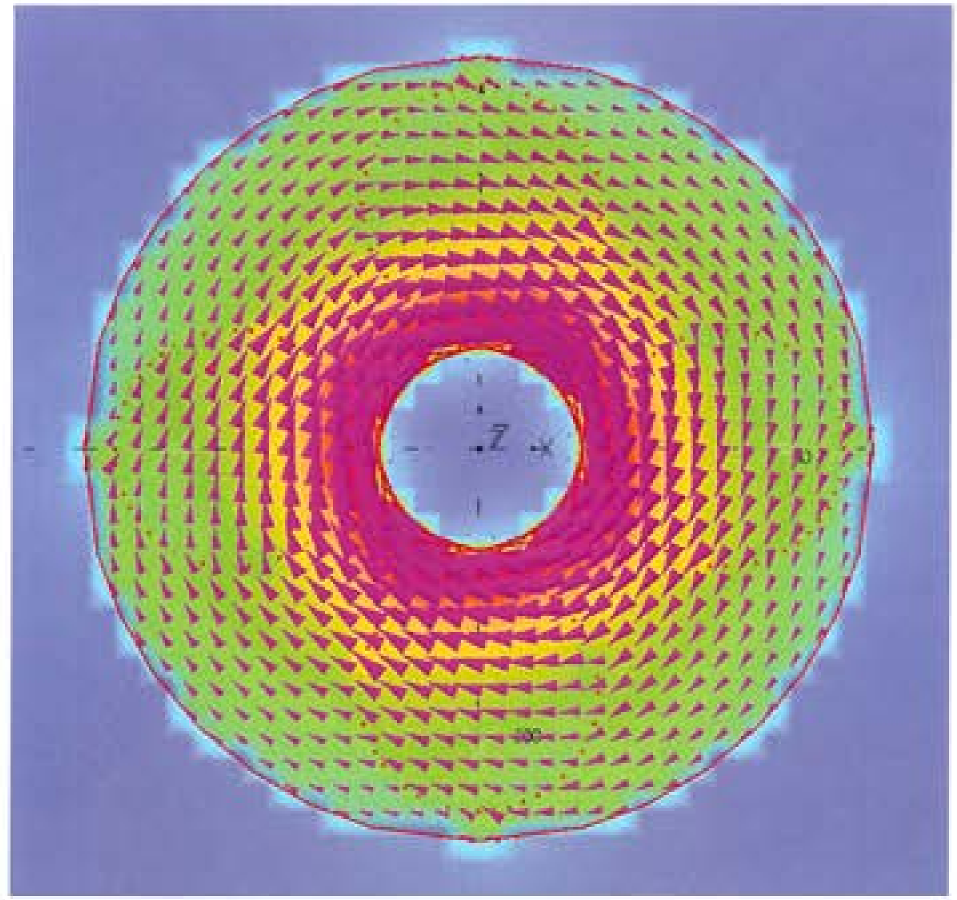
- Power: 10.5 MW
- Rotation Speed: 10 RPM
- Conductor:
  - NbTi, Ø 0.7 mm, $J_C = 944\ A/mm^2$
- Maximum DC Field: 6 T
- Maximum AC Field: 4 T
- AC Superconducting Volume: 0.014 $m^3$
- AC Hysteresis Losses
  - Standard Wire: 1300 W (~655 kW @4.2 K, factor 500)
  - Improved Wire: 600 W (~ 300 kW @4.2 K, factor 500)



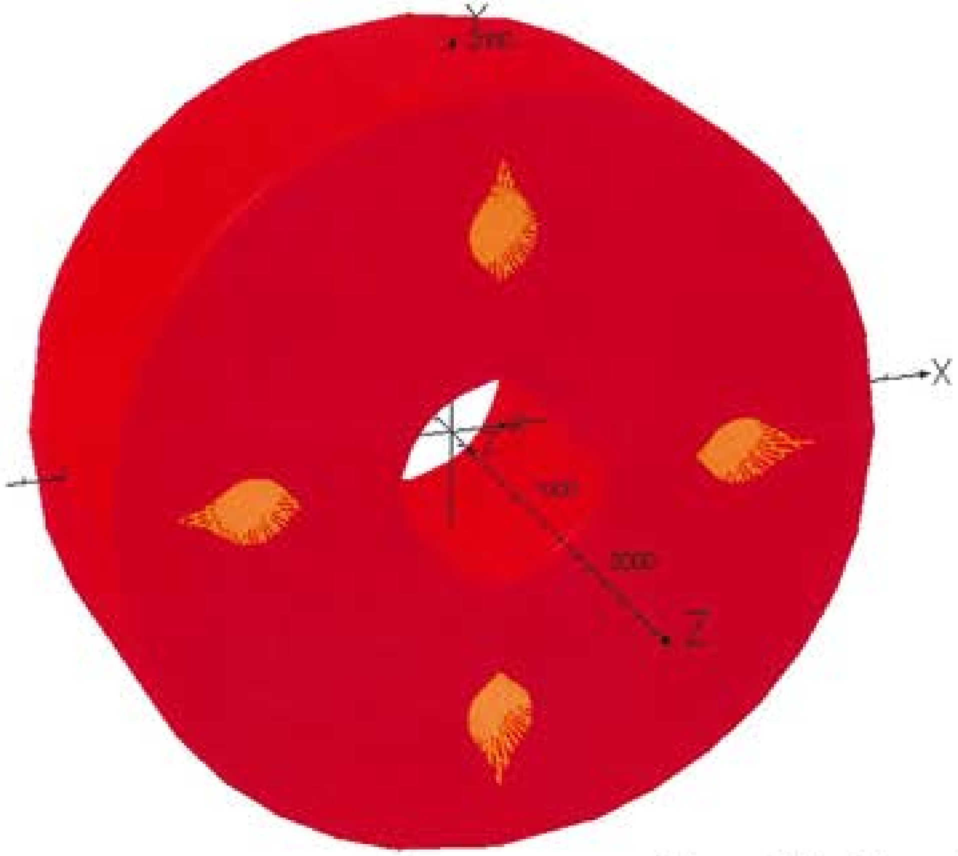


# TOROIDAL WIND TURBINE NbTi GENERATOR

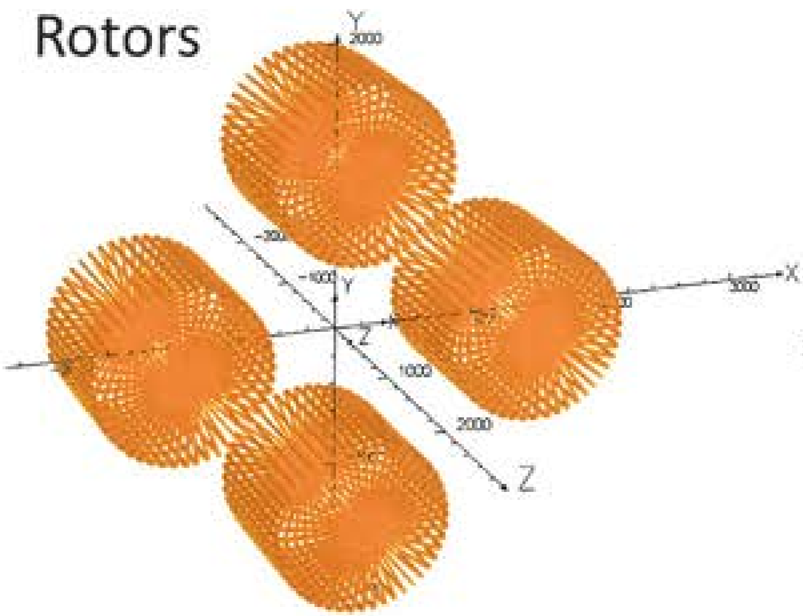
GUINA ENERGY GROUP

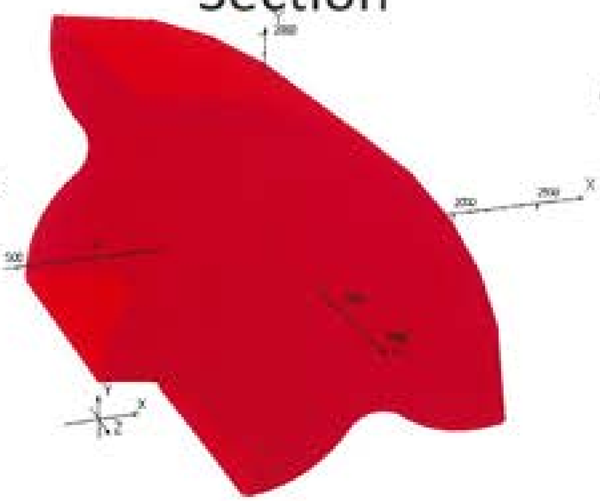
# TOROIDAL WIND TURBINE NbTi/$MgB_2$ GENERATOR




Rotors




Toroid Construction Section

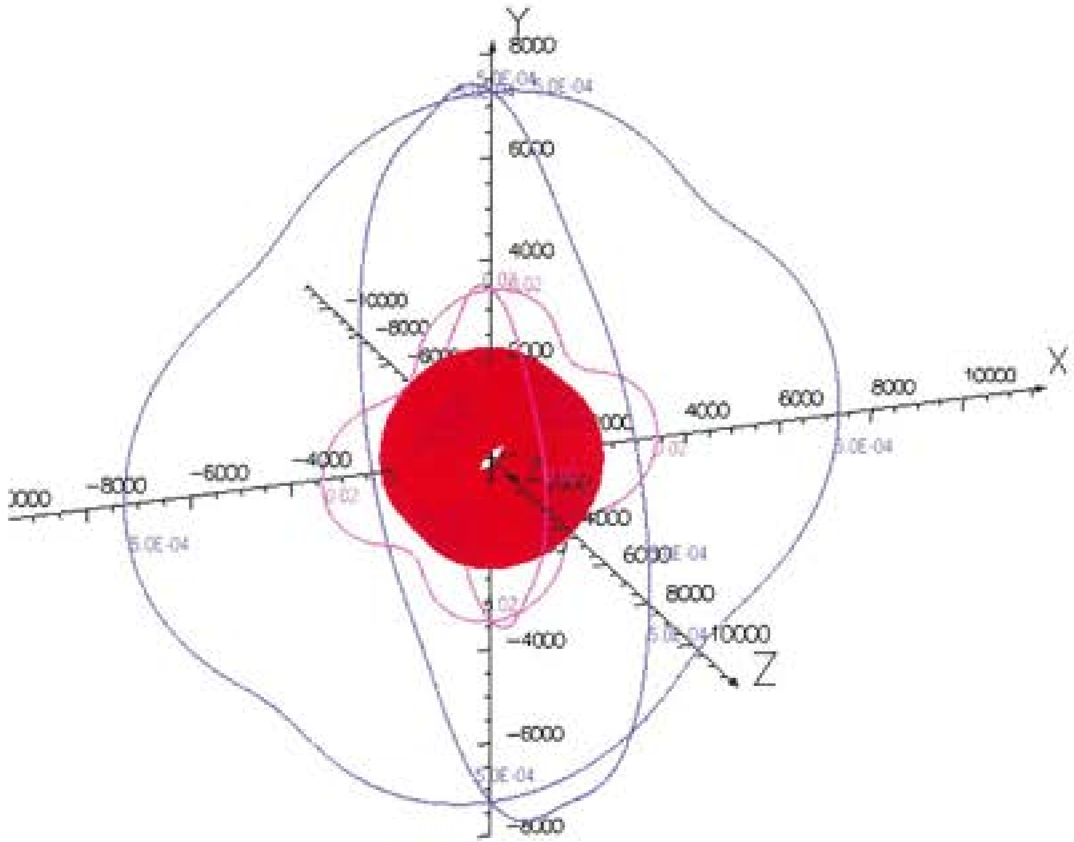


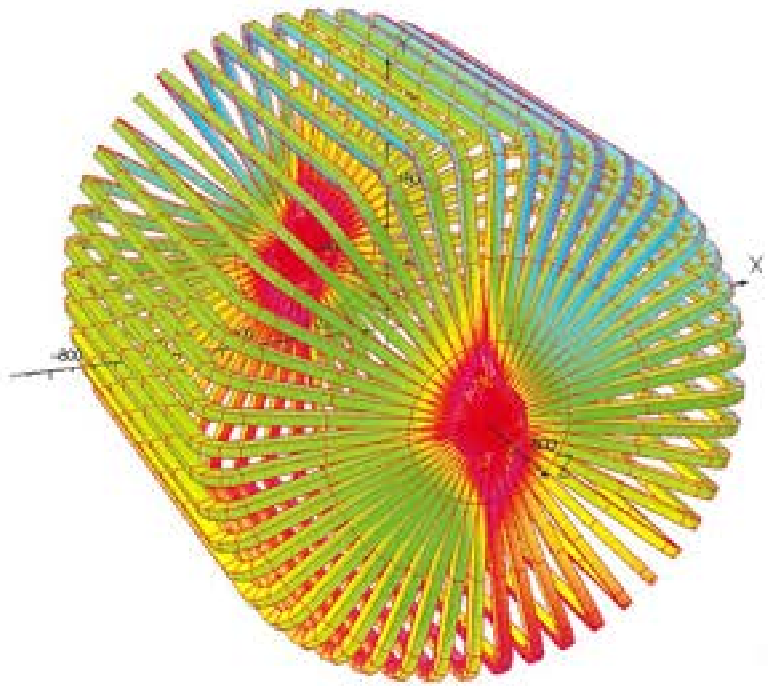
- Dimensions
  - Toroid
    - Inner Diameter: 1 m
    - Outer Diameter: 4 m
    - Length: 2 m
  - Rotor
    - Diameter: 1.2 m
    - Length: 1.2 m
- DC Toroidal Coils (NbTi)
  - Winding Thickness: 2.5 mm
  - Wire Length: 171 km
  - Operating Temperature: 4.2 K
  - Engineering Current Density: 326 ~ 652 A/mm$^2$
- AC Rotor Coils ($MgB_2$)
  - Number of Coils: 4 x 24
  - Width/Thickness: 24/35.5 mm
  - Operating Temperature: 15 K
  - Wire Length: 209 km
  - Engineering Current Density: 73.5 A/mm$^2$

# TOROIDAL WIND TURBINE NbTi/$MgB_2$ GENERATOR

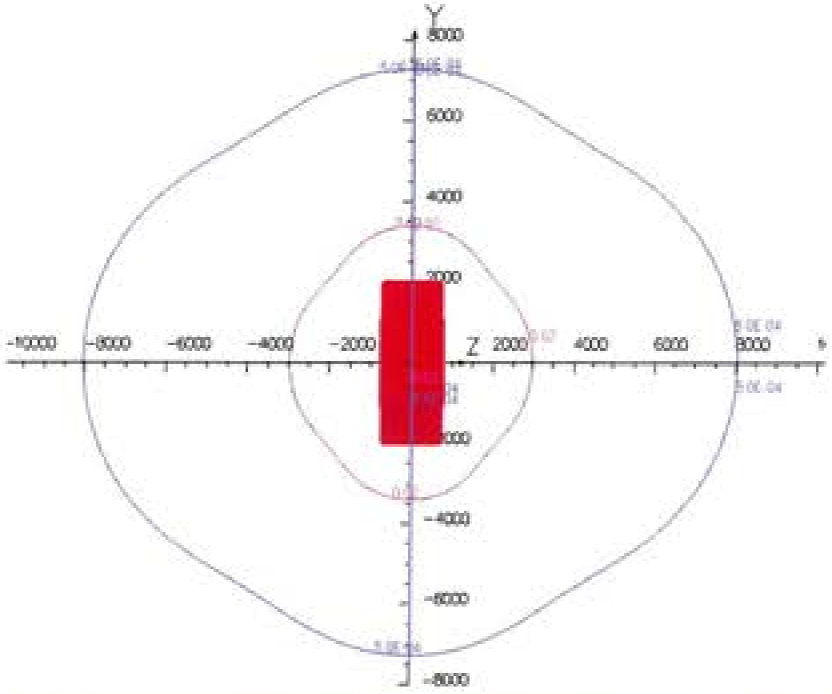
GUINA ENERGY GROUP

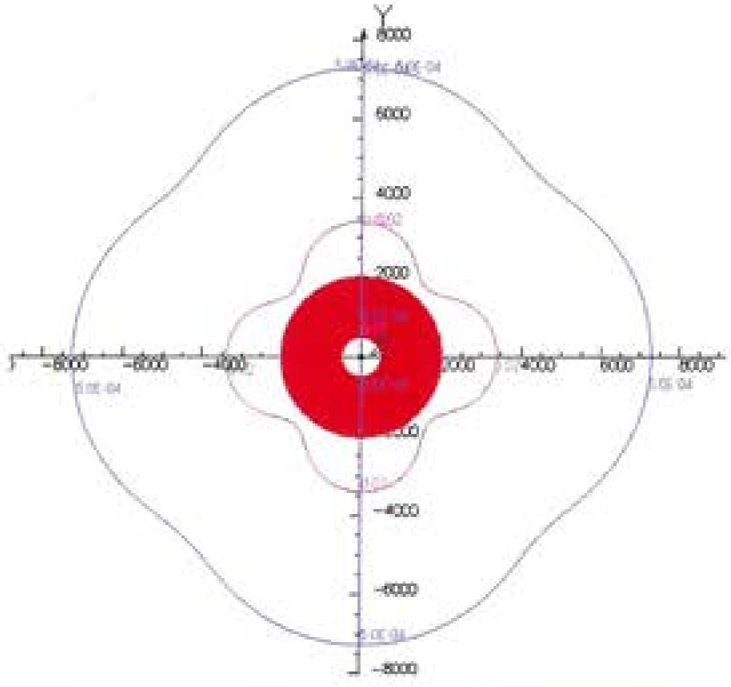
- Power: 10.5 MW
- Rotation Speed: 10 RPM
- Conductor:
  - NbTi, Ø 0.7 mm, $J_C$ = 1371 A/mm$^2$
  - $MgB_2$, 0.5 mm x 3 mm, $J_C$ = 440 A/mm$^2$
- Maximum DC Field: 4 T
- Maximum AC Field: 3 T
- AC Superconducting Volume: 0.0188 m$^3$
- AC Hysteresis Losses
  - Standard Wire: 1200 W (~240 kW @ 15 K, factor 200)
  - Improved Wire: 325 W (~65 kW @ 15 K, factor 200)

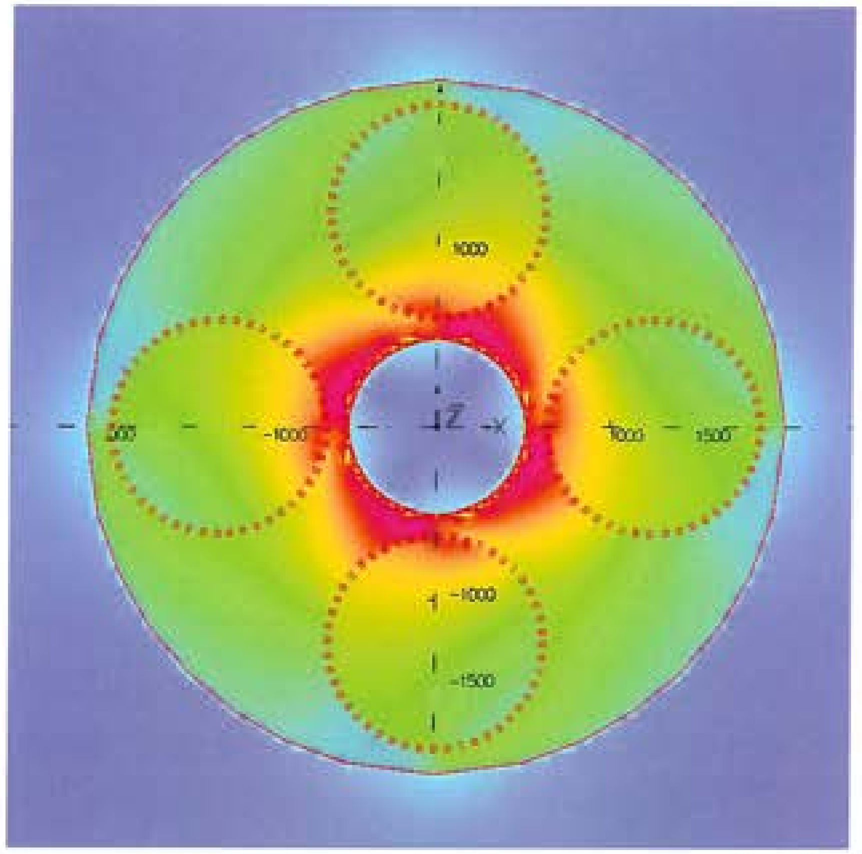


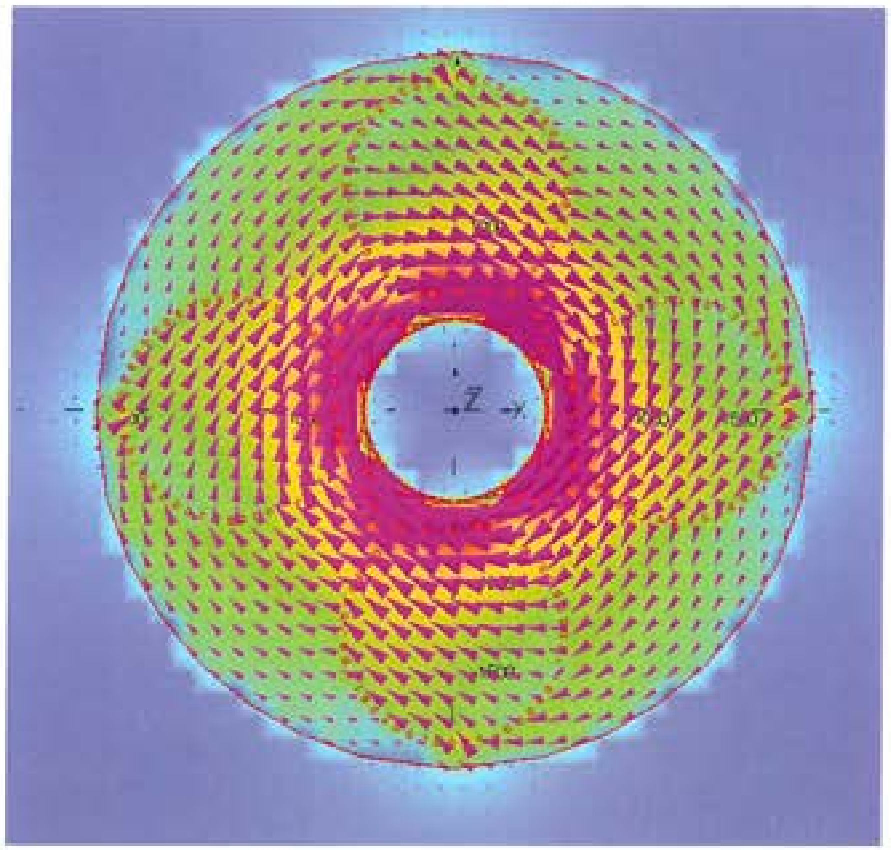



# TOROIDAL WIND TURBINE NbTi/$MgB_2$ GENERATOR









# ALL POLE DRIVE WIND TURBINE GENERATOR

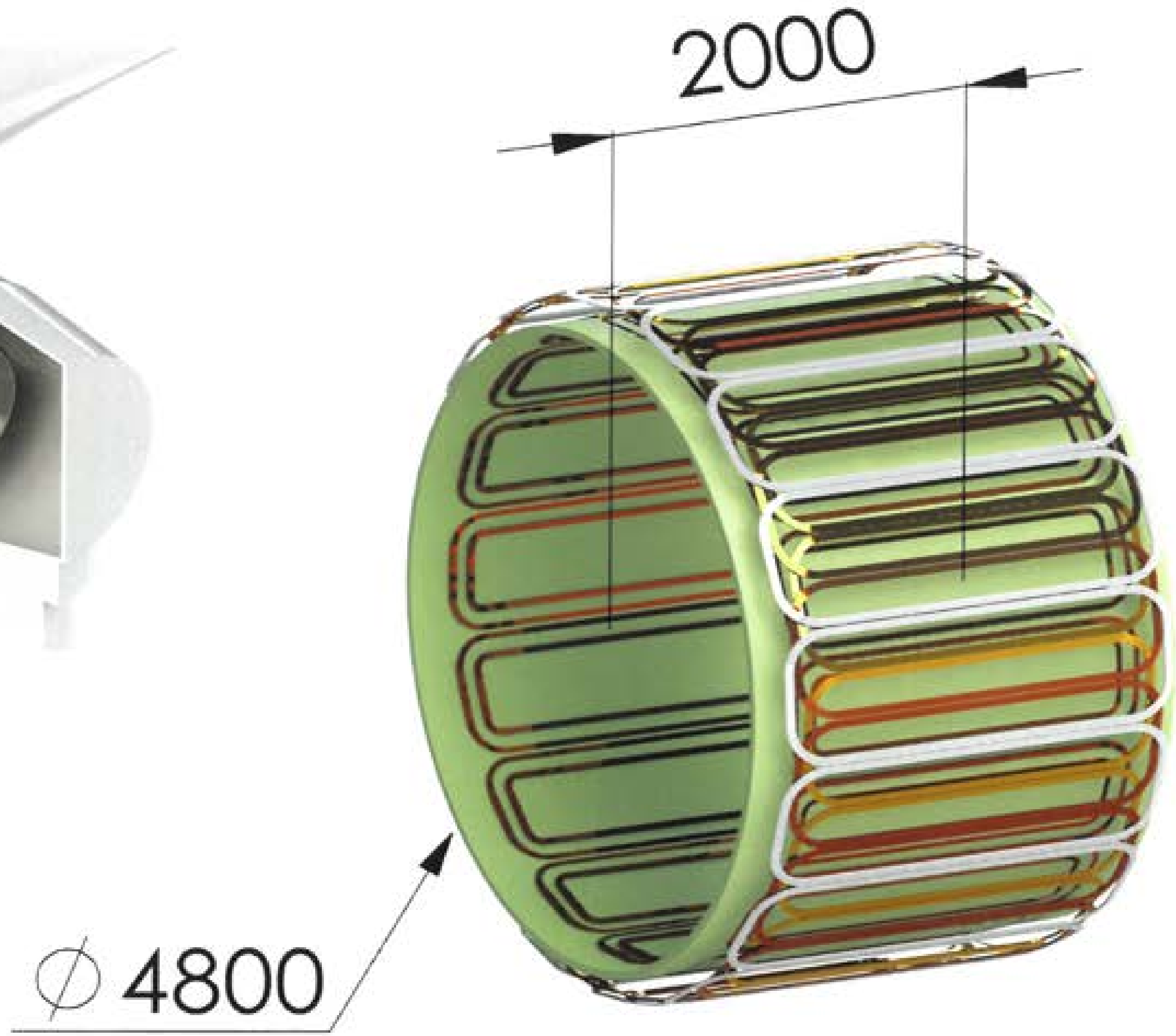
GUINA ENERGY GROUP

- Guina Energy's All Pole Drive uses concentric field coils to reduce the amount of superconducting material used in the windings. Additionally the load on the DC coils is more evenly distributed.

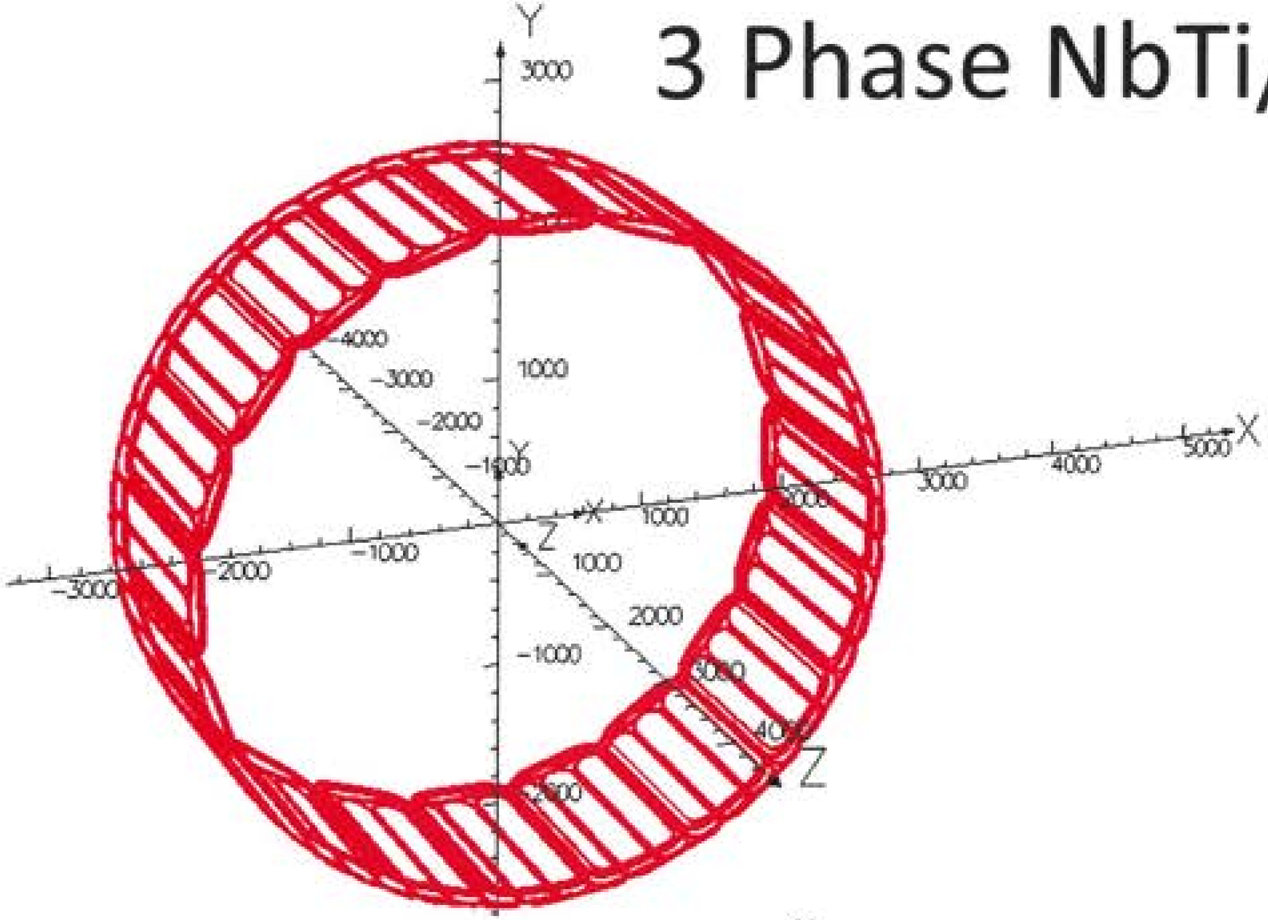
- These Direct Drive generators are most suited to construction using low temperature superconducting wire for the DC coils with the AC coils constructed from $MgB_2$, HTS Roebel cable or copper windings.

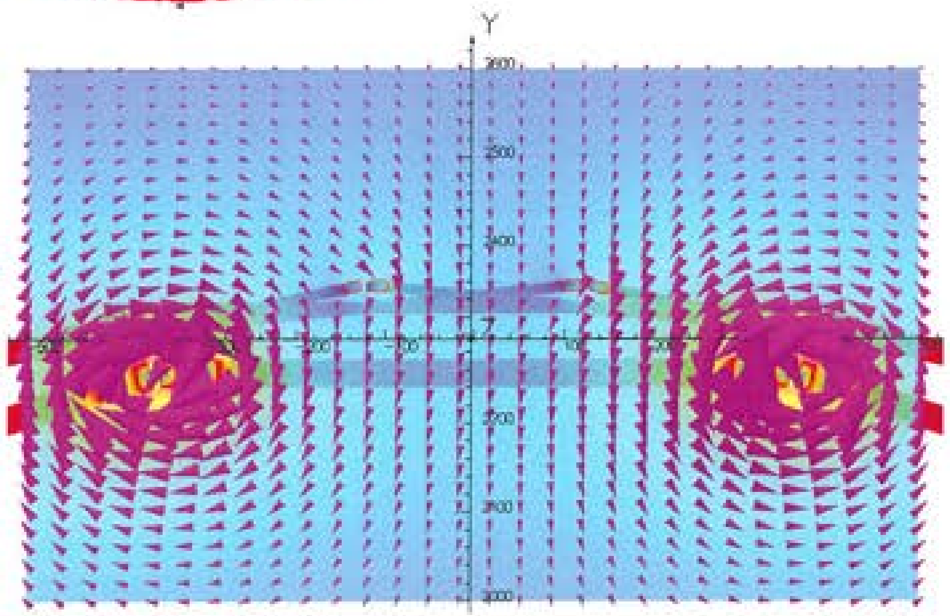
# ALL-POLE WIND TURBINE SUPERCONDUCTING GENERATOR

*Multi-Pole*
*All Superconducting*
*AC Direct Drive Machine*



# 3 Phase NbTi/REBaCuO



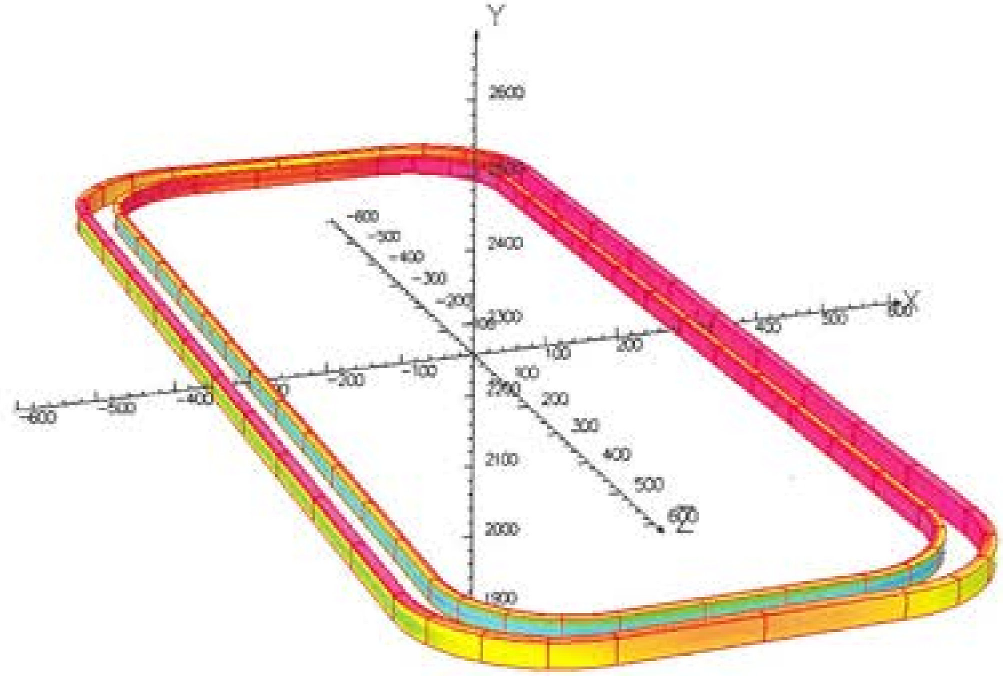


- Dimensions
  - Diameter: 4.6 m
  - Length: 1.8 m
  - Air gap: 50 mm
- DC Rotor Coils (NbTi)
  - Main Coils
    - Number of Coils: 20 (10 Pole)
    - Width/Thickness: 15.2/15.2 mm
    - Wire Length: 63 km
  - Second Coils
    - Space between Coils: 50 mm
    - Width/ Thickness: 12.768/12.768 mm
    - Wire Length: 42 km
  - Operating Temperature: 4.2 K
  - Engineering Current Density: 492 A/mm$^2$
- AC Stator Coils (ReBaCuO)
  - Number of Coils: 20 x 3 (3 Phase)
  - Operating Temperature: 50 K
  - Layers/ Turns per coil: 46/92
  - Wire Length: 25 km
  - Engineering Current Density: 122 A/mm$^2$

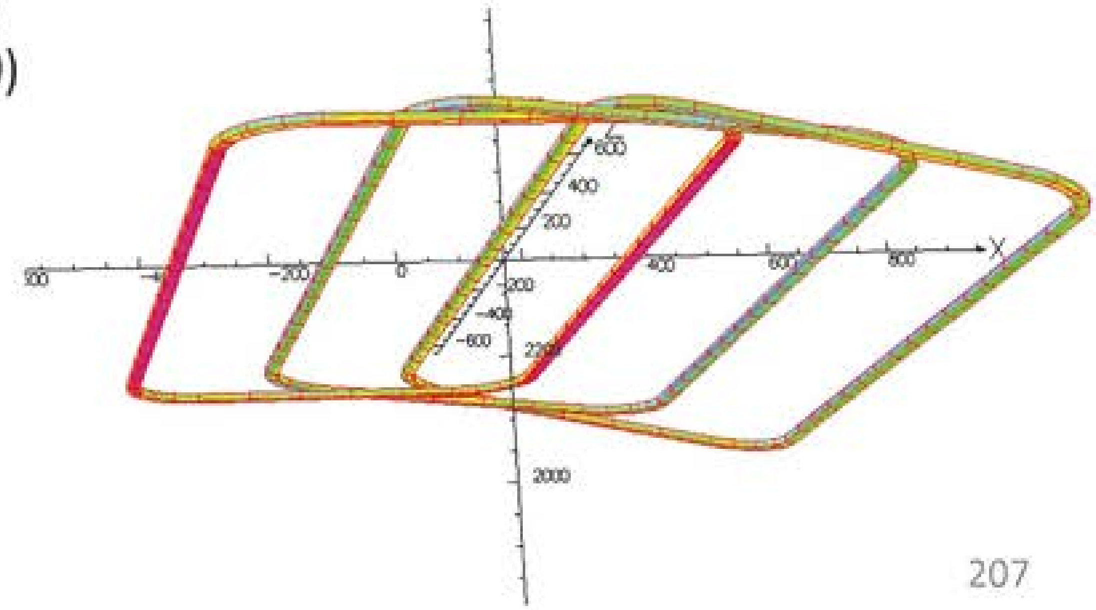
ALL-POLE WIND TURBINE SUPERCONDUCTING GENERATOR

# 3 Phase NbTi/REBaCuO

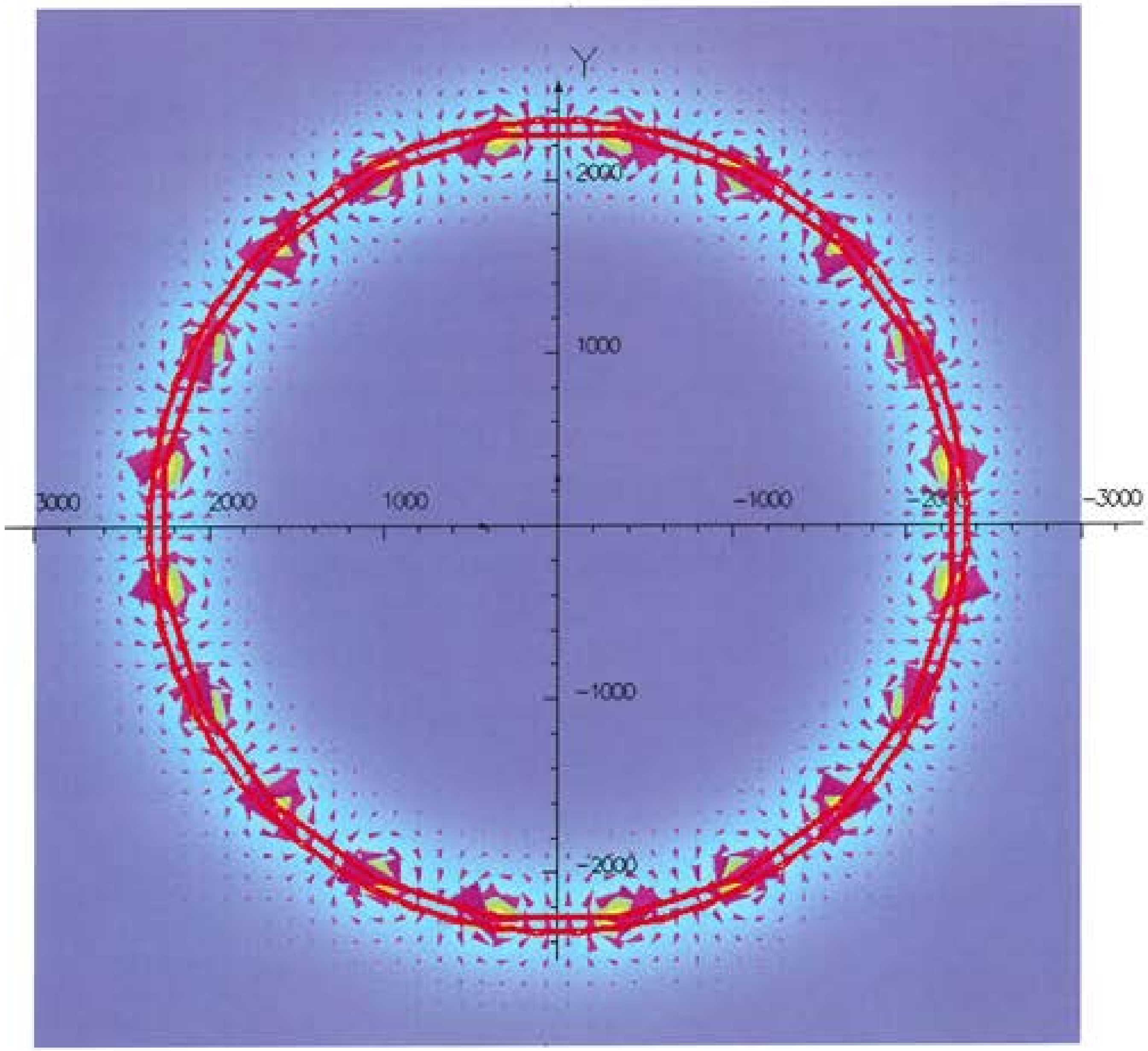
- Power: 10.5 MW
- Rotation Speed: 10 RPM
- Conductor:
  - NbTi, Ø 0.7 mm, $J_C$ = 1182 A/mm²
  - ReBaCuO, 0.26 mm x 10.05 mm, $J_C$ = 45 kA/mm²
- Maximum DC Field: 5 T
- Maximum AC Field: 2.5 T
- AC Superconducting Volume: 0.00025 m³
- AC Hysteresis Losses
  - Standard Wire: 17 kW (~3.4 MW @50 K, factor 20)
  - Improved Wire: 3.4 kW (~680 kW @50 K, factor 20)

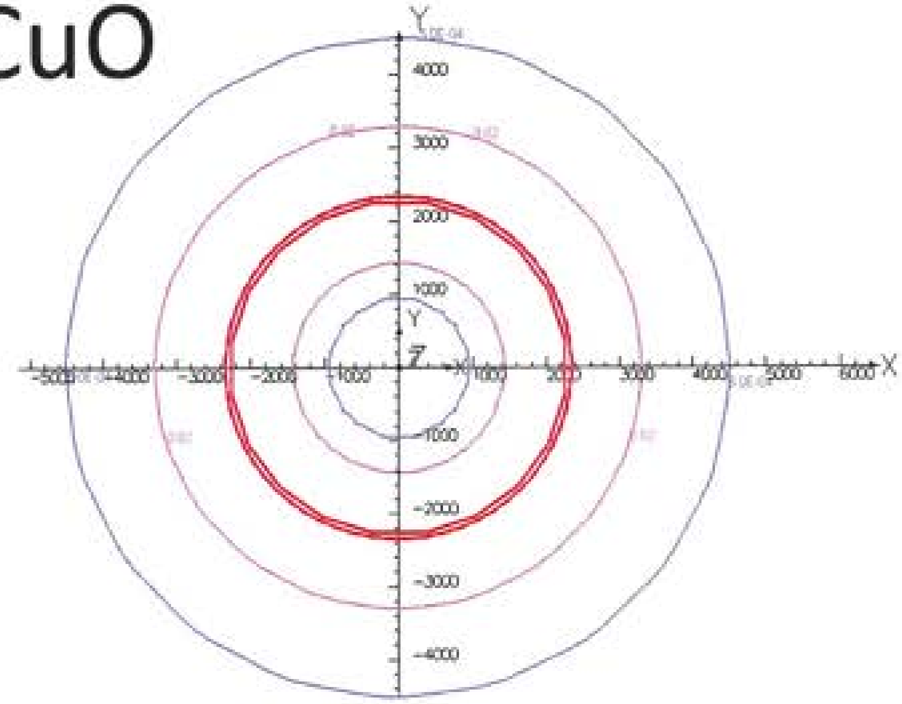


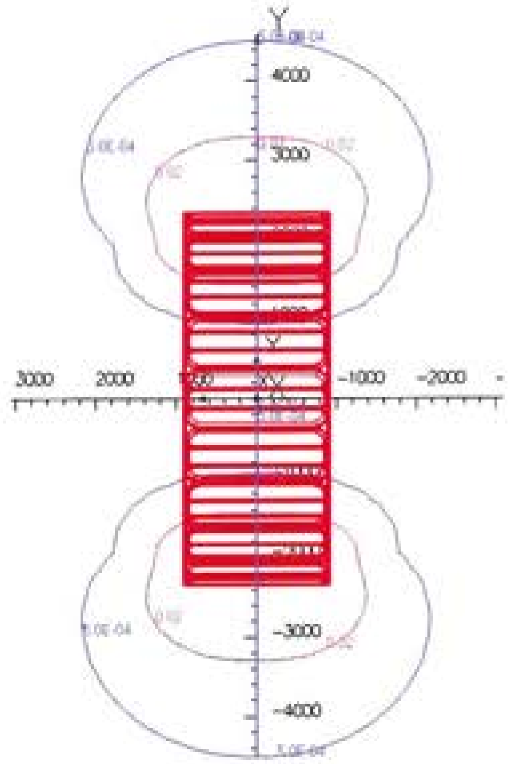
Featuring Guina Energy's Concentric Coil Technology



# 3 Phase NbTi/REBaCuO

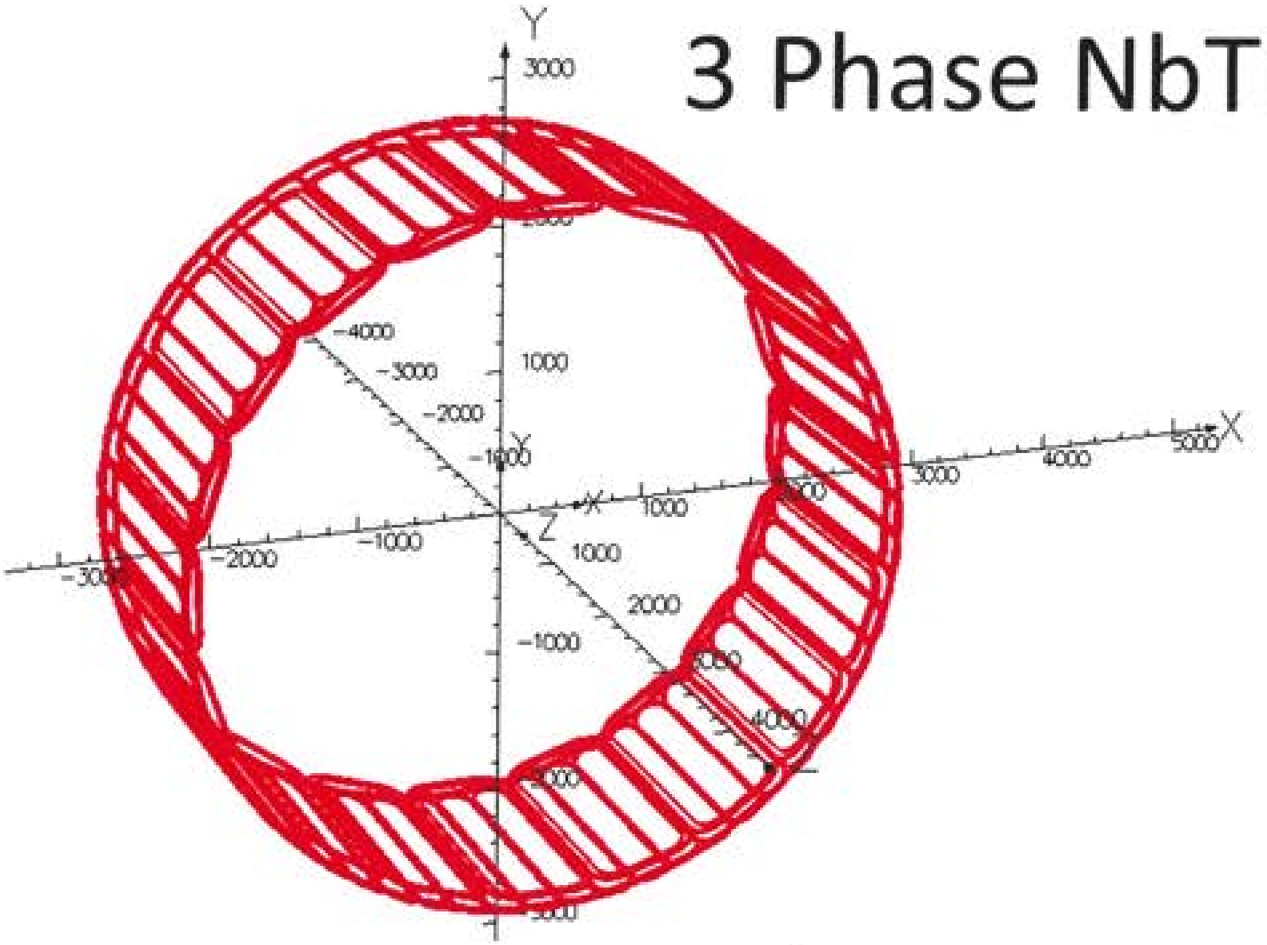


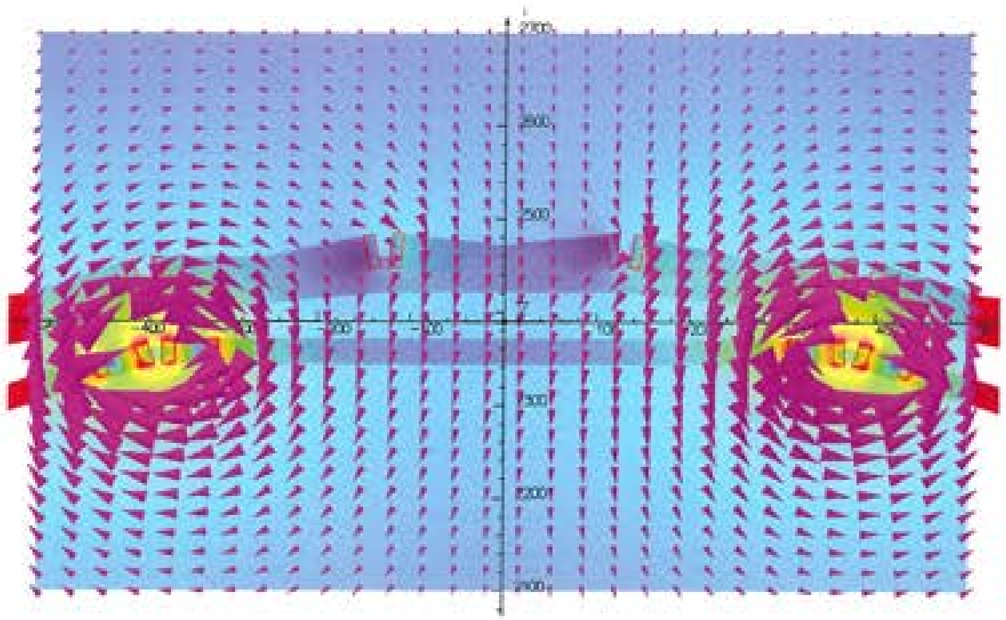



# ALL-POLE WIND TURBINE SUPERCONDUCTING GENERATOR

## 3 Phase NbTi/$MgB_2$





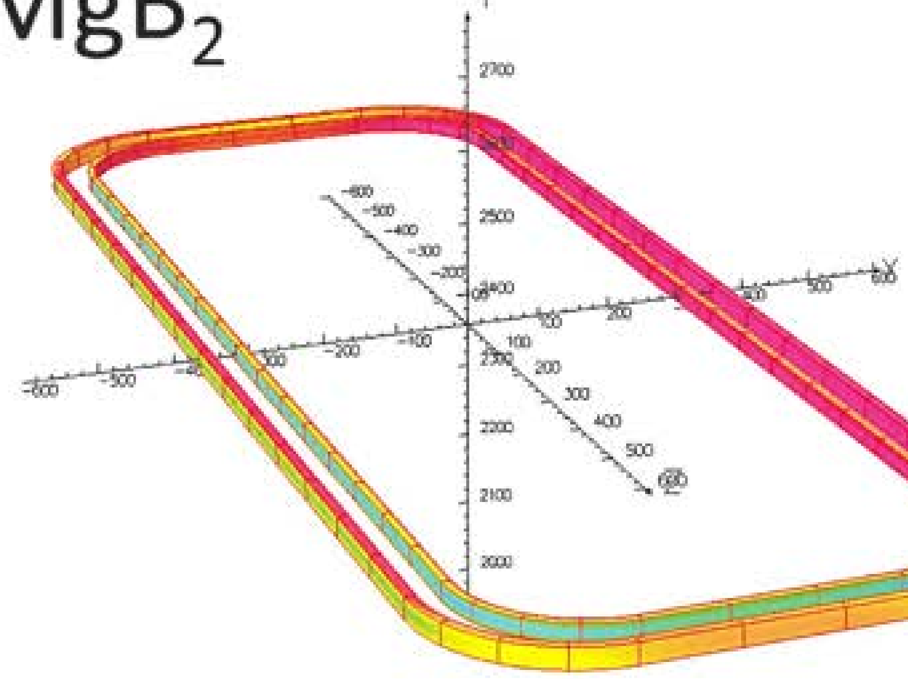
- Dimensions
  - Diameter: 4.8 m
  - Length: 2 m
  - Air gap: 50 mm

- DC Rotor Coils (NbTi)
  - Main Coils
    - Number of Coils: 20 (10 Pole)
    - Width/Thickness: 13.3/13.3 mm
    - Wire Length: 53 km
  - Second Coils
    - Space between Coils: 50 mm
    - Width/ Thickness: 11.172/11.172 mm
    - Wire Length: 35 km
  - Operating Temperature: 4.2 K
  - Engineering Current Density: 537 $A/mm^2$

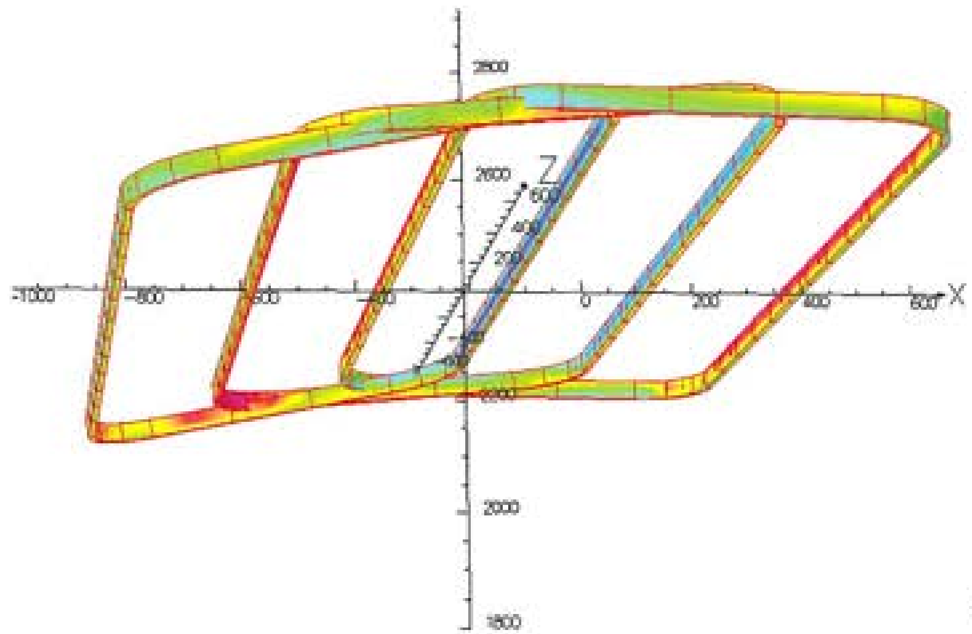
- AC Stator Coils ($MgB_2$)
  - Number of Coils: 20 x 3 (3 Phase)
  - Operating Temperature: 20 K
  - Layers/ Turns per coil: 68/272
  - Wire Length: 79 km
  - Engineering Current Density: 77 $A/mm^2$

# 3 Phase NbTi/$MgB_2$

- Power: 10.5 MW
- Rotation Speed: 10 RPM
- Conductor:
  - NbTi, Ø 0.7 mm, $J_C = 1293\ A/mm^2$
  - $MgB_2$, 0.5 mm x 3 mm, $J_C = 460\ A/mm^2$
- Maximum DC Field: 4.5 T
- Maximum AC Field: 2 T
- AC Superconducting Volume: 0.00711 $m^3$
- AC Hysteresis Losses
  - Standard Wire: 3320 W (~330 kW @20K, factor 100)
  - Improved Wire: 1200 W (~120 kW @20K, factor 100)

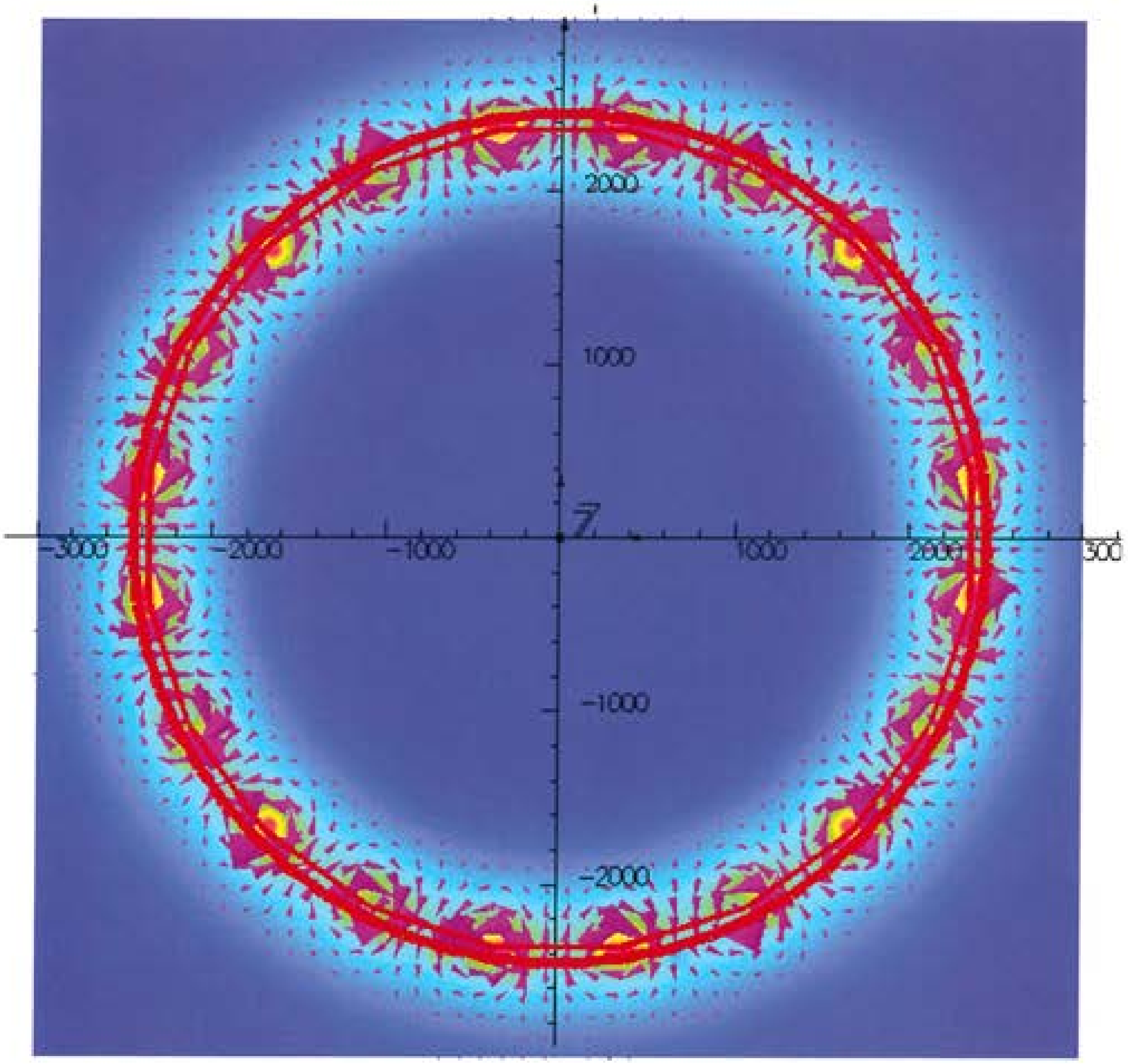


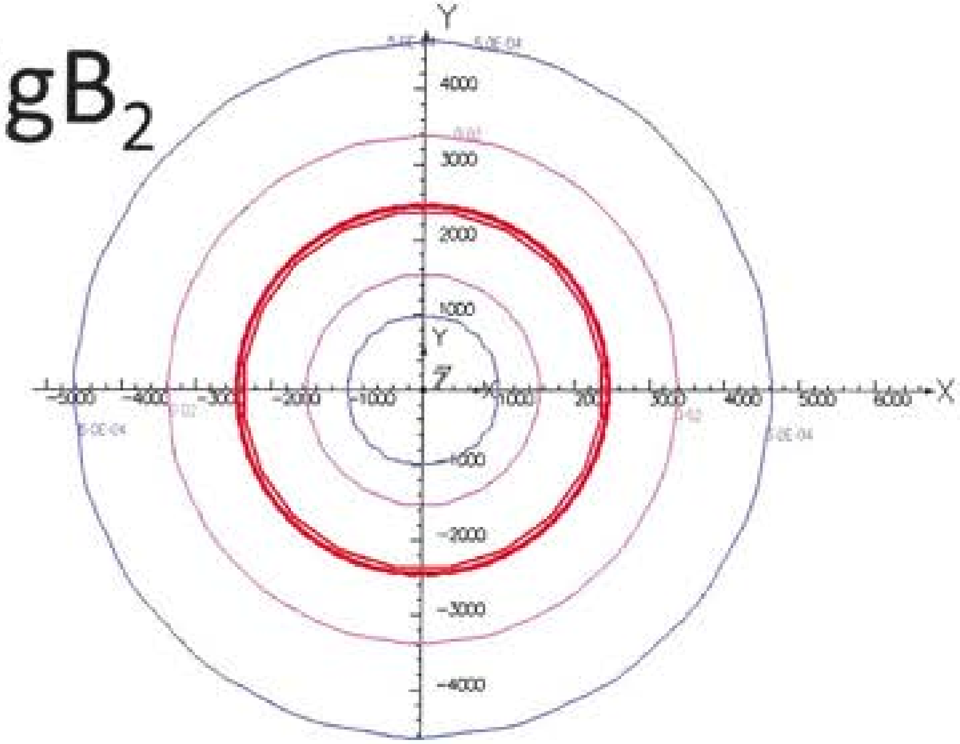

Featuring Guina Energy's Concentric Coil Technology

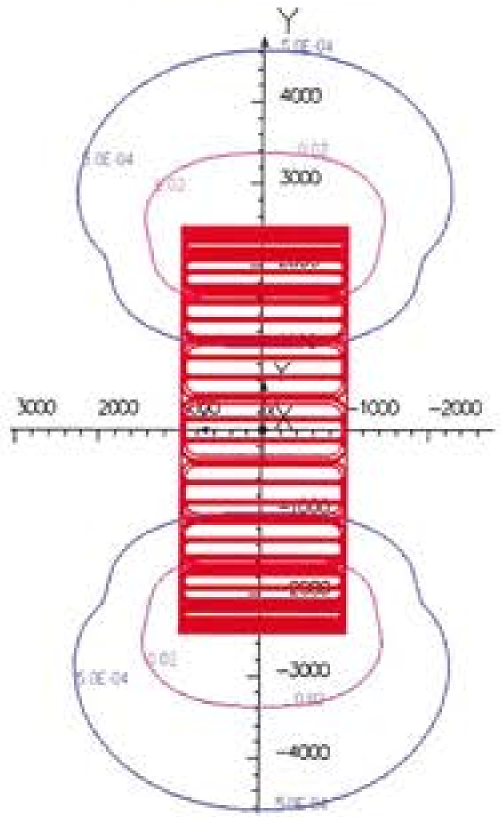


# ALL-POLE WIND TURBINE SUPERCONDUCTING GENERATOR

## 3 Phase NbTi/$MgB_2$



# PRESENTING:
# PERMANENT MAGNET TECHNOLOGY

# OUR TECHNOLOGY

## Technology Overview:

- **Brushless PM Motors/Generators**
- **Permanent Magnet Toroidal Motors/Generators**
- **Brushless PM Cluster Motors/Generators**

# HISTORY OF PERMANENT MAGNETS

- Circa 600 BC – Greek philosophers describe naturally occurring Ferric Ferrite ($Fe_3O_4$) lodestones.
- 1269 – Petrus Pereginus de Marincourt provides an early description of a floating magnetic compass.
- 1740 – Gowen Knight produces the first commercial artificial magnets.
- 1917 – K. Honda and T. Takai discover Cobalt Steel permanent magnets.
- 1930 – Production of the first magnet made from Aluminium, Nickel, Cobalt and Iron (Alnico)
- 1952 – Phillips Company develop ceramic magnets from Barium, Strontium and Lead-Iron oxides.
- 1966 – Early Rare-Earth Samarium Cobalt ($SmCo_5$) Magnets are developed at the US Air Force Materials Laboratory.
- 1972 – Higher energy Samarium Cobalt ($Sm_2Co_{17}$) Magnets are developed by Dr. Karl J. Strnat and Dr. Alden Ray
- 1983 – First commercial development of Neodymium-Iron-Boron high energy (35 MGOe or N35) rare earth magnets by General Motors, Sumitomo Special Metals and the Chinese Academy of Sciences.

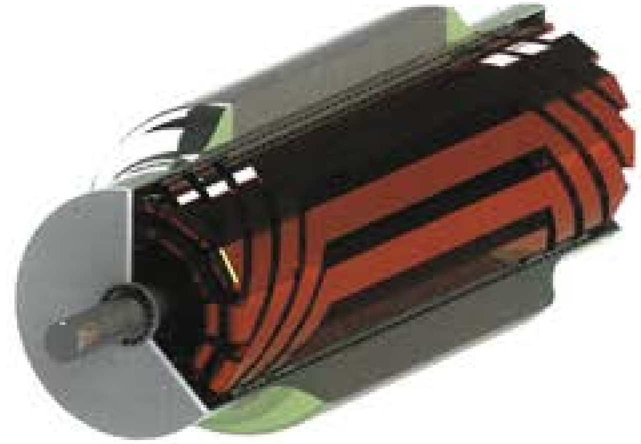
Today:

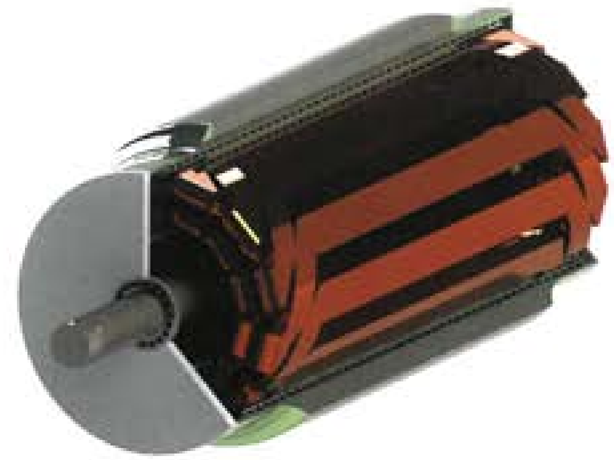
- Neodymium-Iron-Boron permanent magnets are commercially available in grades up to N52 (52 MGOe).
- Special grades of Neodymium-Iron-Boron permanent magnets that are able to operate a high temperatures are commercially available.

# CHALLENGES WE HAVE FACED

In order to increase the power density and efficiency of our Permanent Magnet Machines we had to overcome the following challenges:

- Increase the flux density in the windings by increasing the 'throw' of the permanent magnetic field
- Come up with innovative ways of increasing the cooling capacity to our stator windings
- Find ways to contain the powerful magnetic flux within the device itself



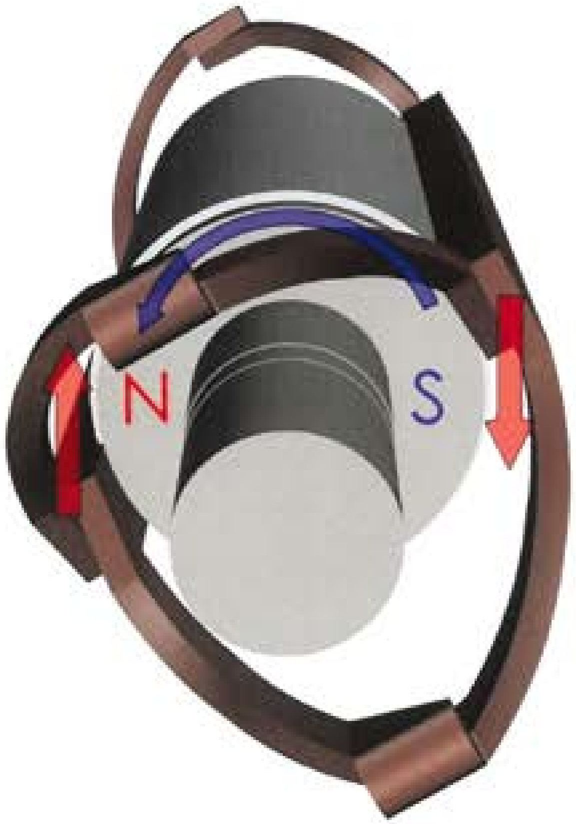


# GUINA'S BRUSHLESS PM MACHINES

## Technology Advantages

- High efficiency
- Low torque ripple (< 1%)
- Configurable number of independent stator windings
- Configurable number of Operating Phases (3, 5, 6, 12, 24 ...)
- High power to weight ratios
- Copper windings are stationary allowing simple implementation of multi-layer active liquid cooling. This results in higher current densities in the windings and quieter running.
- Slotless design – no cogging torque
- Higher magnetic field in windings

# GUINA'S BRUSHLESS PM MACHINES




Driving Torque on
Permanent Magnet Rotor (Blue)

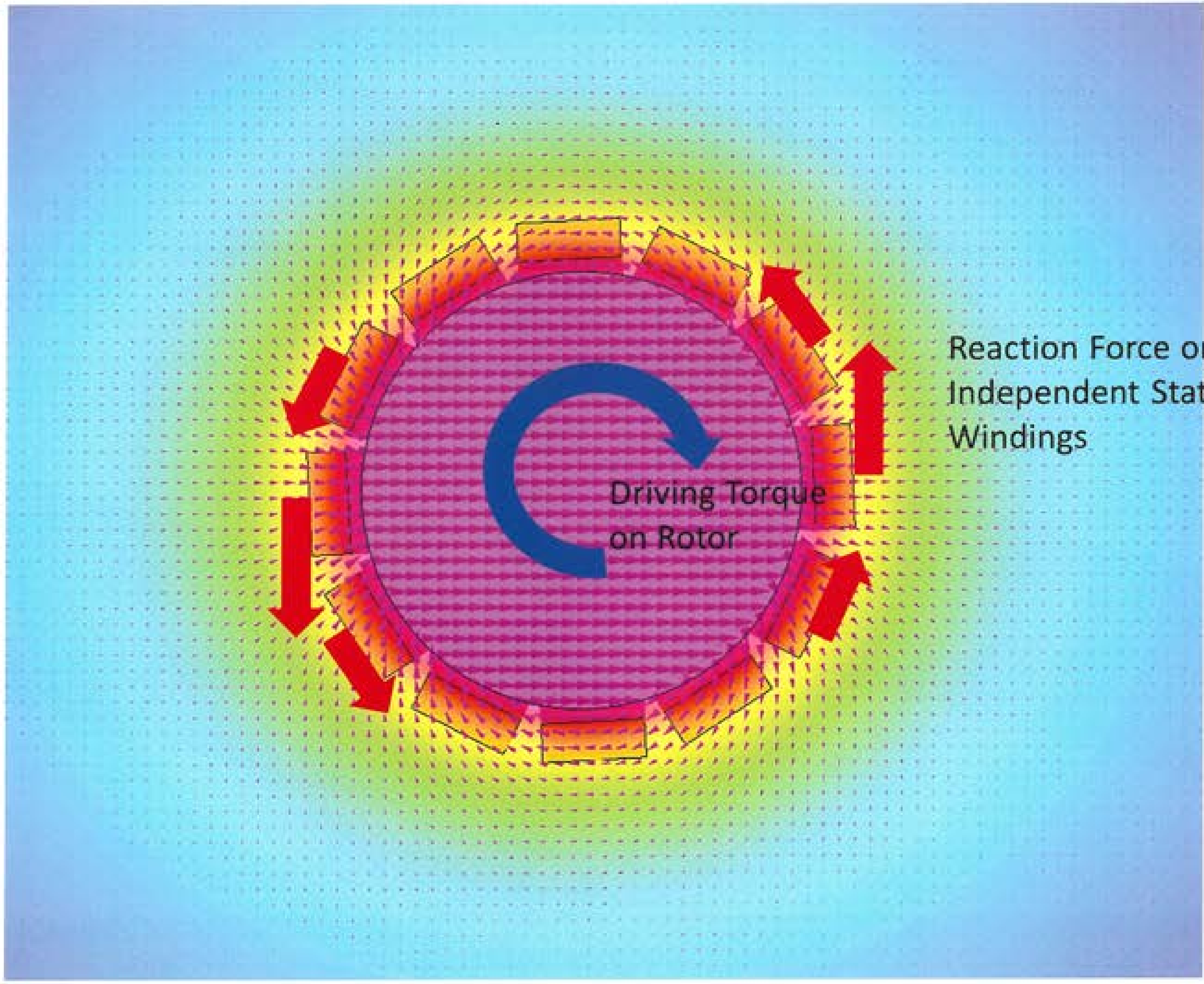
Reaction Torque on
Stator Bars (Red)


Driving Torque on
Permanent Magnet Rotor (Blue)

Reaction Torque on
Stator Bars

# GUINA'S BRUSHLESS PM MACHINES

## Permanent Magnet Field Plot showing Force and Reaction Torque




Reaction Force on
Independent Stator
Windings

# GUINA'S BRUSHLESS PM MACHINES

## Independent Stator Winding Layout


Half Winding Segment

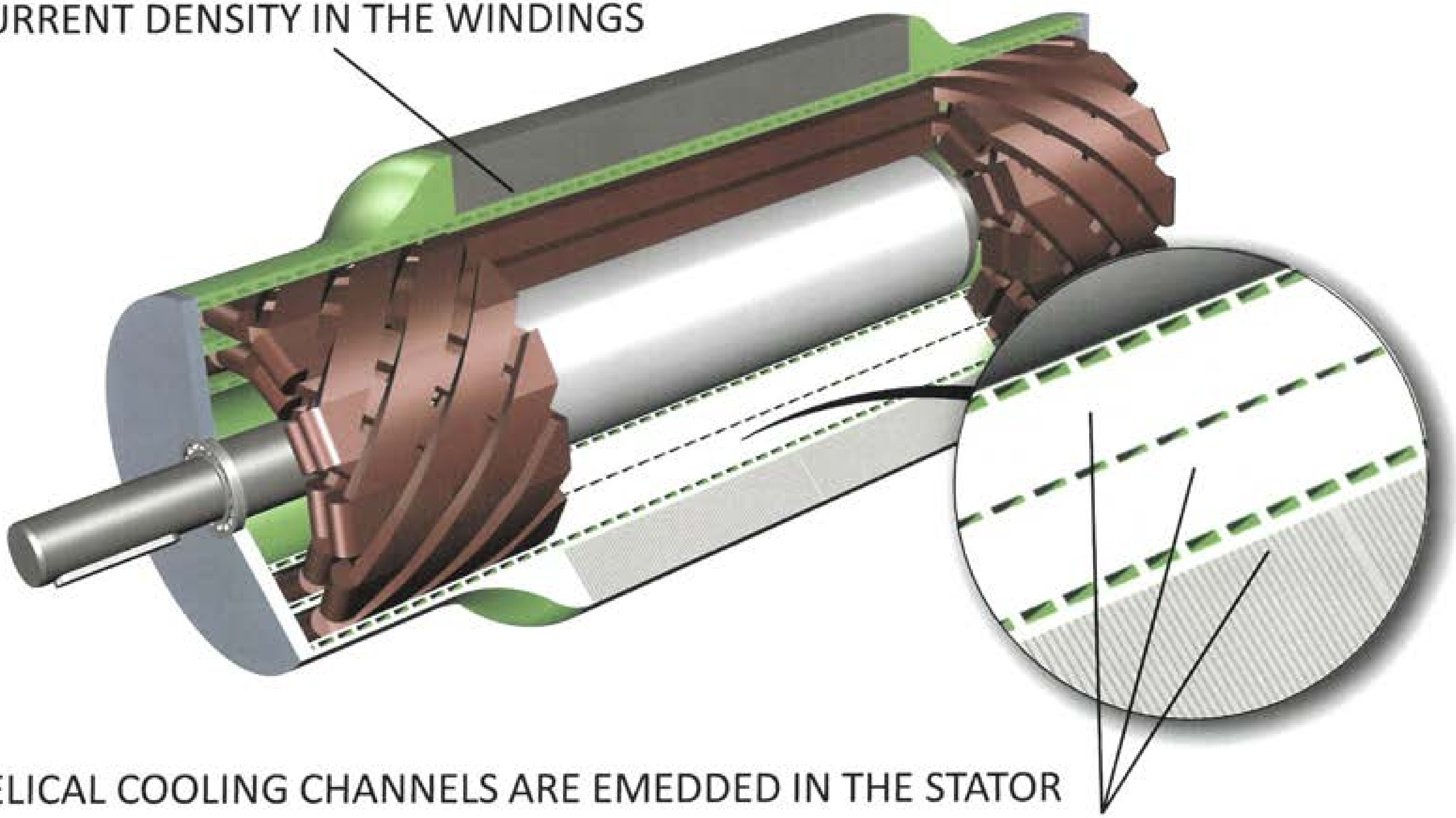

One Full Winding


Six Windings Part Section

Six Windings Complete

# COOLING SYSTEM FOR STATOR WINDINGS

COOLING FLUID IS PUMPED THROUGH
HELICAL WATER COOLING TO
COOL THE WINDINGS AND ALLOW A HIGH
CURRENT DENSITY IN THE WINDINGS

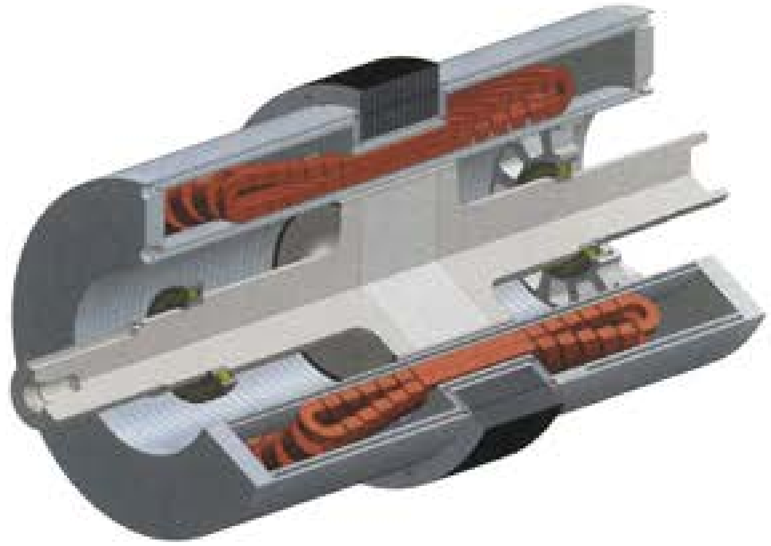


HELICAL COOLING CHANNELS ARE EMEDDED IN THE STATOR
AND LOCATED ON EITHER SIDE OF EACH WINDING LAYER

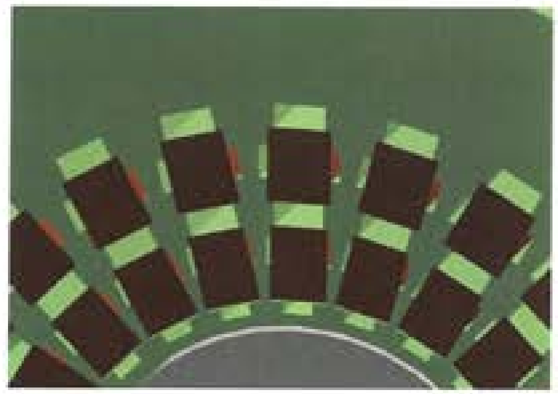
# COOLING SYSTEM FOR STATOR WINDINGS

GUINA ENERGY GROUP

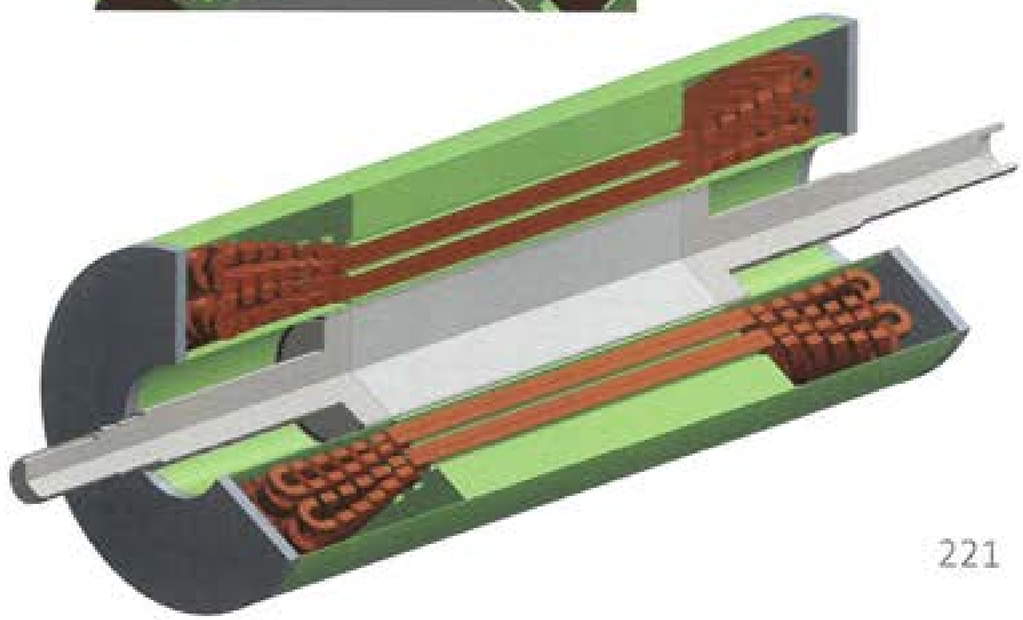
- Conventional liquid cooling techniques operate only on the outer winding layers or on the end windings.



- Guina Energy's laminated liquid cooling solution cools the windings from two sides.



- Our composite cooling solution provides cooling to <u>all four sides</u> of the winding slot while reducing eddy current loss by employing non-metallic support structure thus increasing the efficiency of the device.

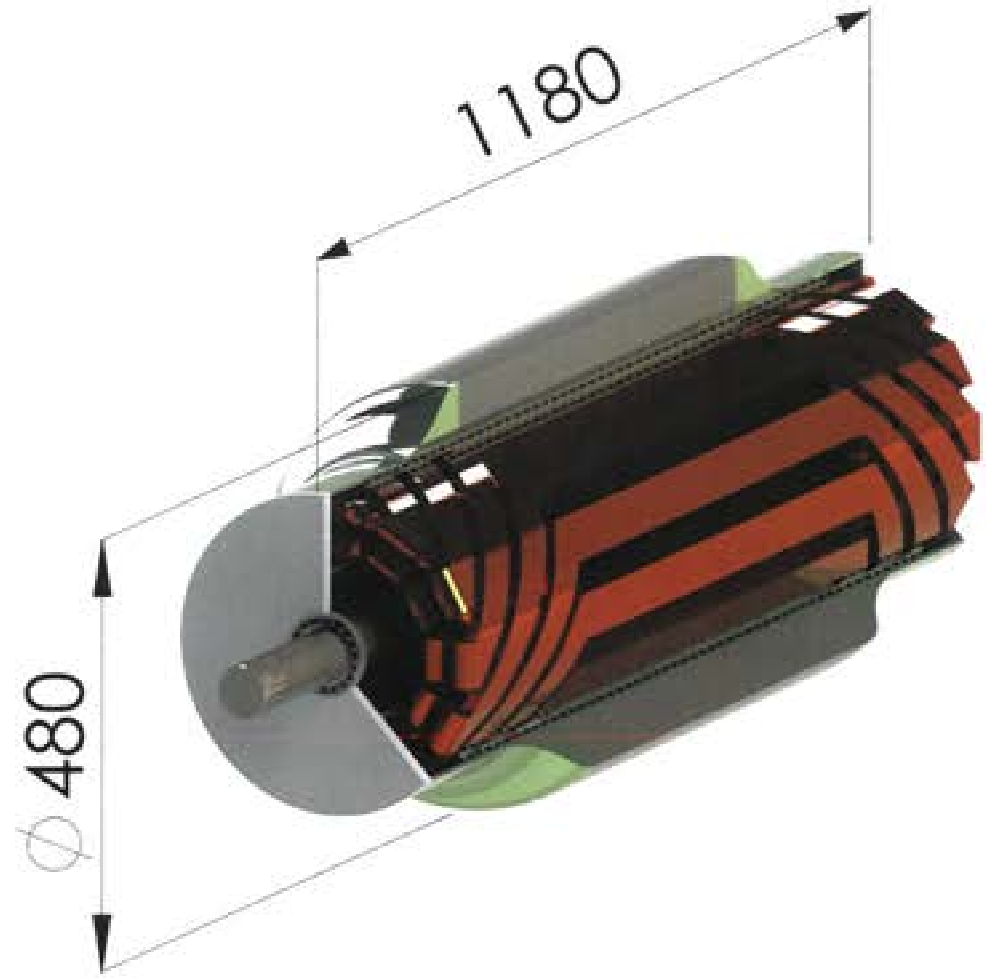


Work in progress...

# GUINA'S BRUSHLESS PM MACHINES

Brushless Permanent Magnet design featuring:

- 2 Poles
- Double layer copper windings
- Slotless construction
- Three layers of liquid cooling




At 10 A/mm$^2$ RMS Current Density:

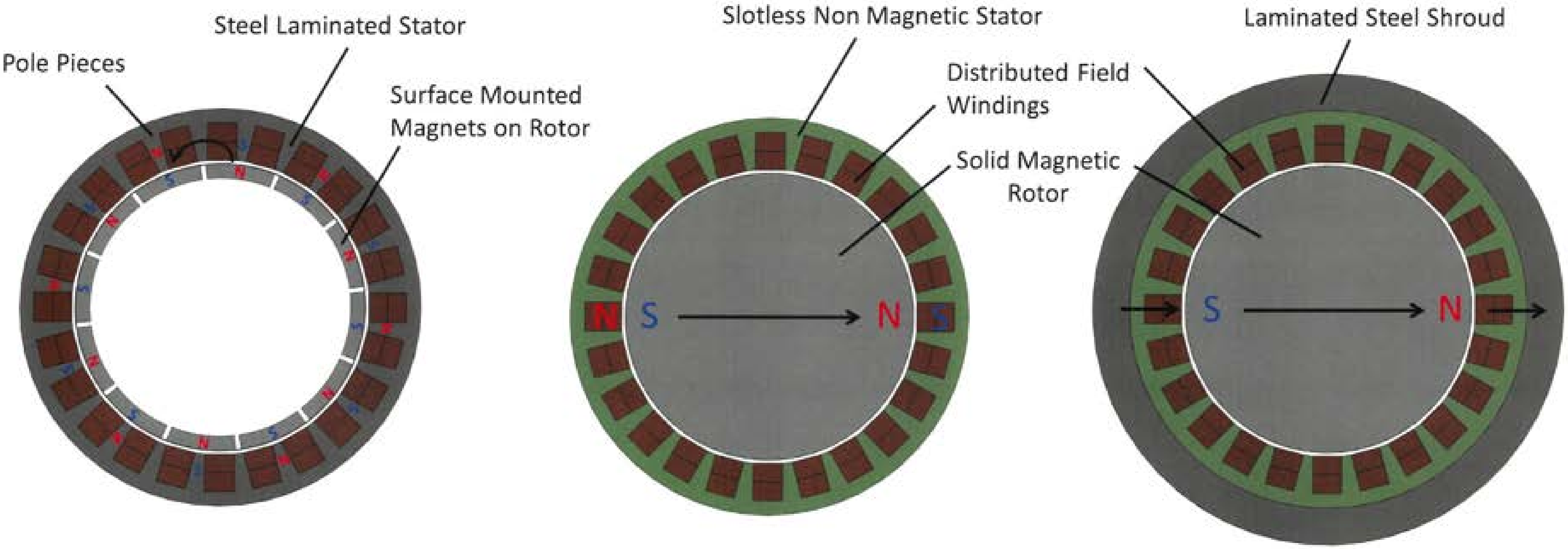
- **4 MW at 5000 RPM (P/W=3.6 kW/kg)**
- **16 MW at 20000 RPM (P/W=14.4 kW/kg)**

At 18 A/mm$^2$ RMS Current Density:

- **6.8MW at 5000 RPM (P/W=6.1 kW/kg)**
- **27 MW at 20000 RPM (P/W=24.4 kW/kg)**

**For an estimated device weight of 1110 kg**

# GUINA'S NOVEL DESIGN LAYOUT




Typical PM Motor with a Steel Stator and Surface Mounted Magnets

Guina Energy's Slotless Stator features a solid magnet to extend the 'throw' of the magnetic field

**The addition of an outer ring of laminated electrical steel captures stray magnetic field and increases the output torque by 30-40%**

**The key to efficient machines is to create regions of high magnetic flux density that couple with the current carrying windings to create high torque and power.**

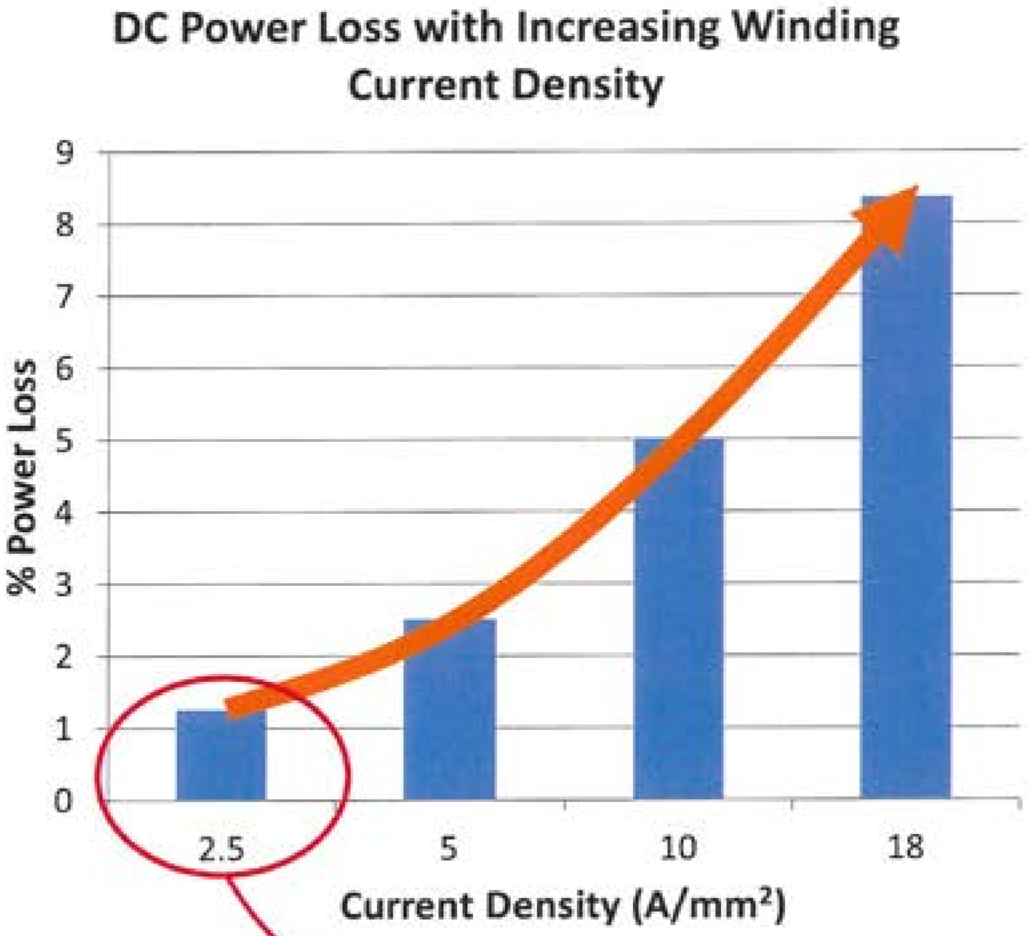
# LOSSES IN PM TECHNOLOGY

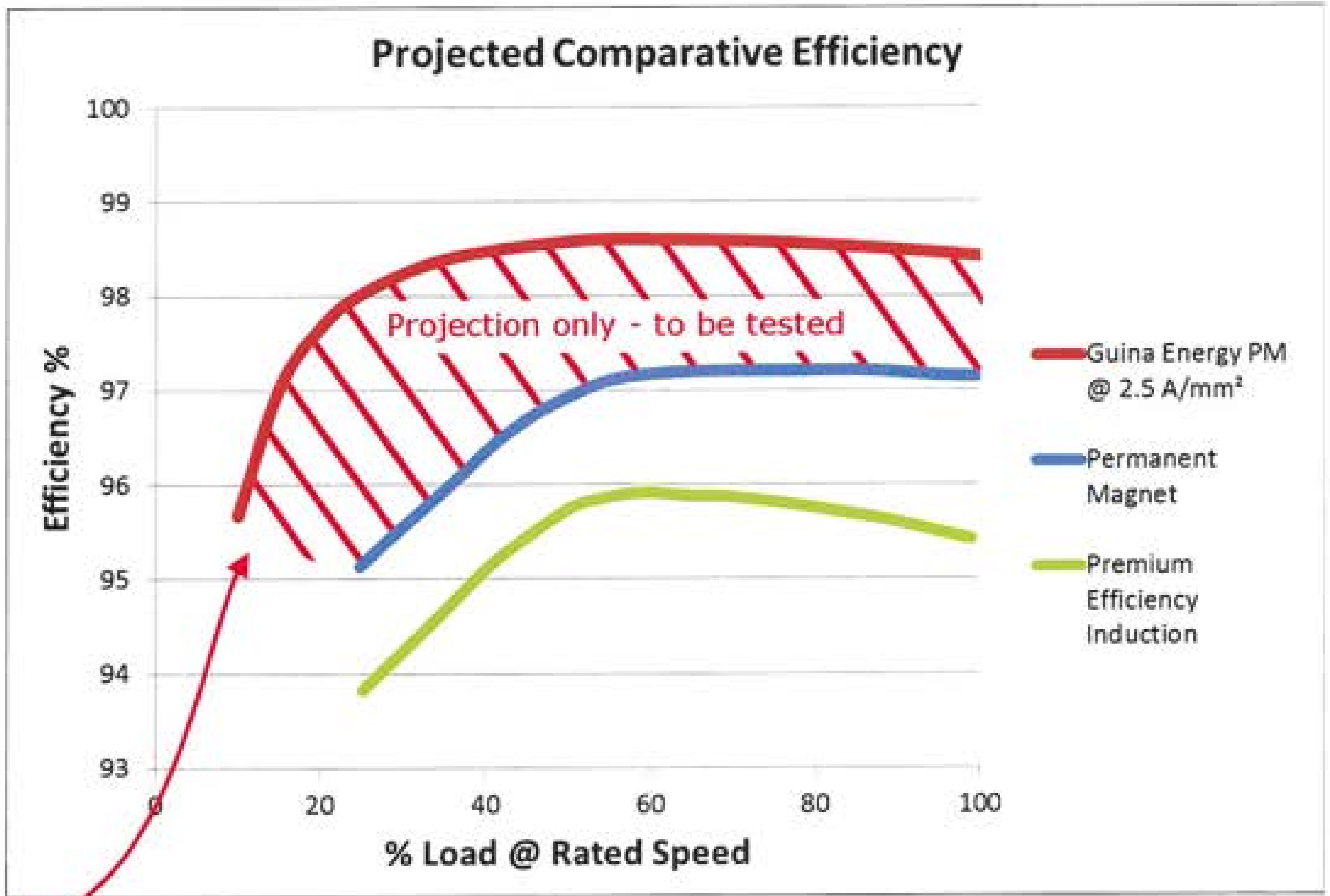
Some Key Equations for PM Technology:

- High Power Density, Smaller Size = Lower efficiency.
- High Efficiency = Larger Size and Lower Power Density.

HOWEVER...

**Guina Energy's PM Technology is readily configurable for either High Power Density or High Efficiency.**






Note: The figures presented in this document are calculations and projections based on available data and may be subject to change.

# HEAT LOSS IN PM TECHNOLOGY

GUINA ENERGY GROUP

The power density of out permanent magnet technology stems from the high current densities in the copper windings.

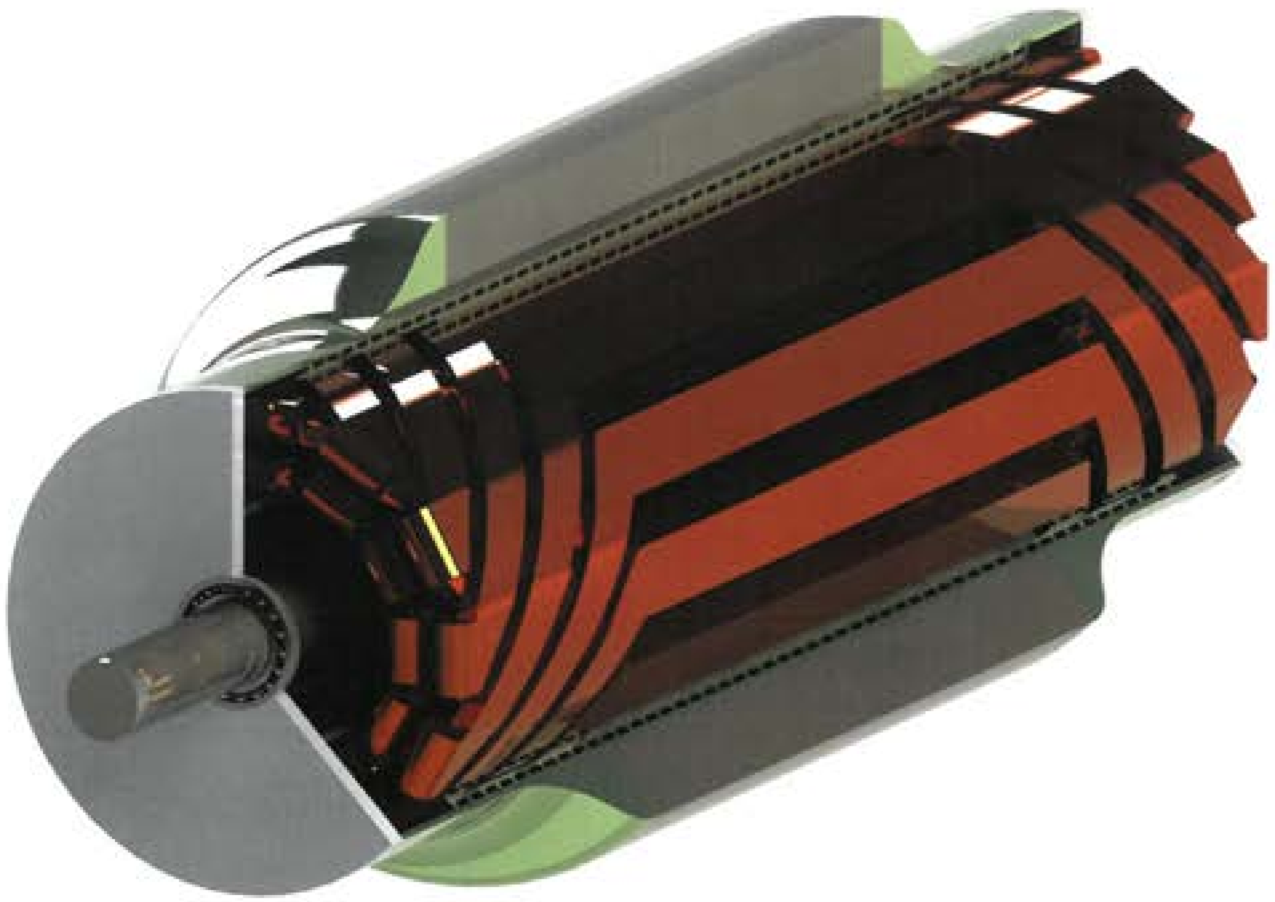
- Case 1 – 4 MW PM Motor at 5000 RPM with 10 A/mm$^2$ RMS current density - Efficiency (estimated) ≈ 94%

The efficiency of the devices can be increased by decreasing the current density in the windings.

- Case 2 – 1 MW PM Motor at 5000 RPM with 2.5 A/mm$^2$ RMS current density - Efficiency (estimated) ≈ 98.4%

Note: The figures presented in this document are calculations and projections based on available data and may be subject to change.

# Brushless Double Layer Permanent Magnet Motor/Generator with Shielding



High power to weight

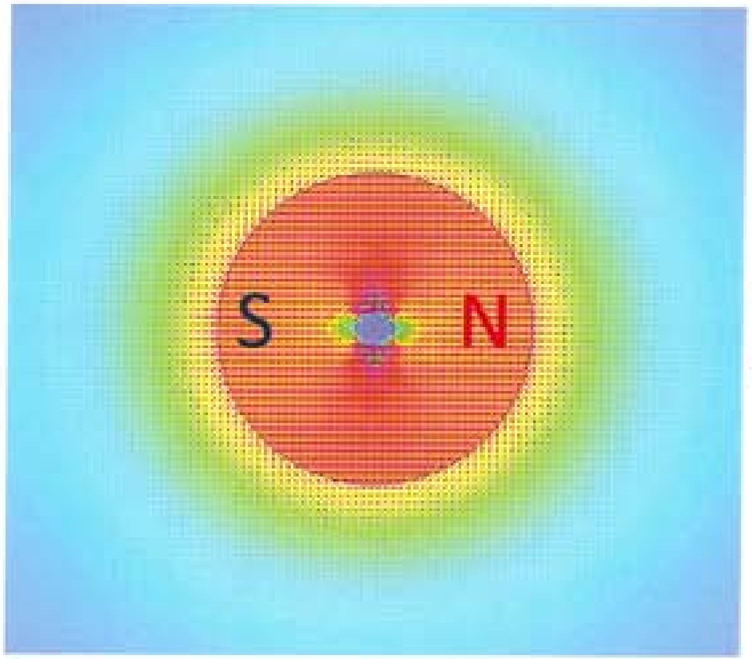
# GUINA'S BRUSHLESS PM MACHINES

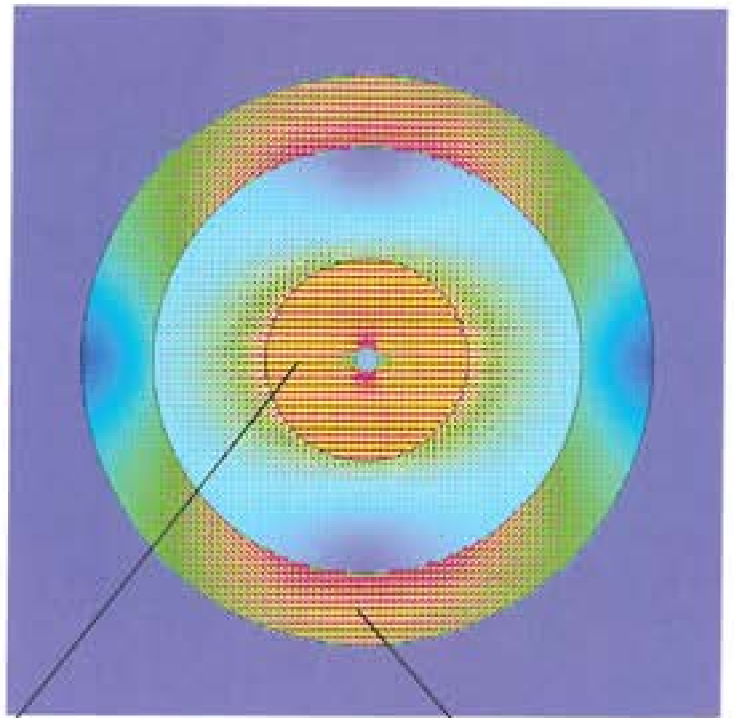
## Brushless Double Layer Permanent Magnet Motor/Generator - Field Components

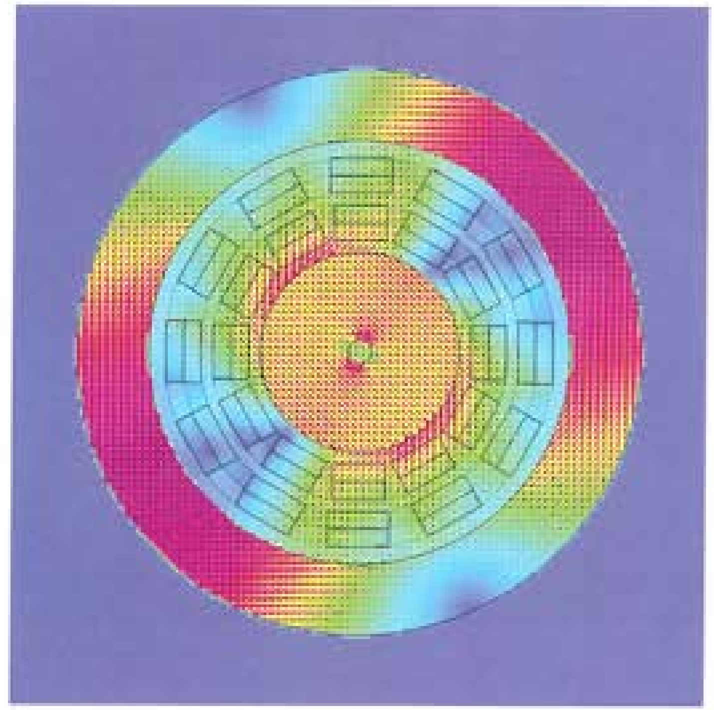
High Strength Neodymium Permanent Magnet

High Permeability Steel Laminations

Dual Layer High Current Density Stator Windings





Permanent Magnet

Laminated Steel

The Three Components for Maximum Power Density

# GUINA'S BRUSHLESS PM MACHINES

GUINA ENERGY GROUP

## Brushless Double Layer Permanent Magnet Motor/Generator – 16 MW at 20000 RPM

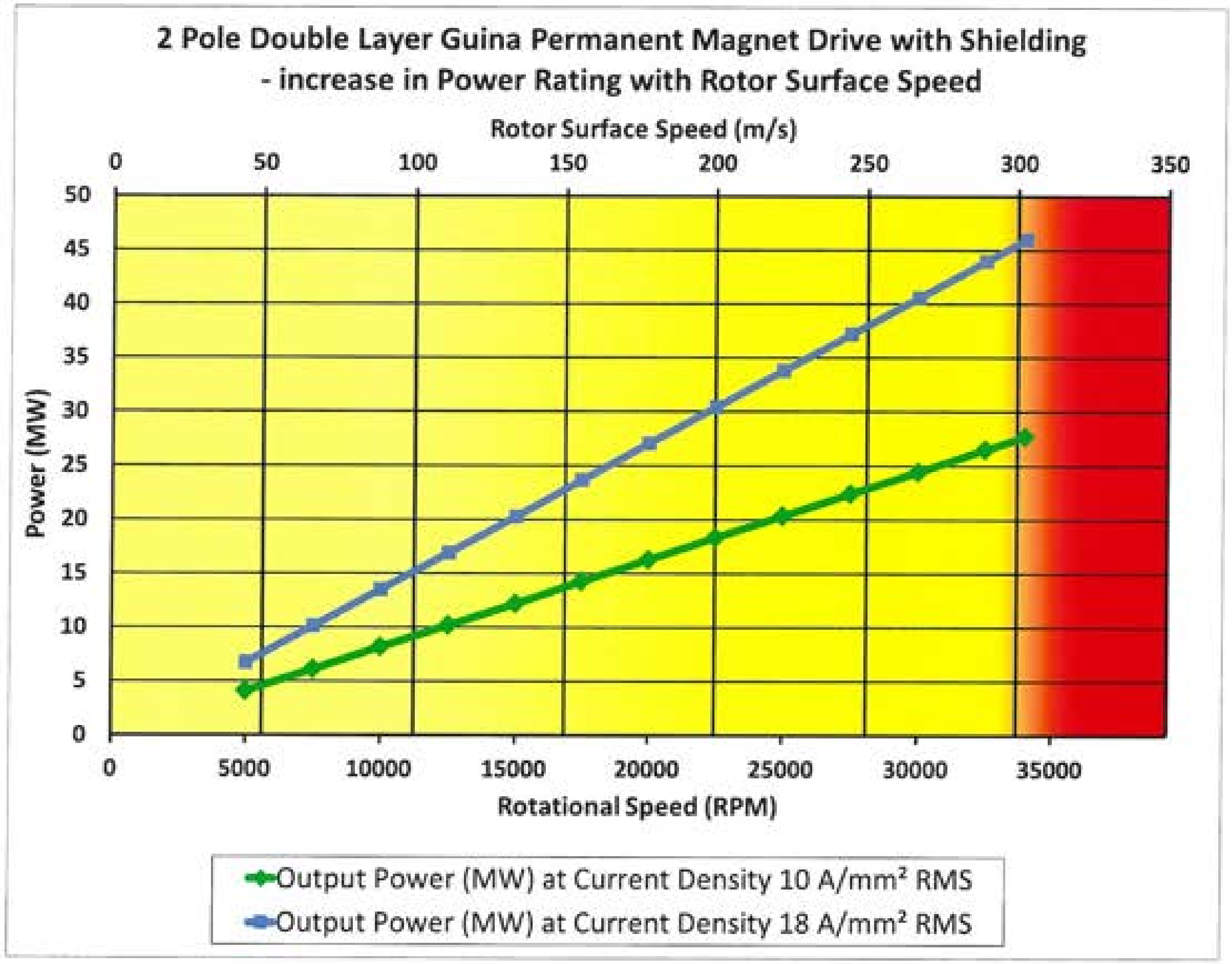
| | |
|---|---|
| Power (MW) | **16** |
| Rated Speed (RPM) | **20000** |
| Torque @ 20000RPM (Nm) | **7773** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **27.6** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm$^2$ | **1000** |
| Stator Windings Diameter (mm) | **360** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **236** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **103** |
| Steel Shield Weight (kg) | **364** |
| Cooling | **Pumped Liquid** |

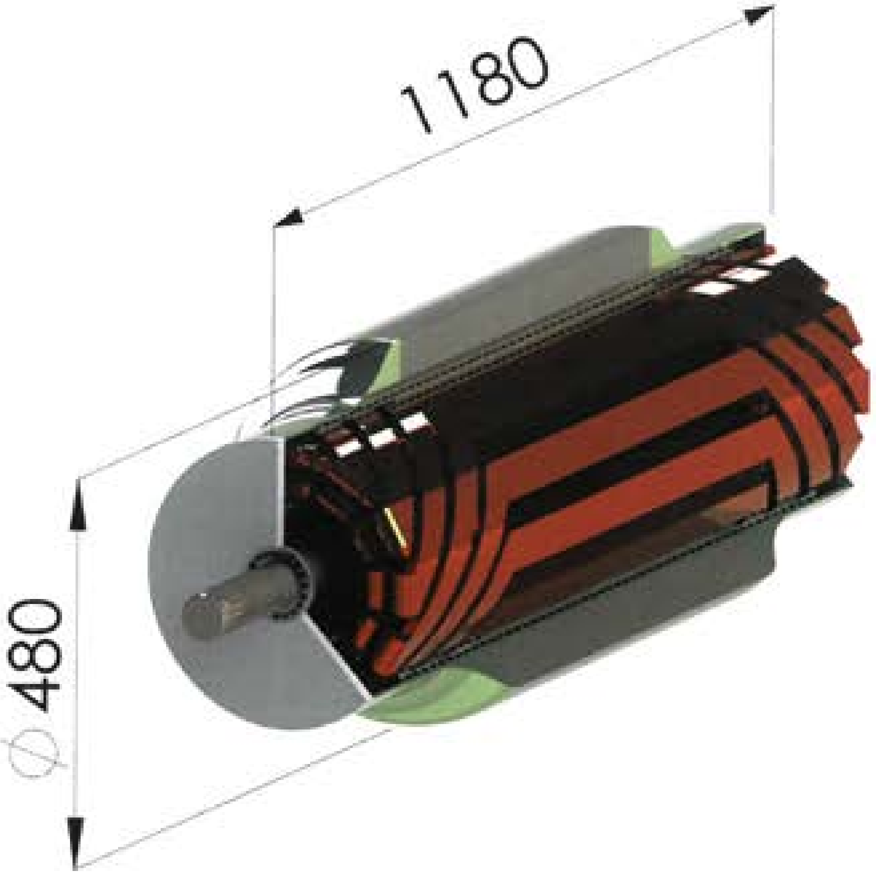
## Brushless Double Layer Permanent Magnet Motor/Generator – 4 MW at 5000 RPM

| | |
|---|---|
| Power (MW) | **4** |
| Rated Speed (RPM) | **5000** |
| Torque @ 5000RPM (Nm) | **7773** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm$^2$ | **1000** |
| Stator Windings Diameter (mm) | **360** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **236** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Max. Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **103** |
| Steel Shield Weight (kg) | **364** |
| Cooling | **Pumped Liquid** |

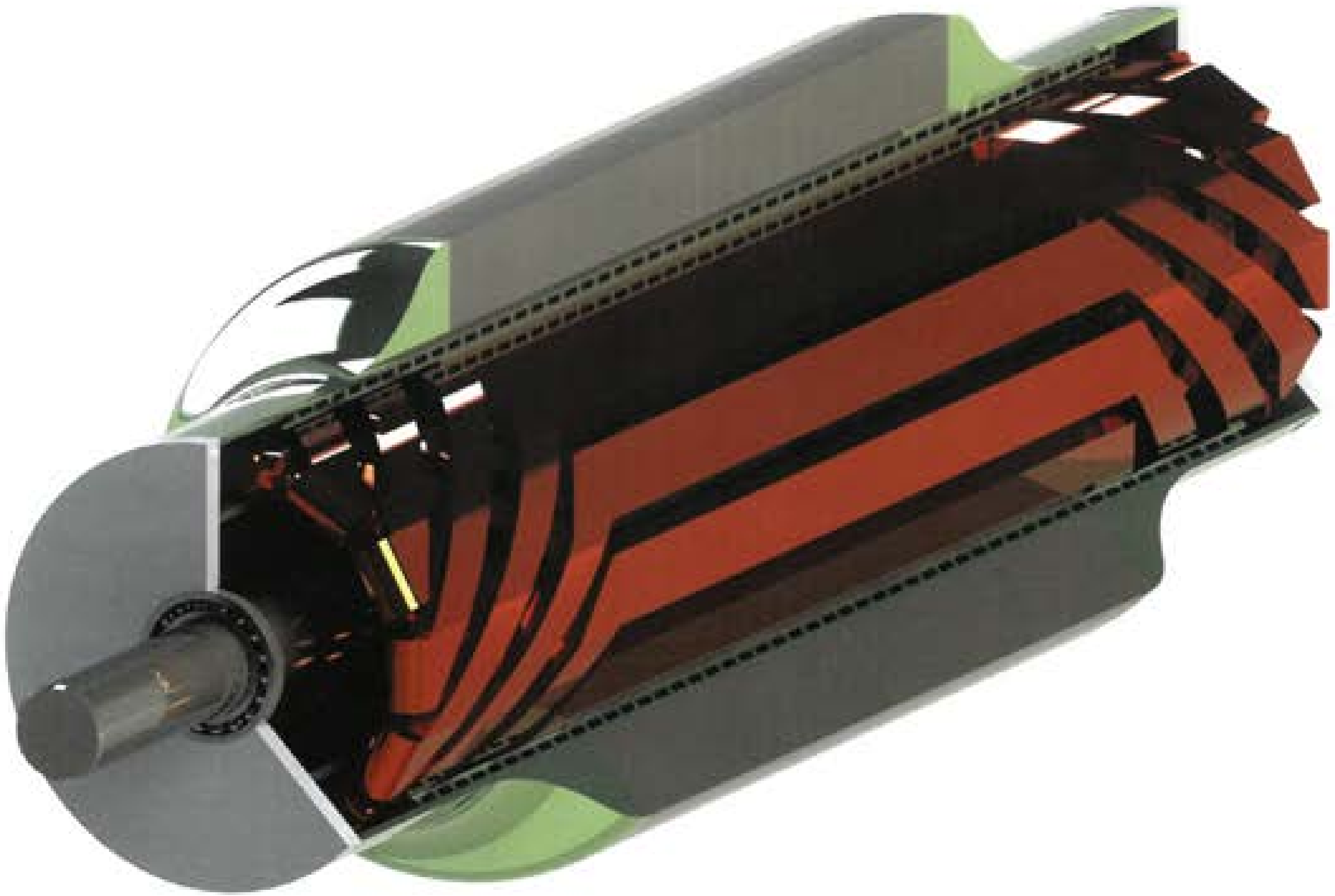
# GUINA'S BRUSHLESS PM MACHINES

## Brushless Double Layer Permanent Magnet Motor/Generator Power Scalability and Overall Dimensions



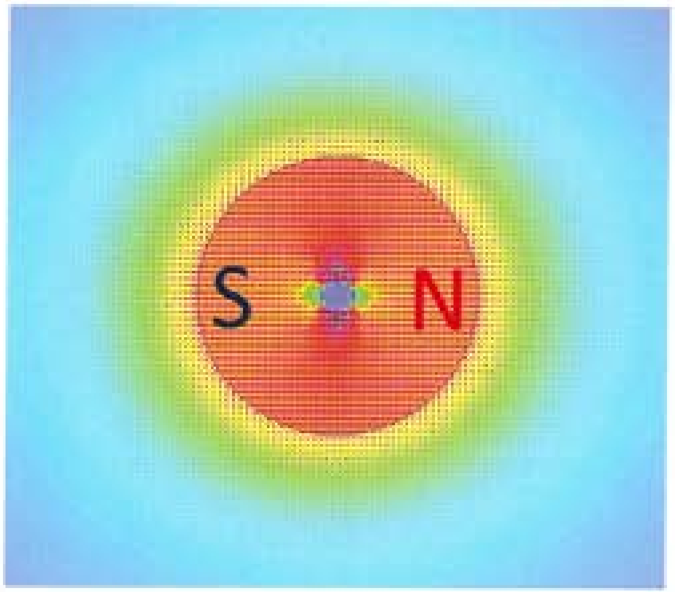



# Brushless Single Layer Permanent Magnet Motor/Generator with Shielding

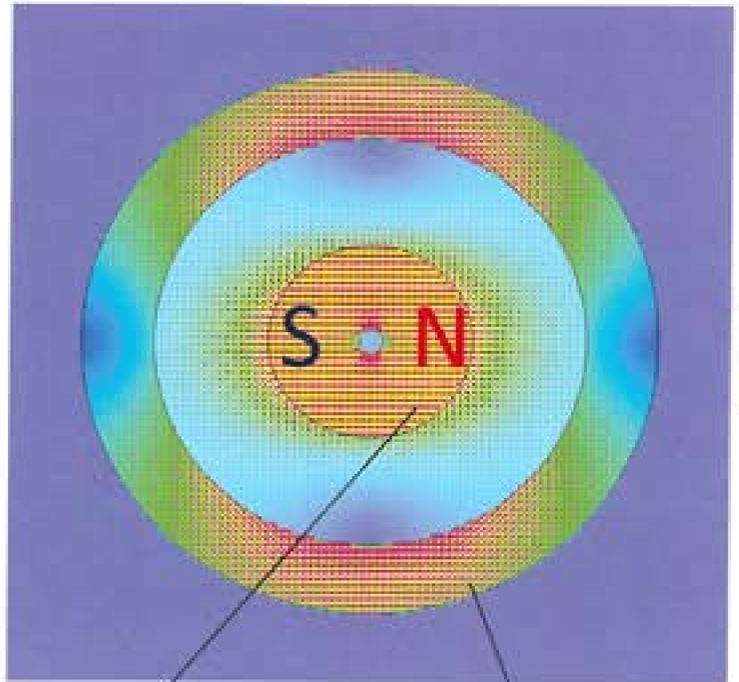


# Brushless Single Layer Permanent Magnet Motor/Generator Field Components

High Strength Neodymium Permanent Magnet



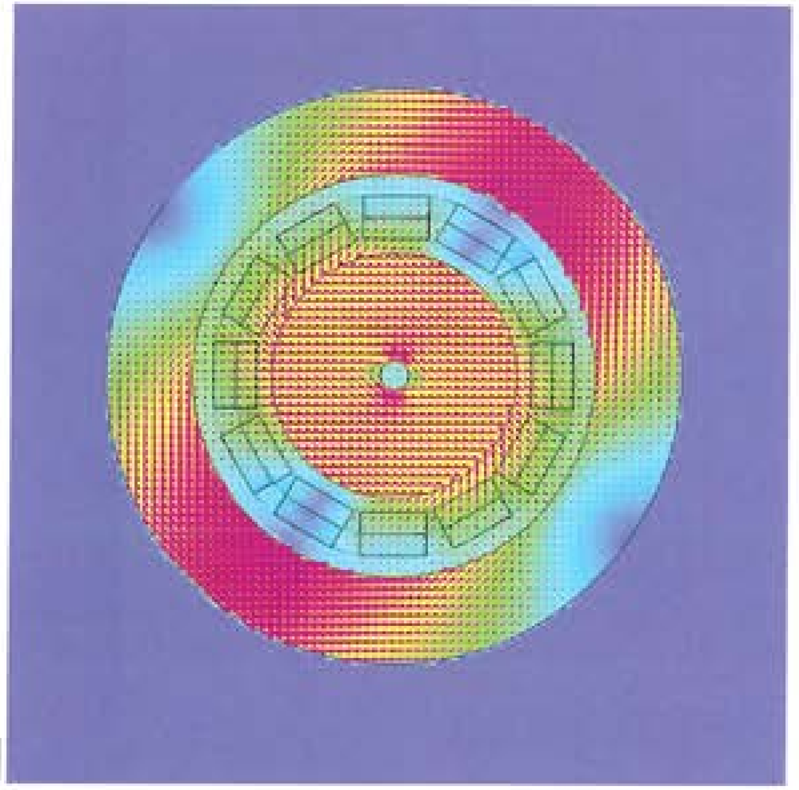

High Permeability Steel Laminations




Permanent Magnet

Laminated Steel

High Current Density Stator Windings



# GUINA'S BRUSHLESS PM MACHINES

GUINA ENERGY GROUP

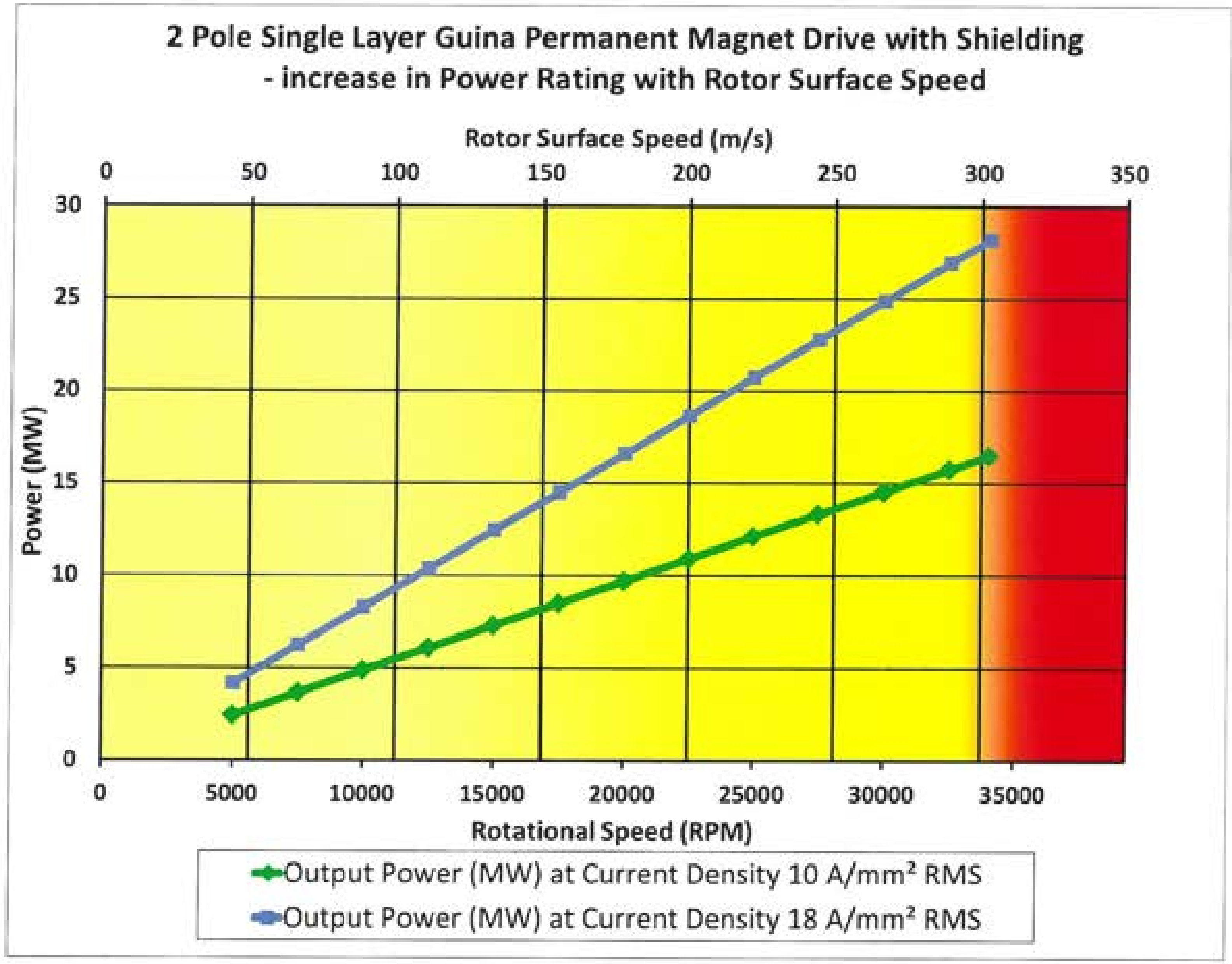
## Brushless Single Layer Permanent Magnet Motor/Generator – 9.6 MW at 20000 RPM

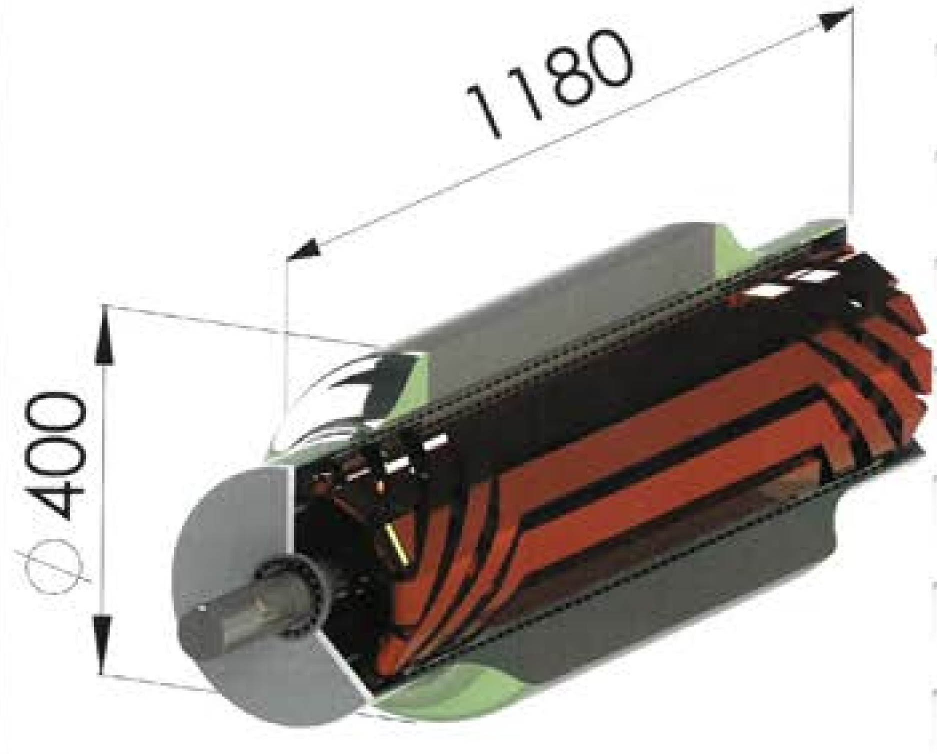
| | |
|---|---|
| Power (MW) | **9.6** |
| Rated Speed (RPM) | **20000** |
| Torque @ 20000RPM (Nm) | **4584** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **16.4** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm² | **1000** |
| Stator Windings Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **104** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **103** |
| Steel Shield Weight (kg) | **294** |
| Cooling | **Pumped Liquid** |

## Brushless Single Layer Permanent Magnet Motor/Generator - 2.4 MW at 5000RPM

| | |
|---|---|
| Power (MW) | **2.4** |
| Rated Speed (RPM) | **5000** |
| Torque @ 5000RPM (Nm) | **4584** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm² | **1000** |
| Stator Windings Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **104** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Max. Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **103** |
| Steel Shield Weight (kg) | **294** |
| Cooling | **Pumped Liquid** |

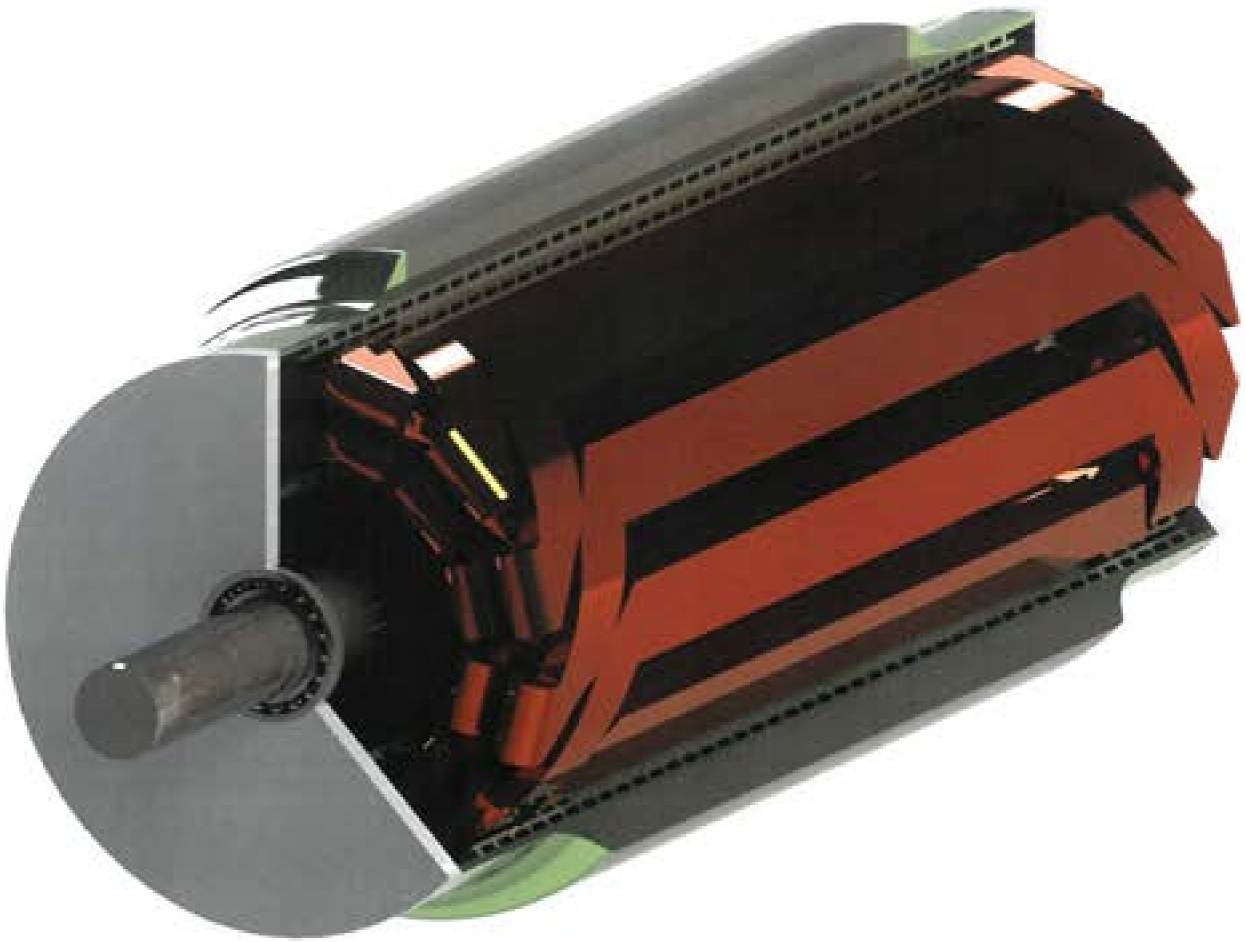
# Brushless Single Layer Permanent Magnet Motor/Generator - Power Scalability and Overall Dimensions



## GUINA'S BRUSHLESS PM MACHINES

# Brushless Permanent Magnet Motor/Generator
# Double Layer 4 Pole with Shielding



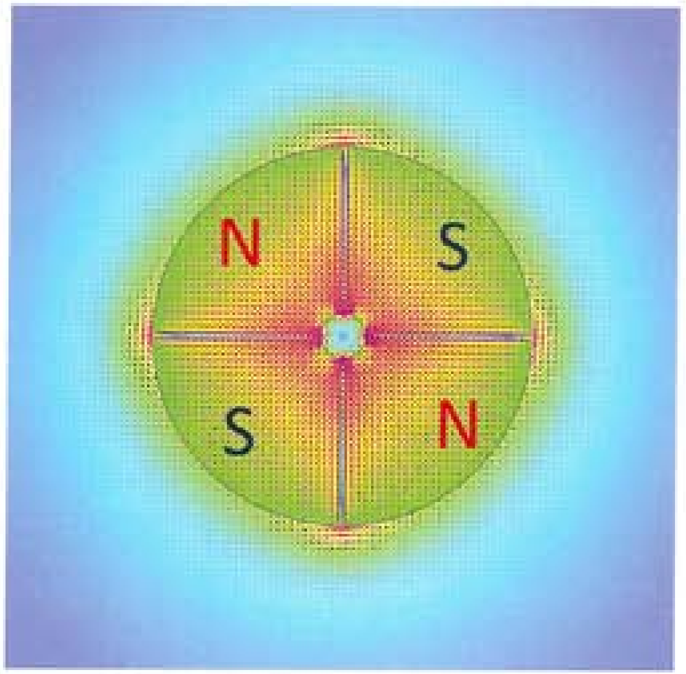
Guina Energy's novel 4 Pole Permanent Magnet technology features compacted end windings and lower copper volumes.

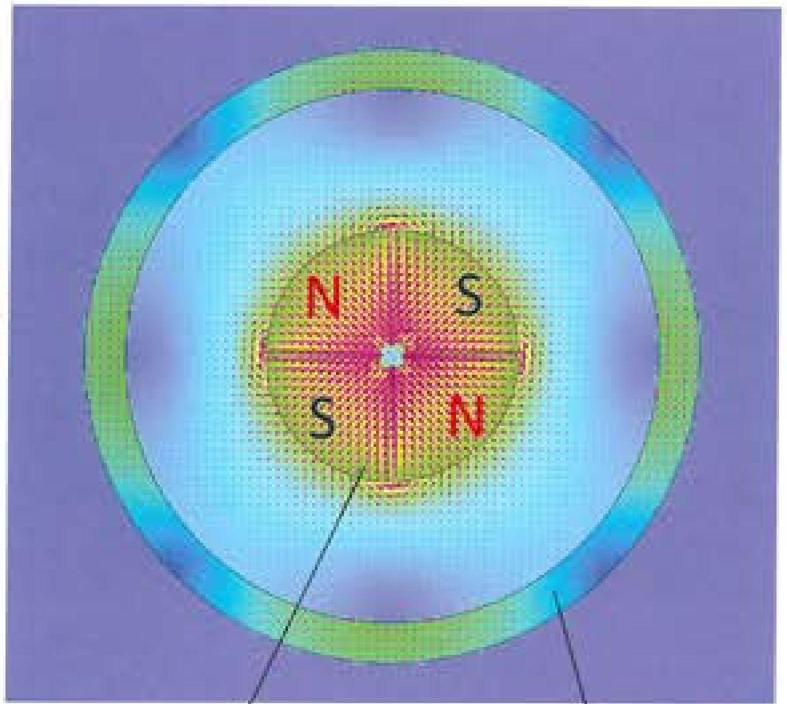
# Brushless Permanent Magnet Motor/Generator Double Layer 4 Pole with Shielding - Field Components

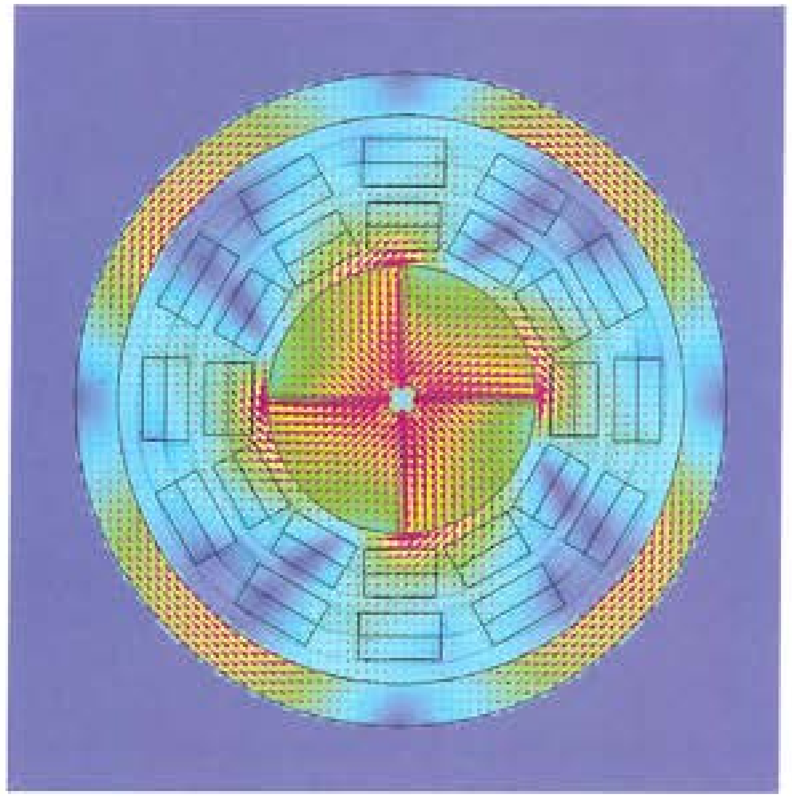
High Strength Neodymium Permanent Magnet

High Permeability Steel Laminations

<u>Dual Layer </u>High Current Density Stator Windings



Permanent Magnet

Laminated Steel

# GUINA'S BRUSHLESS PM MACHINES

GUINA ENERGY GROUP

## Brushless Permanent Magnet Motor/Generator Double Layer 4 Pole with Shielding - 10.8 MW

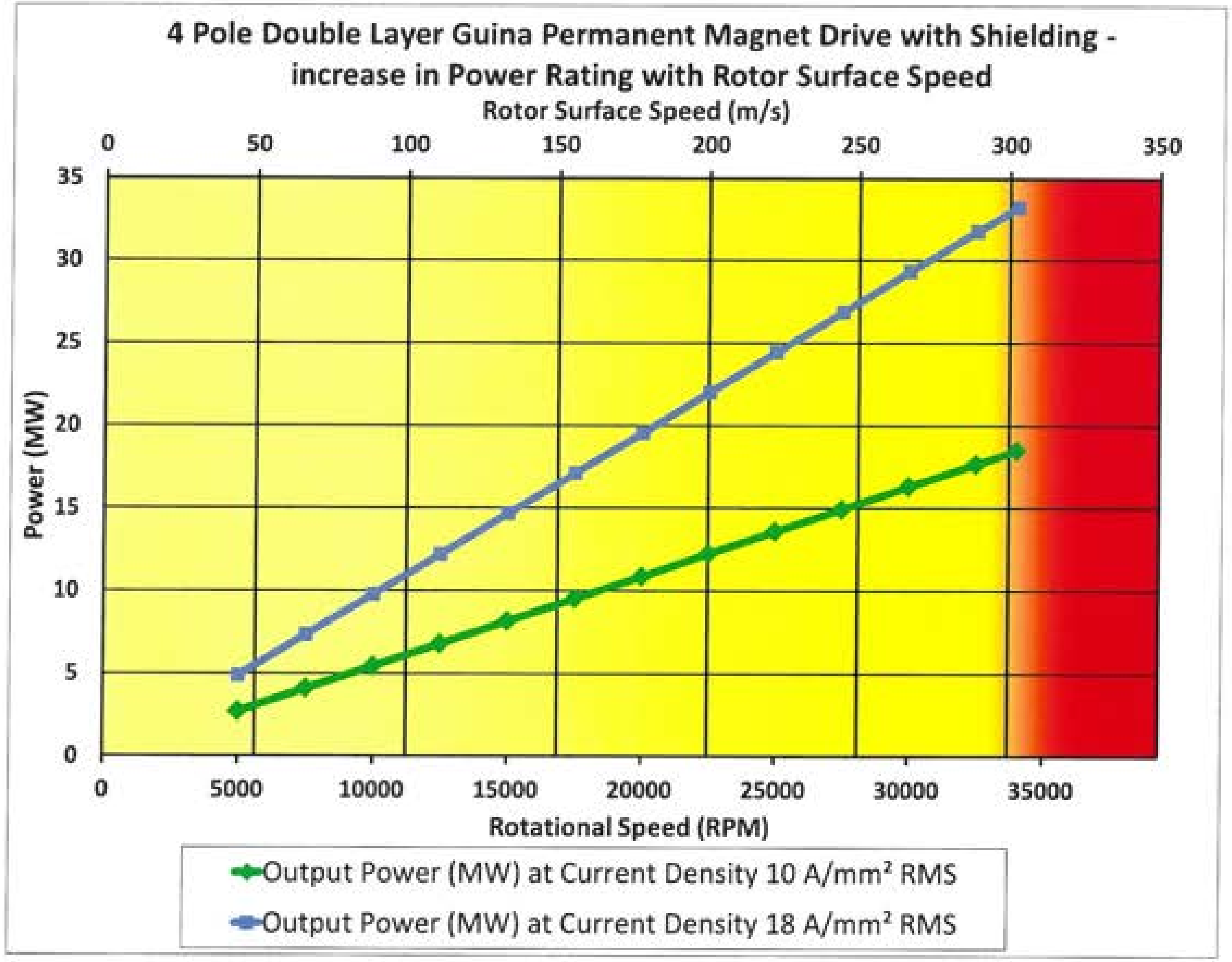
| | |
|---|---|
| Power (MW) | **10.8** |
| Rated Speed (RPM) | **20000** |
| Torque @ 20000RPM (Nm) | **5156** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **18.5** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm² | **1000** |
| Stator Windings Diameter (mm) | **360** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **189** |
| Rotor Material | **Neodymium N45SH/Steel** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **100** |
| Steel Shield Weight (kg) | **151** |
| Cooling | **Pumped Liquid** |

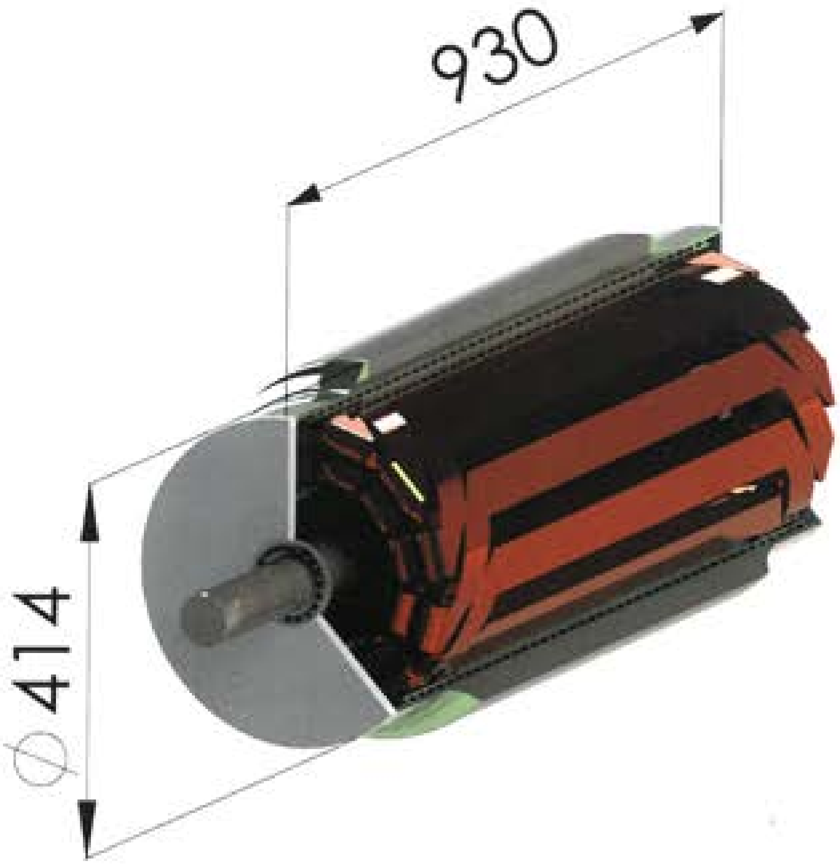
## Brushless Permanent Magnet Motor/Generator Double Layer 4 Pole with Shielding - 2.7 MW

| | |
|---|---|
| Power (MW) | **2.7** |
| Rated Speed (RPM) | **5000** |
| Torque @ 5000RPM (Nm) | **5156** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm² | **1000** |
| Stator Windings Diameter (mm) | **360** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **189** |
| Rotor Material | **Neodymium N45SH/Steel** |
| Rotor Max. Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **100** |
| Steel Shield Weight (kg) | **151** |
| Cooling | **Pumped Liquid** |

# GUINA'S BRUSHLESS PM MACHINES

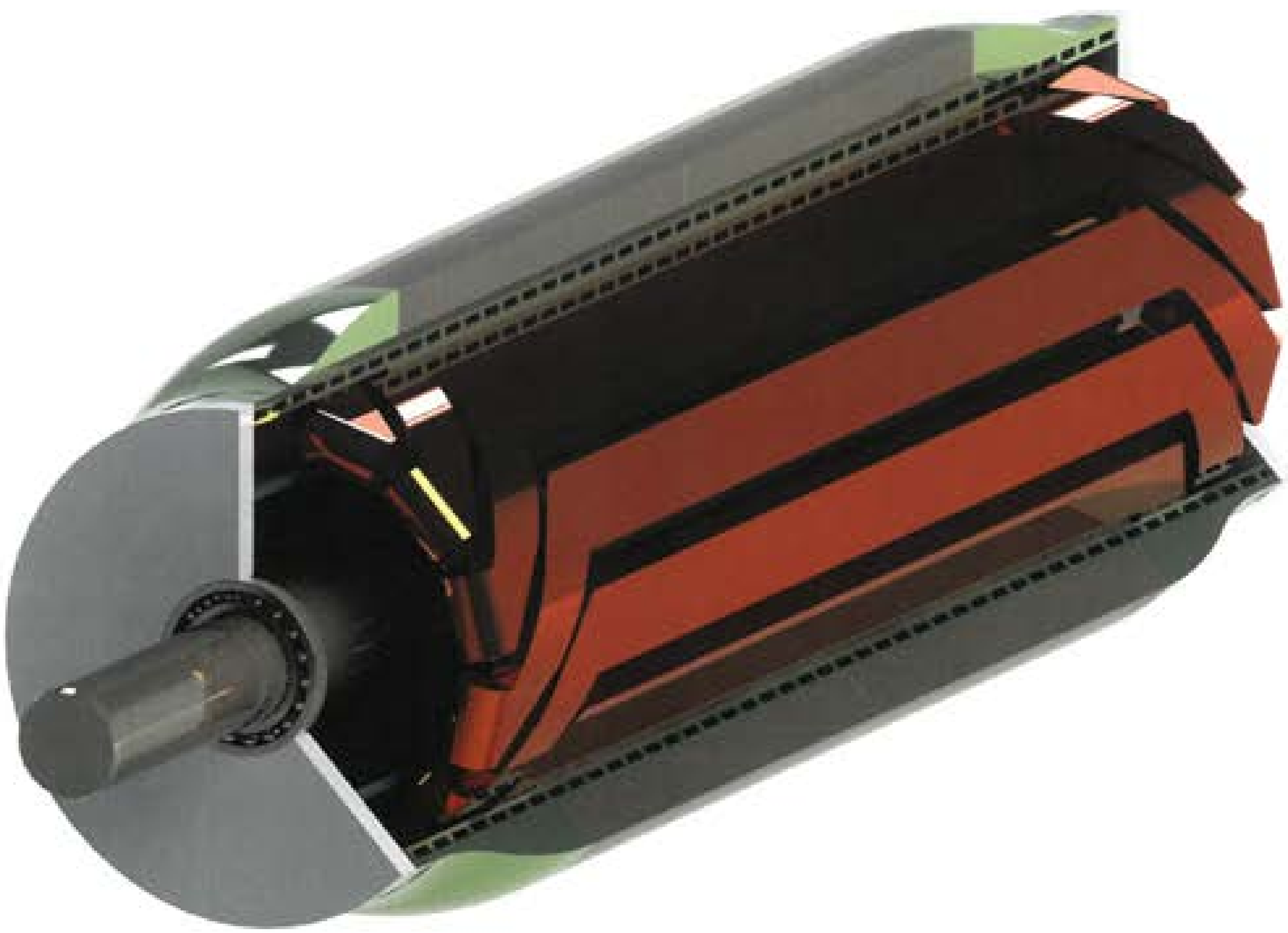
## Brushless Permanent Magnet Motor/Generator
## Double Layer 4 Pole with Shielding
## Power Scalability and Overall Dimensions



# GUINA'S BRUSHLESS PM MACHINES

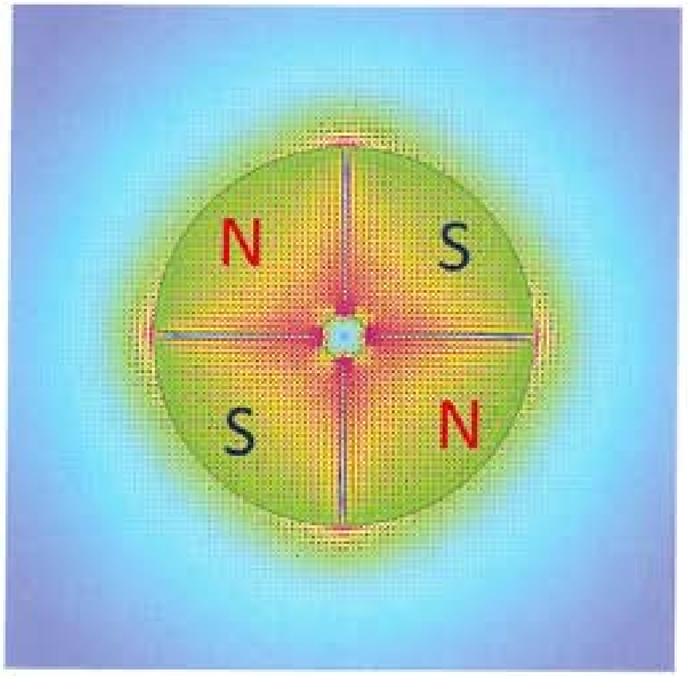
## Brushless Permanent Magnet Motor/Generator
## Single Layer 4 Pole with Shielding



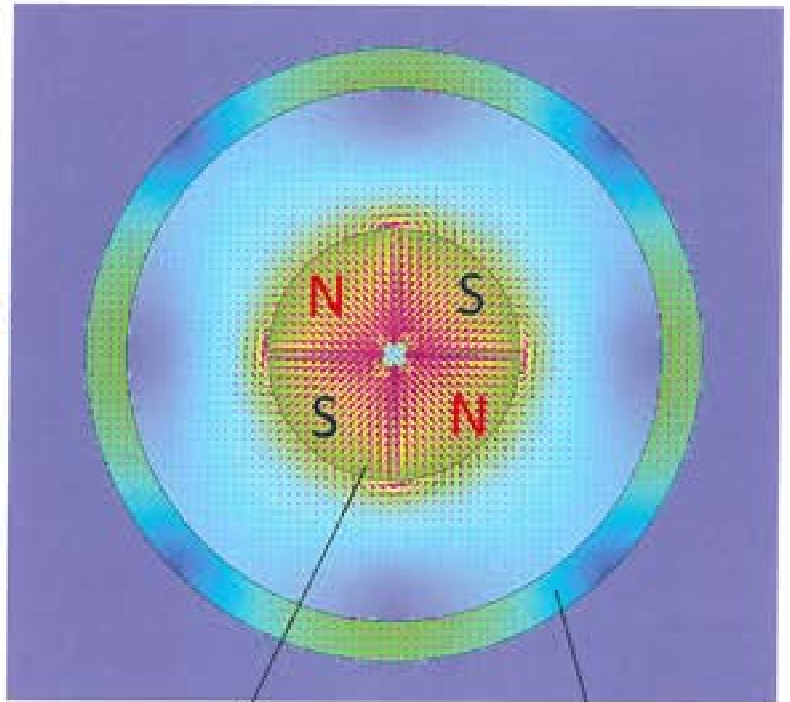
High power density motor/generator

# Brushless Permanent Magnet Motor/Generator
# Single Layer 4 Pole with Shielding - Field Components

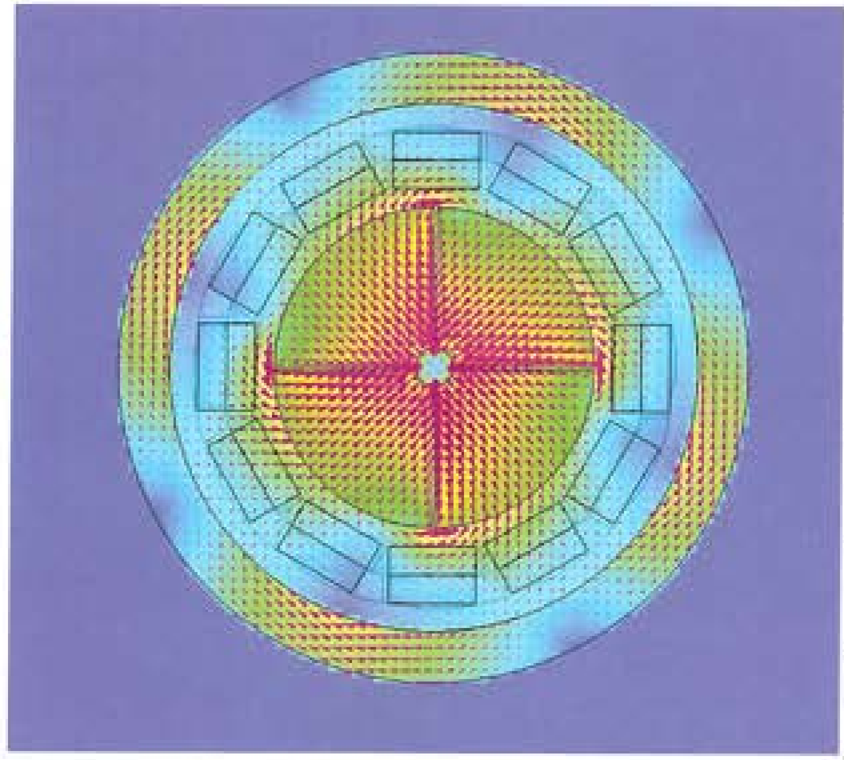
High Strength Neodymium Permanent Magnet




High Permeability Steel Laminations




High Current Density Stator Windings



# GUINA'S BRUSHLESS PM MACHINES

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## Brushless Permanent Magnet Motor/Generator Single Layer 4 Pole with Shielding - 7.6 MW

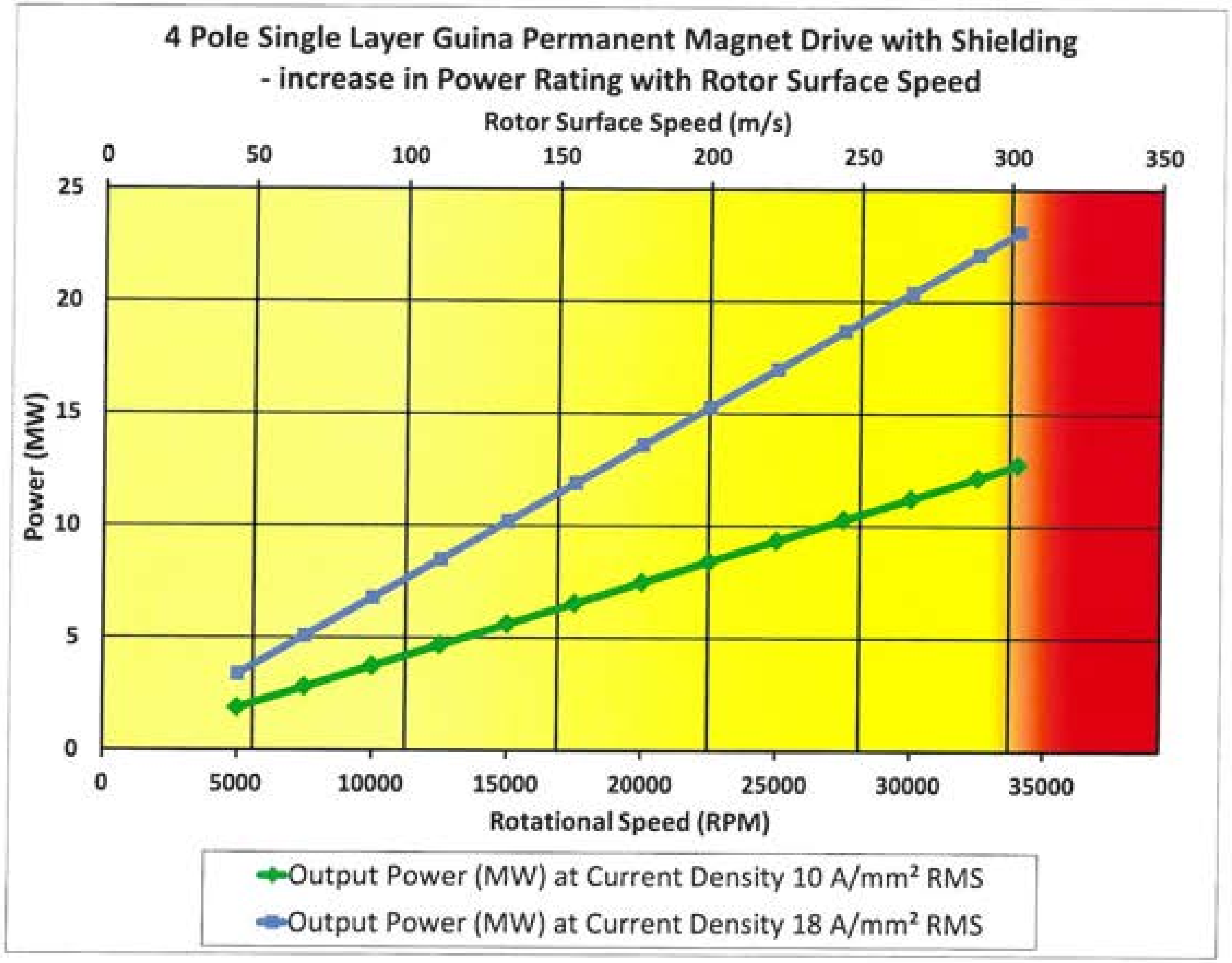
| | |
|---|---|
| Power (MW) | **7.6** |
| Rated Speed (RPM) | **20000** |
| Torque @ 20000RPM (Nm) | **3629** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **12.7** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm$^2$ | **1000** |
| Stator Windings Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **85** |
| Rotor Material | **Neodymium N45SH/Steel** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **100** |
| Steel Shield Weight (kg) | **120** |
| Cooling | **Pumped Liquid** |

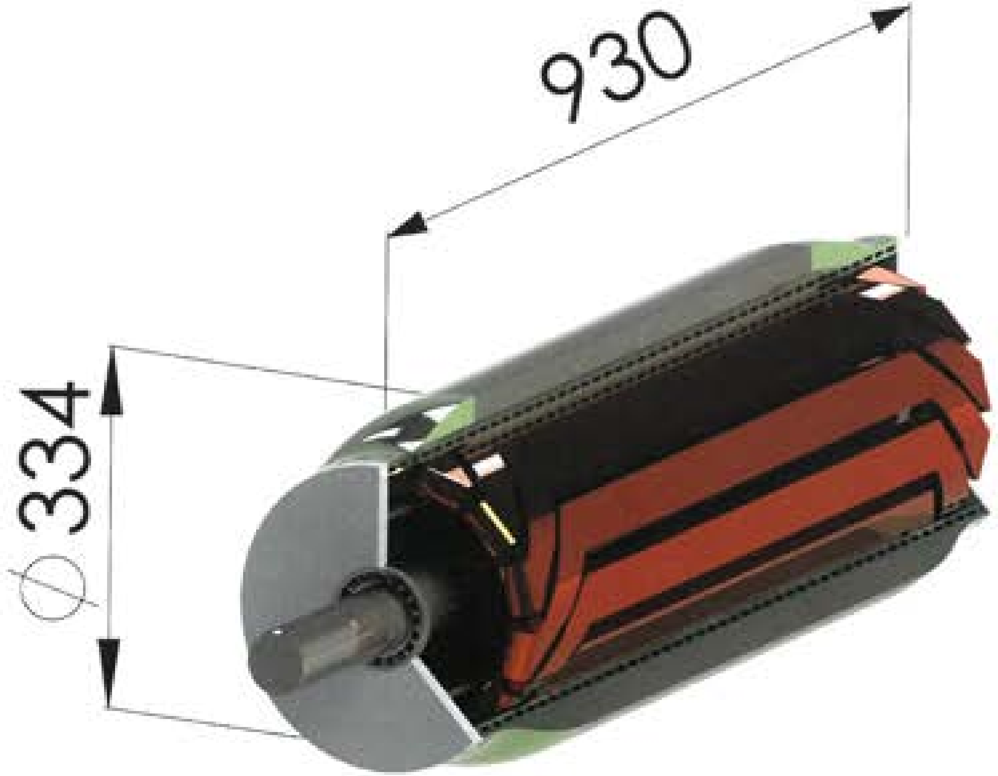
## Brushless Permanent Magnet Motor/Generator Single Layer 4 Pole with Shielding - 1.9 MW

| | |
|---|---|
| Power (MW) | **1.9** |
| Rated Speed (RPM) | **5000** |
| Torque @ 5000RPM (Nm) | **3629** |
| No. of Rotor Assemblies | **1** |
| Stator Current Density A/cm$^2$ | **1000** |
| Stator Windings Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **85** |
| Rotor Material | **Neodymium N45SH/Steel** |
| Rotor Max. Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **100** |
| Steel Shield Weight (kg) | **120** |
| Cooling | **Pumped Liquid** |

# GUINA'S BRUSHLESS PM MACHINES

## Brushless Permanent Magnet Motor/Generator
## Single Layer 4 Pole with Shielding
## Power Scalability and Overall Dimensions



# 250kW PROTOTYPE

Rated Power:

- 250 kW @ 5000 RPM

Rotor Material:

- N45SH Permanent Magnet - Ø170 mm x 100 mm

Winding Construction:

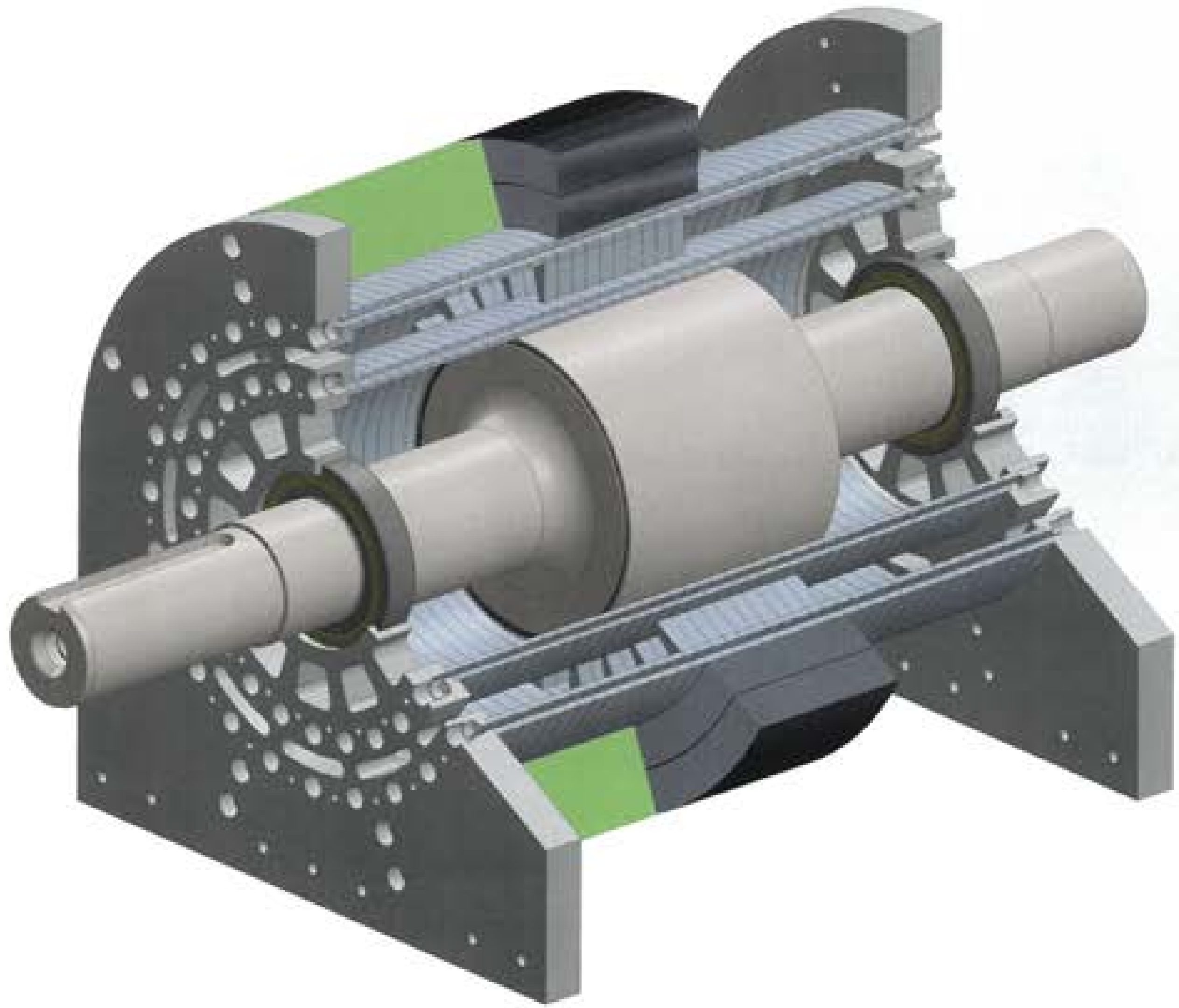
- Single Layer Random Wound.
- 6 Phases in 12 Slots.

Current Density:

- 10 $A/mm^2$ RMS

Stator Cooling:

- Two fluid cooling layers (inner and outer)



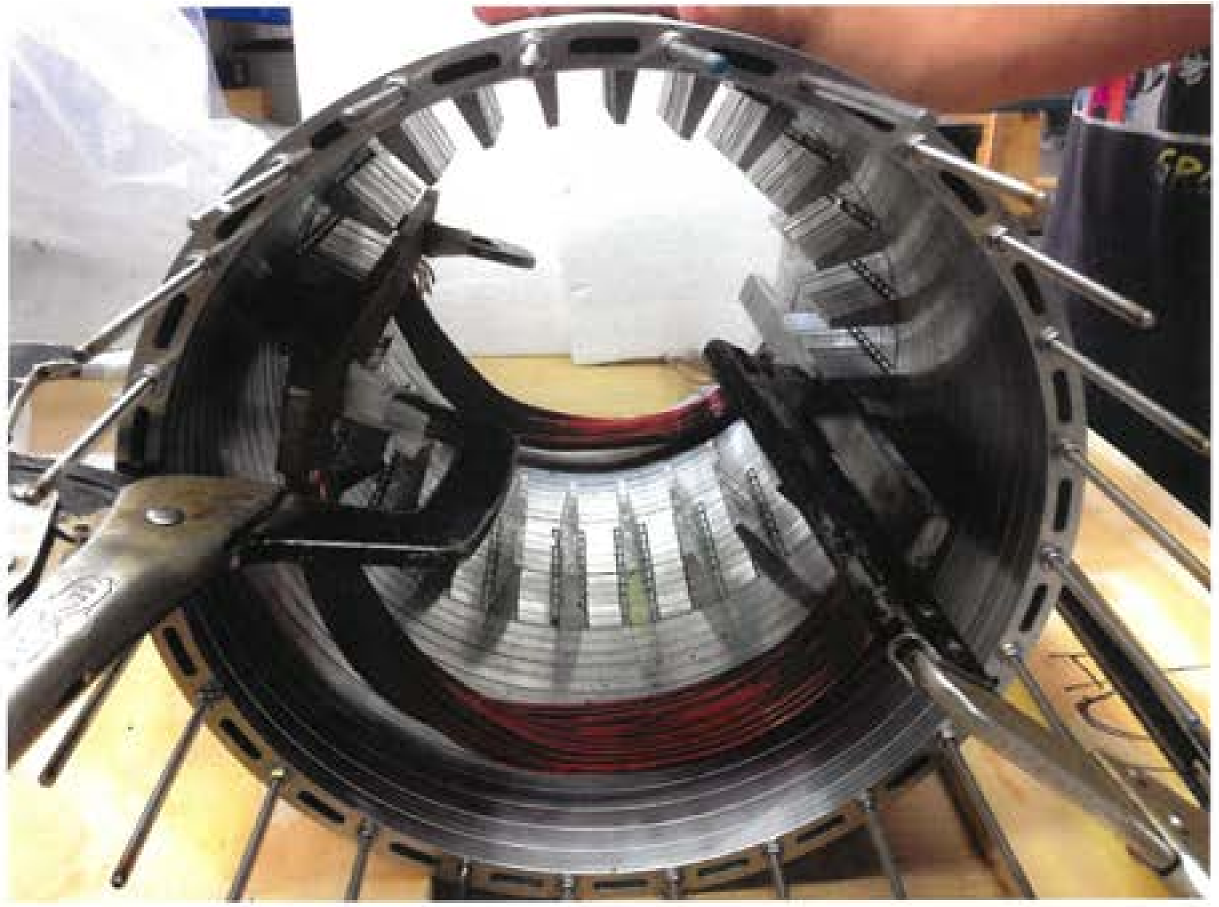
# PROTOTYPE WINDING CONSTRUCTION

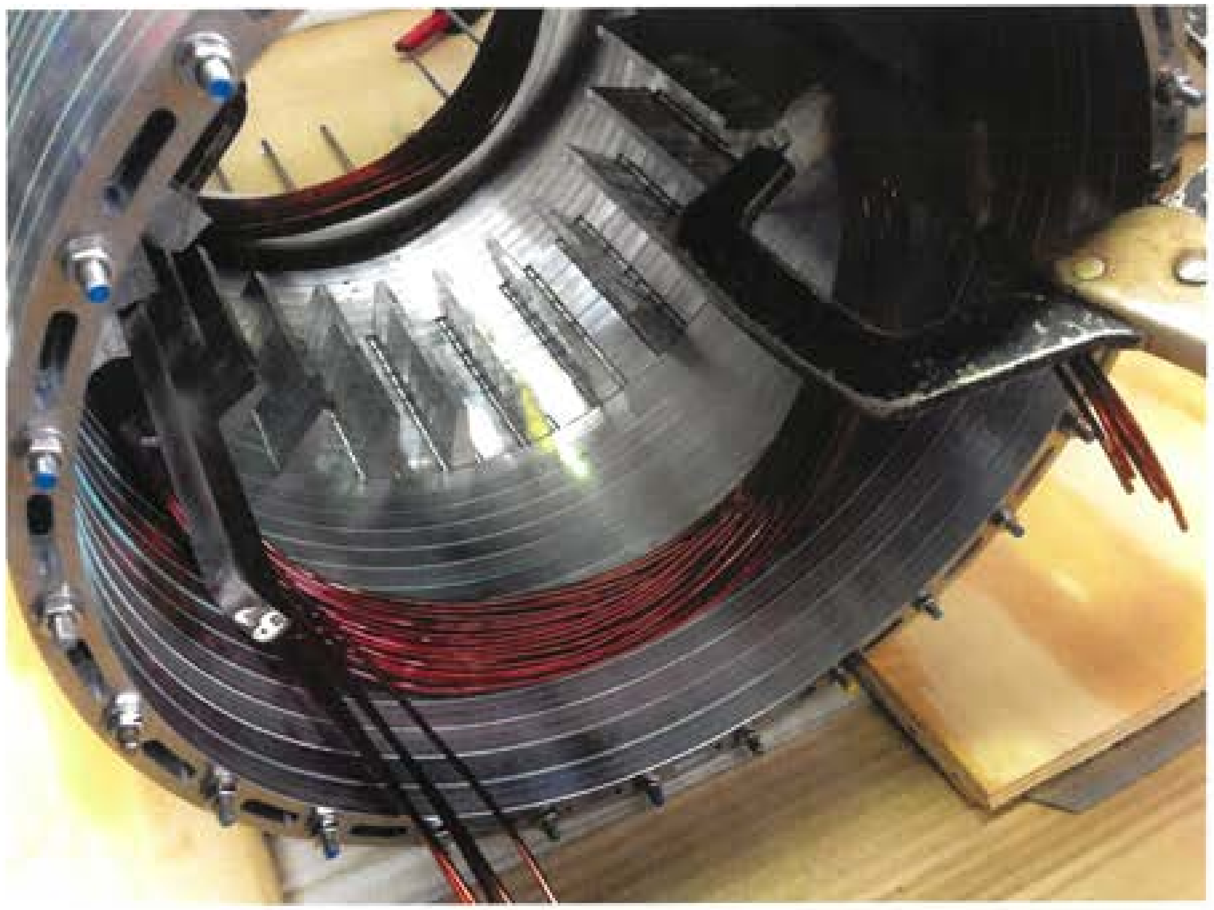
Parallel strands are wound into coils with the required number of turns.

The coils are then pressed and consolidated into the correct shape to fit in the stator slots

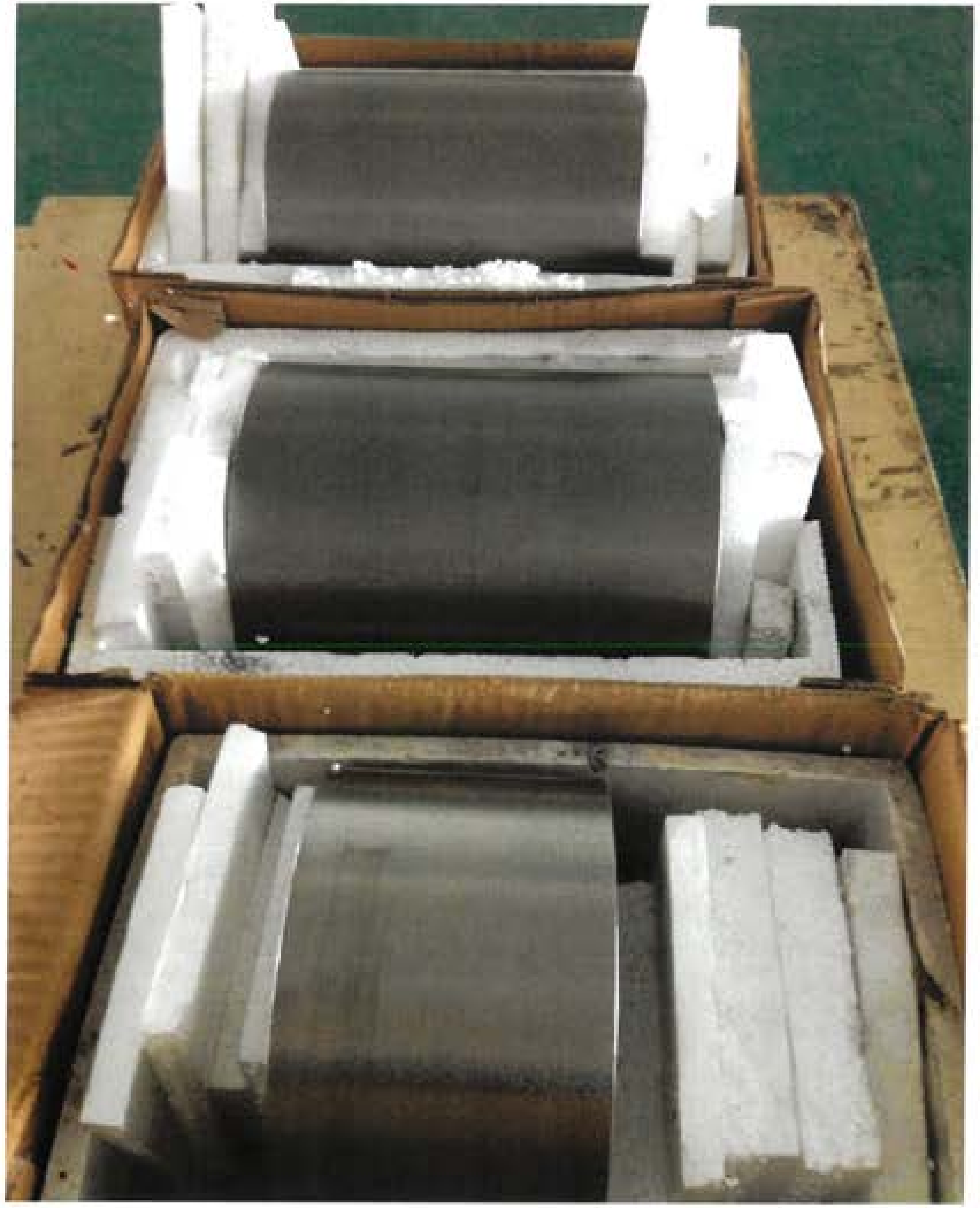
# PROTOTYPE WINDING CONSTRUCTION

The consolidated windings undergo a test fit in the stator slots.





# PROTOTYPE MAGNET CONSTRUCTION



# PERMANENT MAGNET PROTOTYPES

GUINA ENERGY GROUP

Three Prong prototype approach:

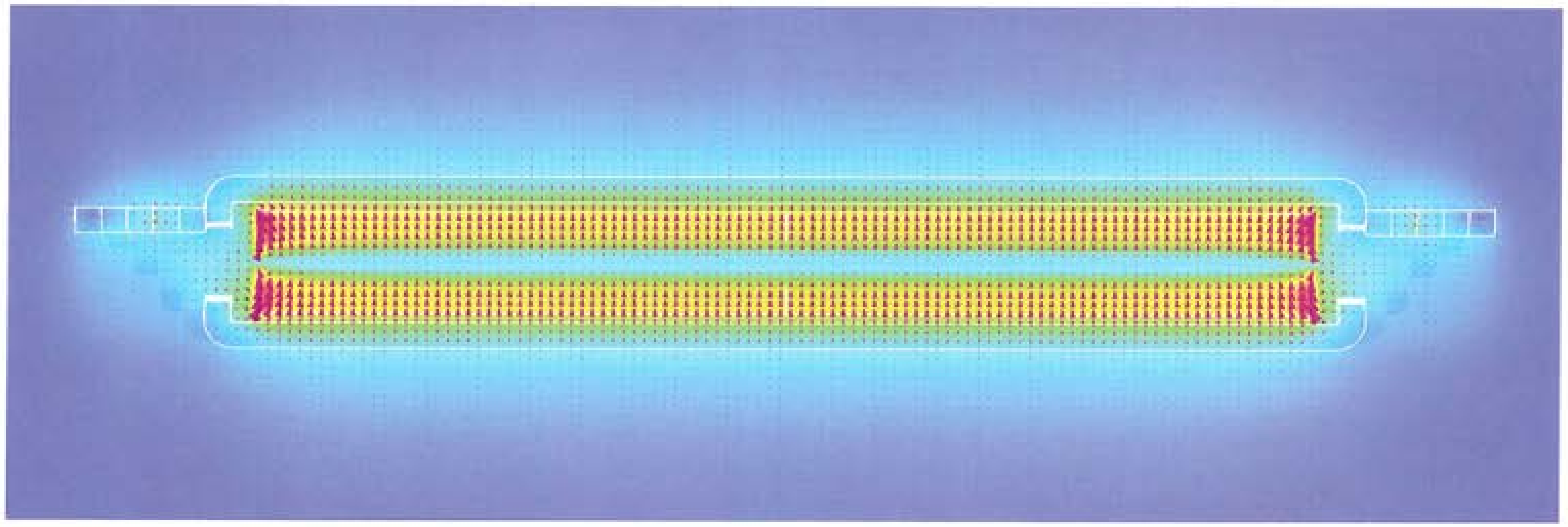
- 250 kW - Ø170 mm x 100 mm Magnet
- 250 kW - Ø85 mm x 300 mm Magnet
- 850 kW - Ø170 mm x 200 mm Magnet

Testing:

- Scalability – (1/6$^{th}$ Length, 1/3$^{rd}$ Length and 50% magnetic volume of 4 MW full scale device).
- Construction approach.
- Cooling techniques and winding ampacity.
- Power electronics and motor control.
- Loss validation.

# GUINA'S PENCIL TYPE PM TECHNOLOGY – THE FUTURE

Very High Speed – High Aspect Ratio Pencil Type PM motors for up to 16.5% greater power density than Guina's other PM technology…



The high-aspect motors can form the building blocks for our next generation of Toroidal and Cluster devices.

# GUINA'S PM TOROIDAL TECHNOLOGY

Our Permanent Magnet Toroidal Technology features independent windings that rotate around permanent magnets which remain stationary. The special toroidal arrangement of the permanent magnets inherently contains the magnetic field removing the need for extensive, heavy steel shielding.

The toroidal magnet arrangement increases the power to weight of the devices. Our innovative machines produce higher magnetic flux density at a larger effective working radius than other machines. This higher field allows us to pack more conductive windings around the permanent magnet resulting in greater power density than all other PM electrical machines.

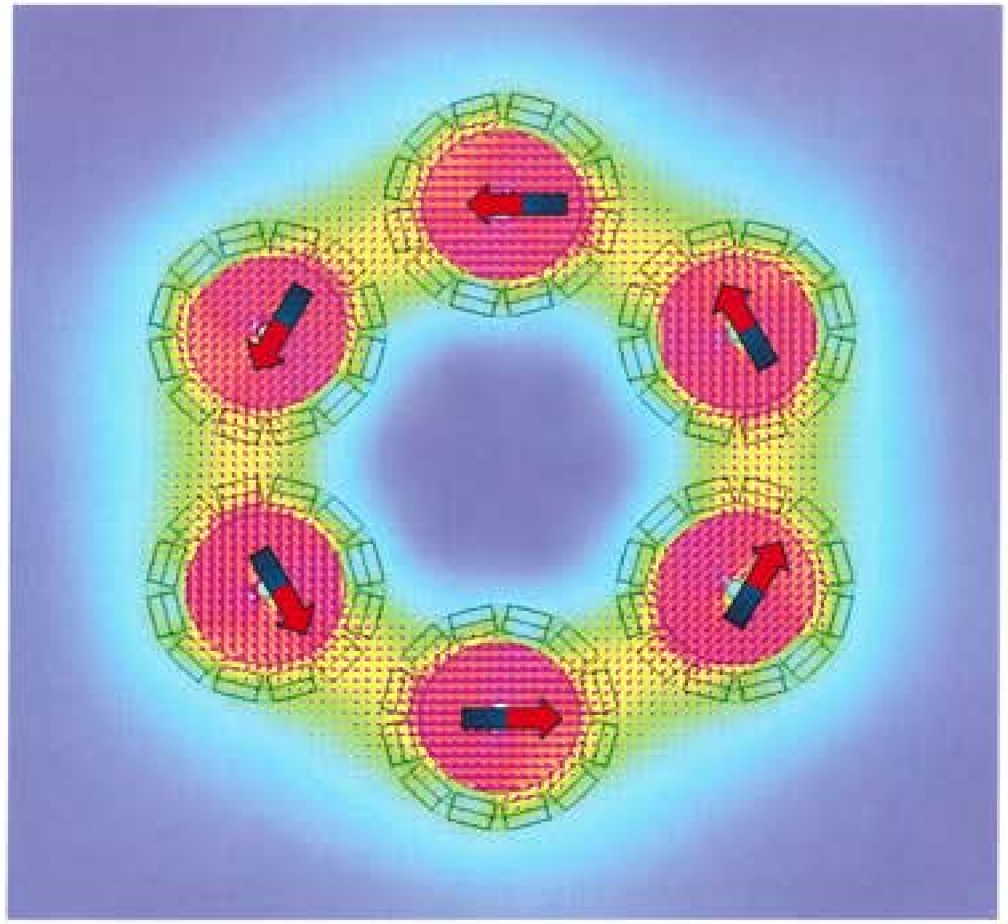
The technology shown has been extensively modelled and simulated using Vector Fields and Solidworks modelling software. The quoted power levels of the devices presented are based on 10 A/mm$^2$ RMS sinusoidal AC current in the windings. The devices can be constructed with 3 or more phases. Where employed, the steel shielding used includes a lamination fill factor of 95%.

Power can be effectively transferred to and from the independent windings using our liquid metal current collector technology or rotary transformers/DC exciters.

# GUINA'S PM TOROIDAL TECHNOLOGY

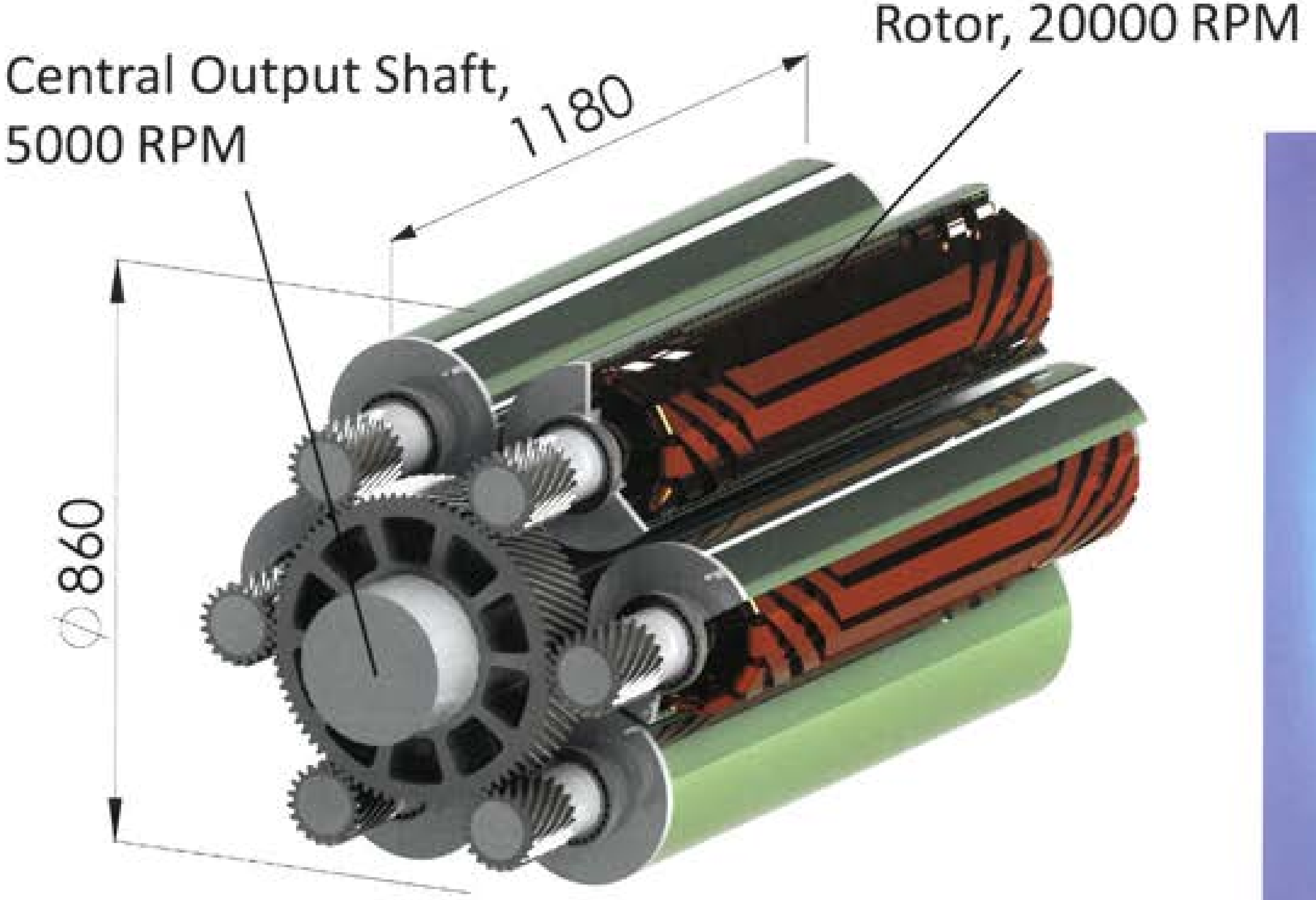
## Key Technology Advantages

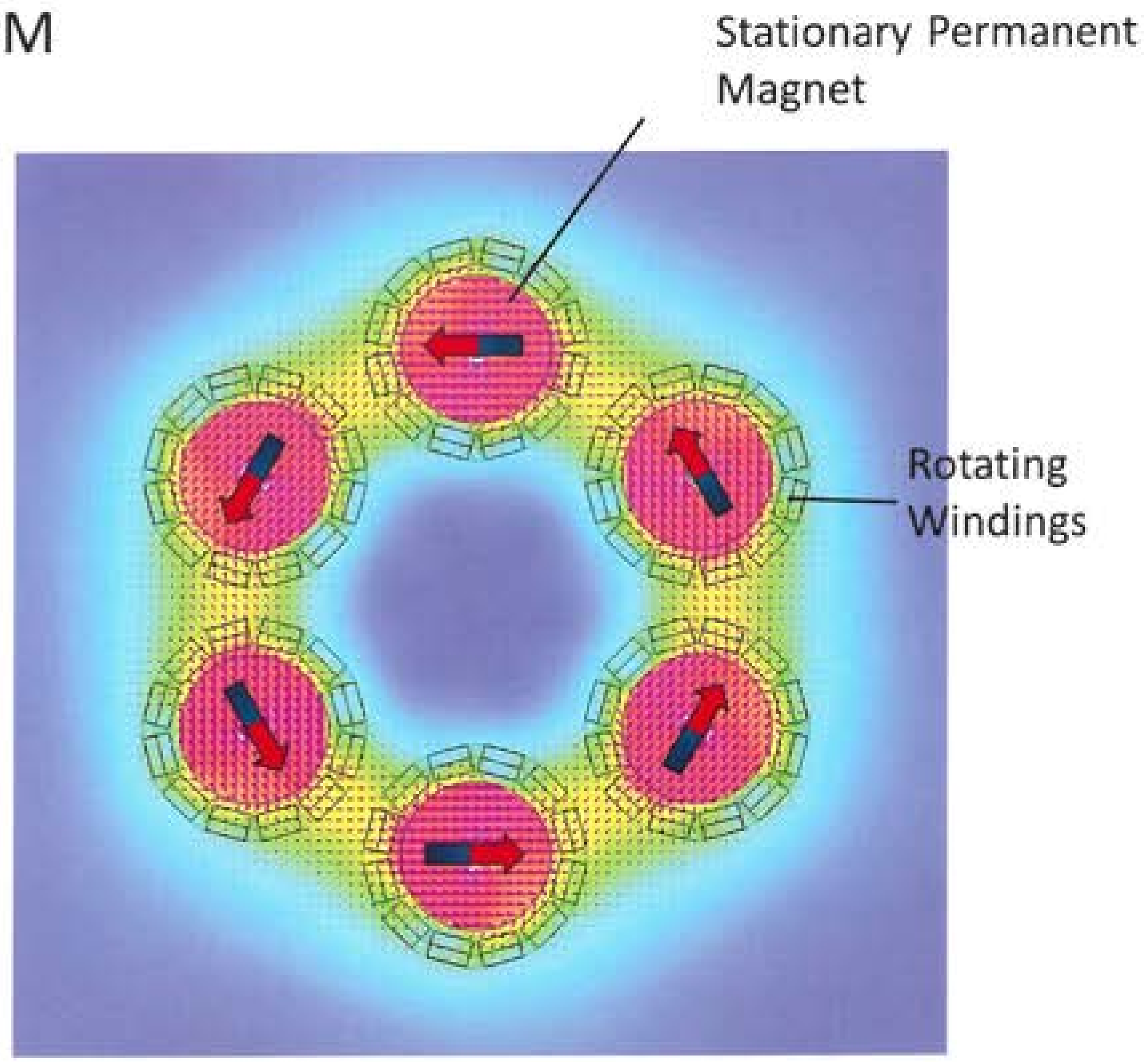
- Circular toroidal array of our single rotor PM Technology
- Inherent containment of the magnetic field which increases power to weight
- Low torque ripple
- Configurable number of independent rotor windings
- Configurable number of rotor assemblies. More assemblies result in improved field containment.
- High power to weight ratios



# GUINA'S PM TOROIDAL TECHNOLOGY

## Toroidal Permanent Magnet Motor/Generator
## 6 Rotor – 50 MW High Speed



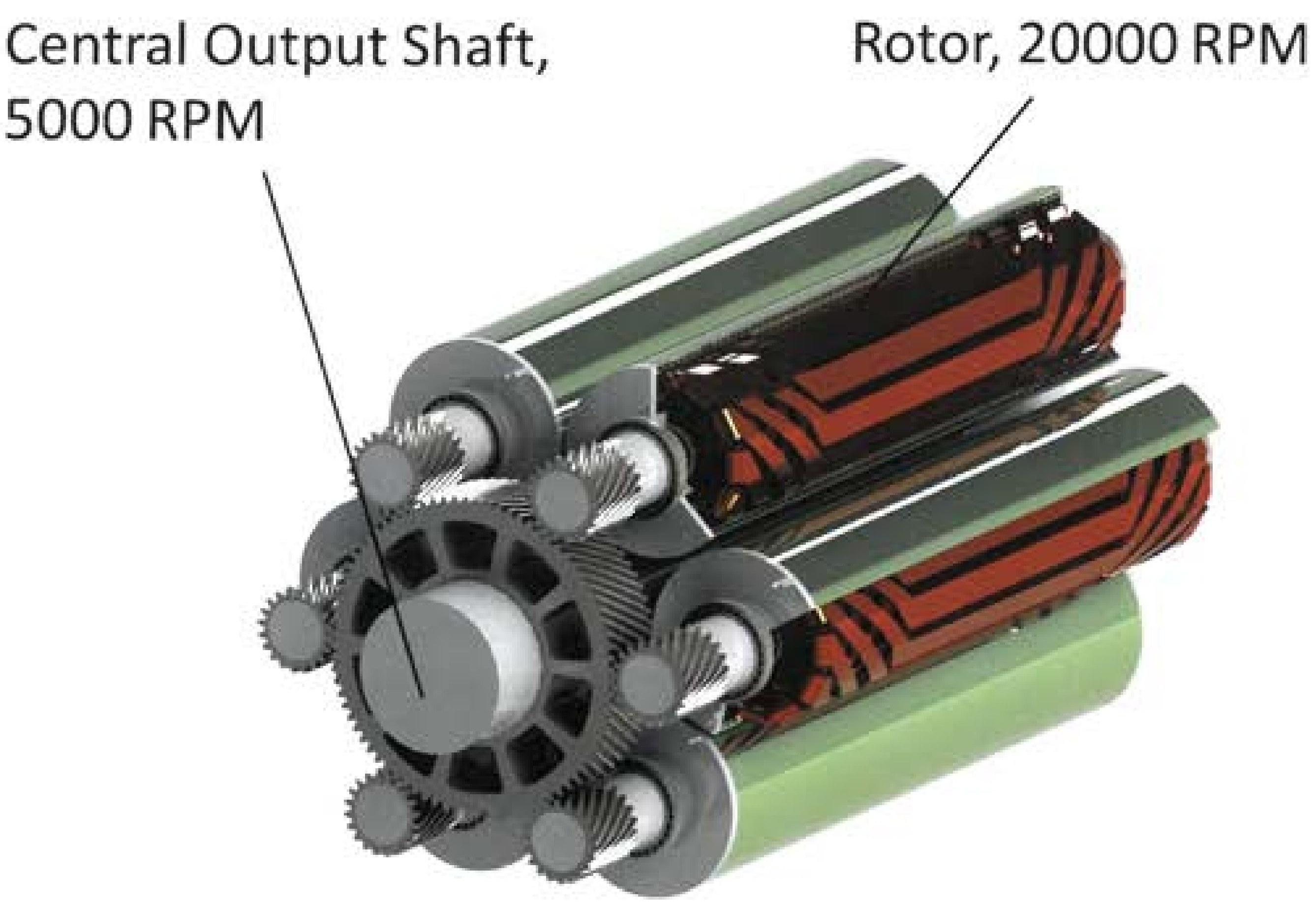



# GUINA'S PM TOROIDAL TECHNOLOGY

GUINA ENERGY GROUP

## 6 Rotor - 4:1 Gearbox - 50M W High Speed

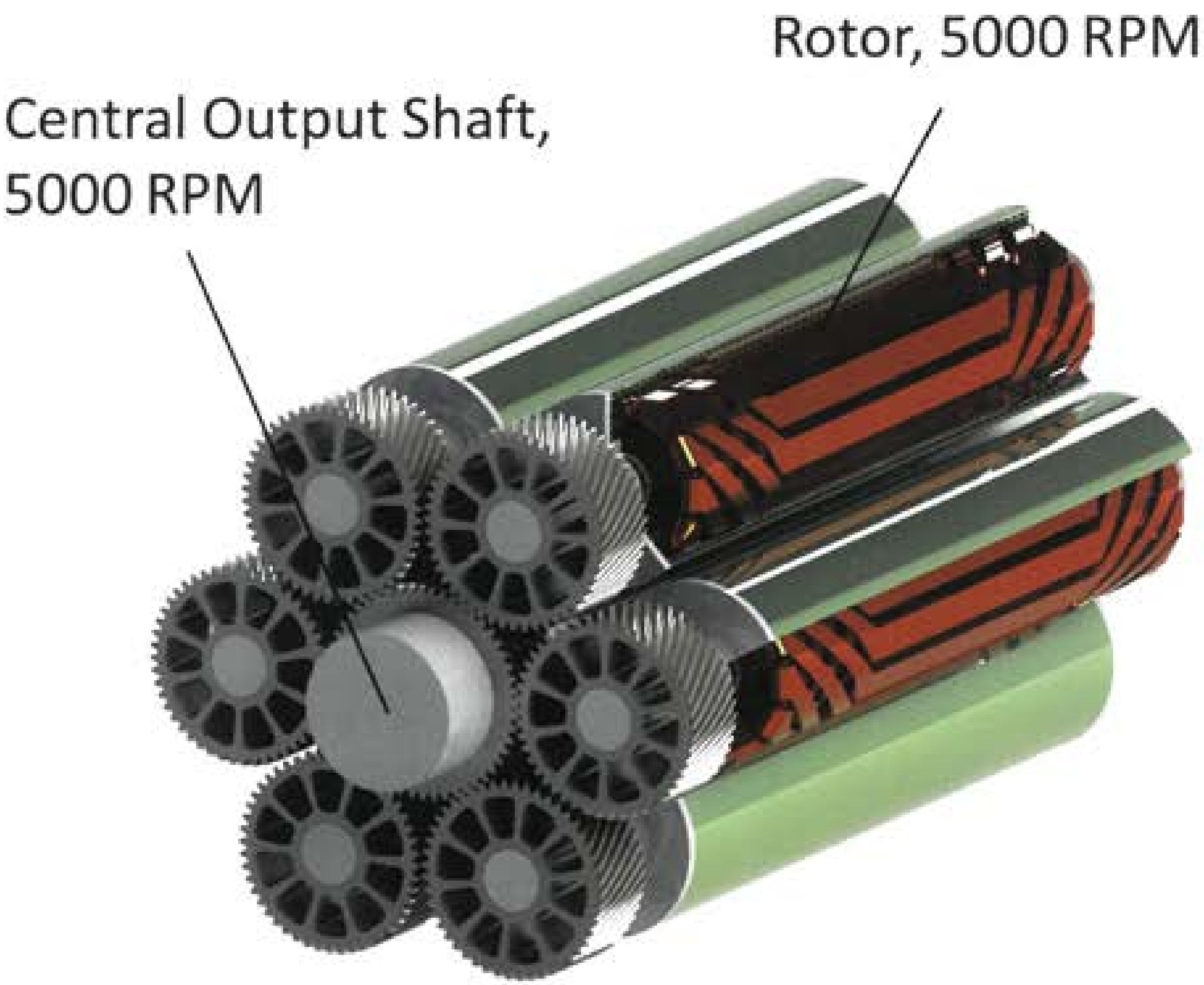
| | |
|---|---|
| Power (MW) | **50** |
| Rated Central Shaft Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **6** |
| Rotor Current Density A/cm$^2$ | **1000** |
| Rated Rotor Shaft Speed (RPM) | **20000** |
| Rotor Diameter (mm) | **280** |
| No. of Independent Rotor Windings | **6** |
| Rotor Material | **Oxygen Free Copper Wire** |
| Rotor Wire Packing Factor | **0.7** |
| Rotor Winding Weight Estimate (kg) | **619** |
| Stator Material | **Neodymium N45SH** |
| Stator Diameter (mm) | **170** |
| Stator Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **618** |
| Cooling | **Pumped Liquid** |



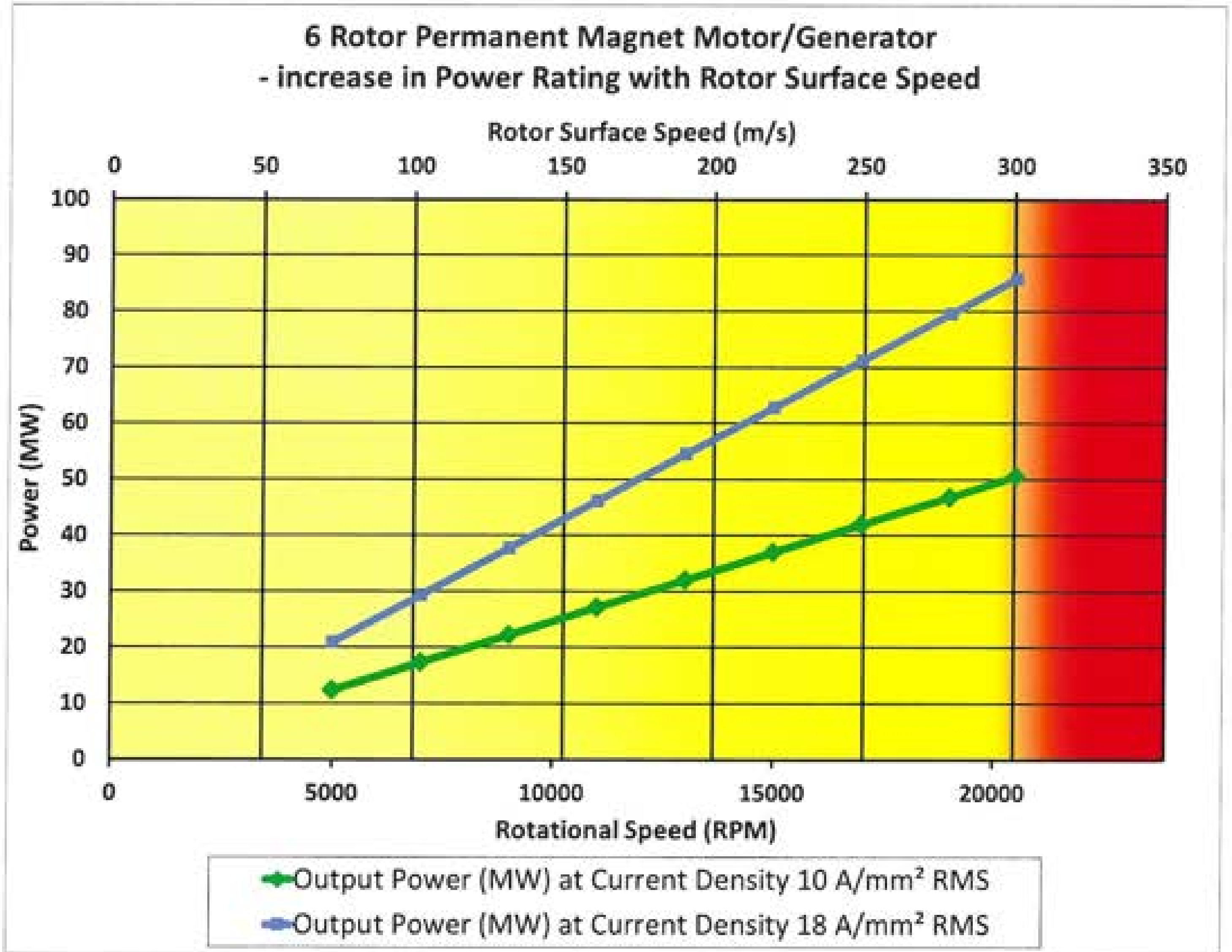
# GUINA'S PM TOROIDAL TECHNOLOGY

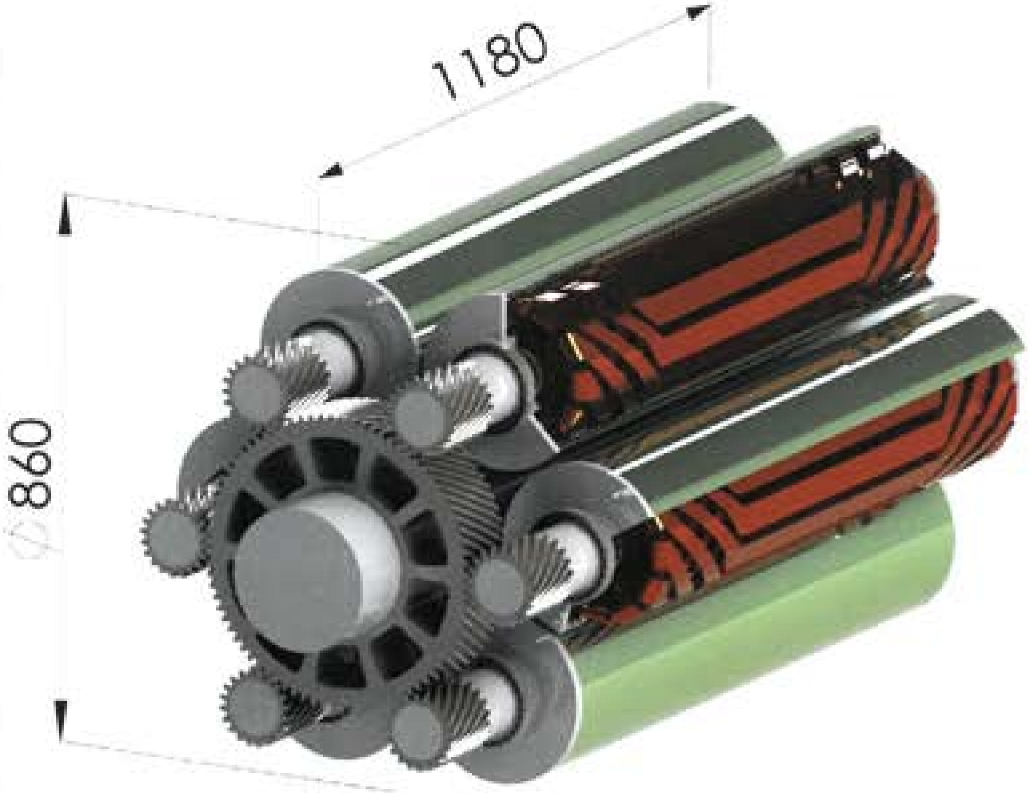
## 6 Rotor - 1:1 Gearbox - 12.5 MW High Speed

| | |
|---|---|
| Power (MW) | **12.5** |
| Rated Central Shaft Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **6** |
| Rotor Current Density A/cm² | **1000** |
| Rated Rotor Shaft Speed (RPM) | **5000** |
| Rotor Diameter (mm) | **280** |
| No. of Independent Rotor Windings | **6** |
| Rotor Material | **Oxygen Free Copper Wire** |
| Rotor Wire Packing Factor | **0.7** |
| Rotor Winding Weight Estimate (kg) | **619** |
| Stator Material | **Neodymium N45SH** |
| Stator Diameter (mm) | **170** |
| Stator Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **618** |
| Cooling | **Pumped Liquid** |

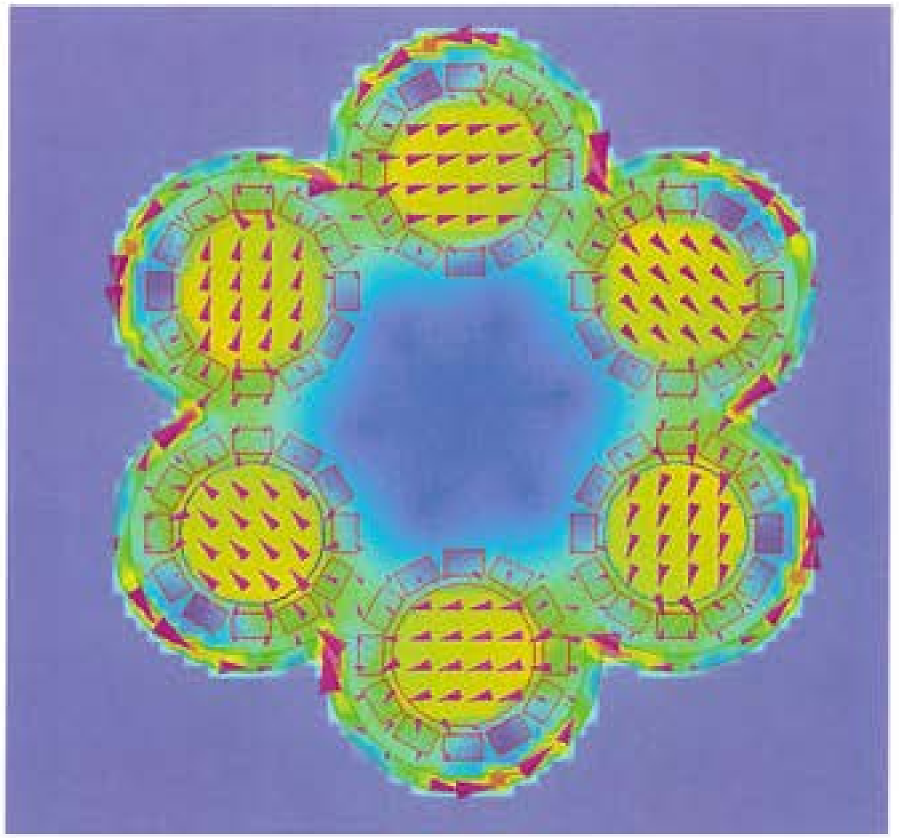


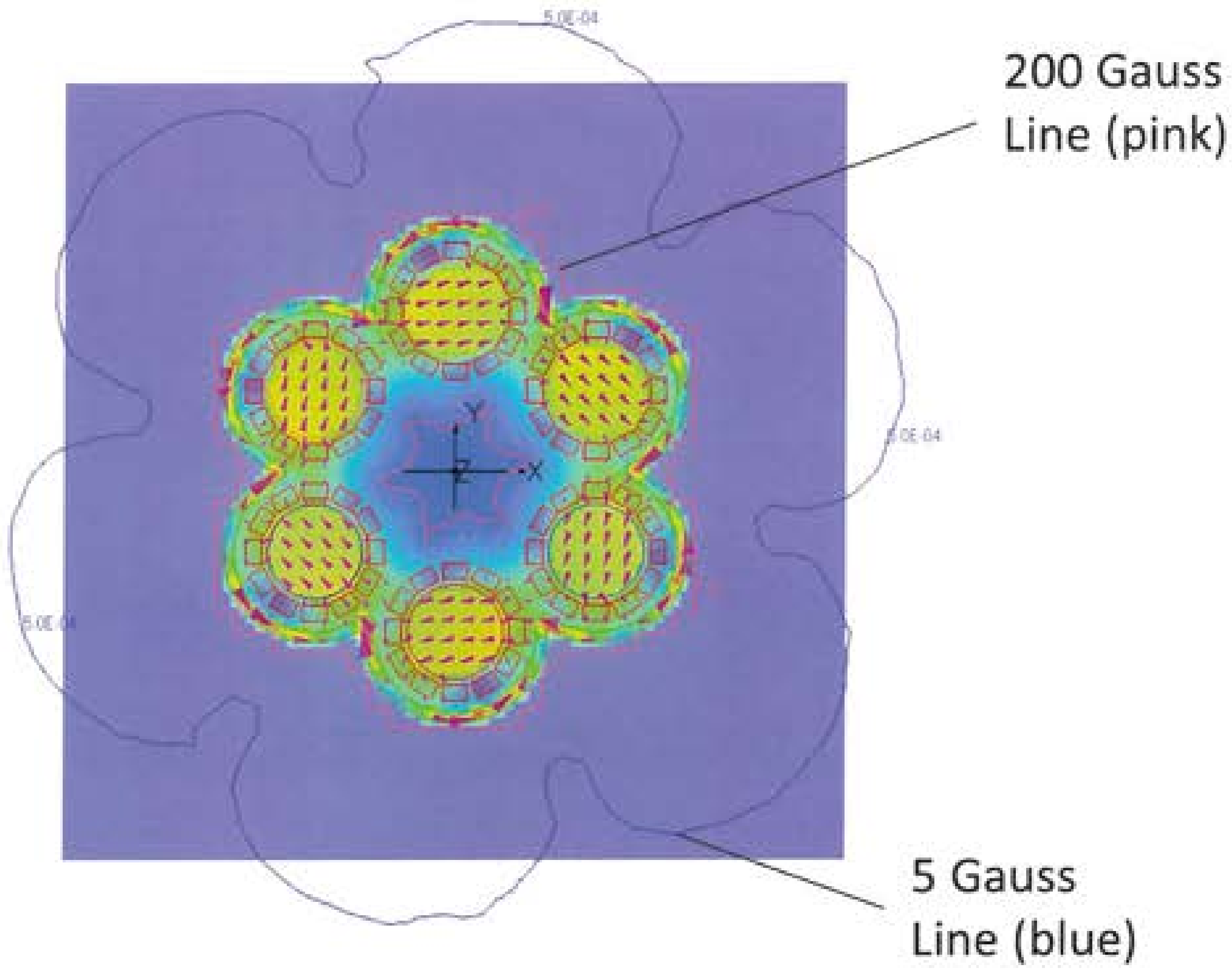
# 6 Rotor - Power Scalability and Overall Dimensions



# 6 Rotor with Shielding

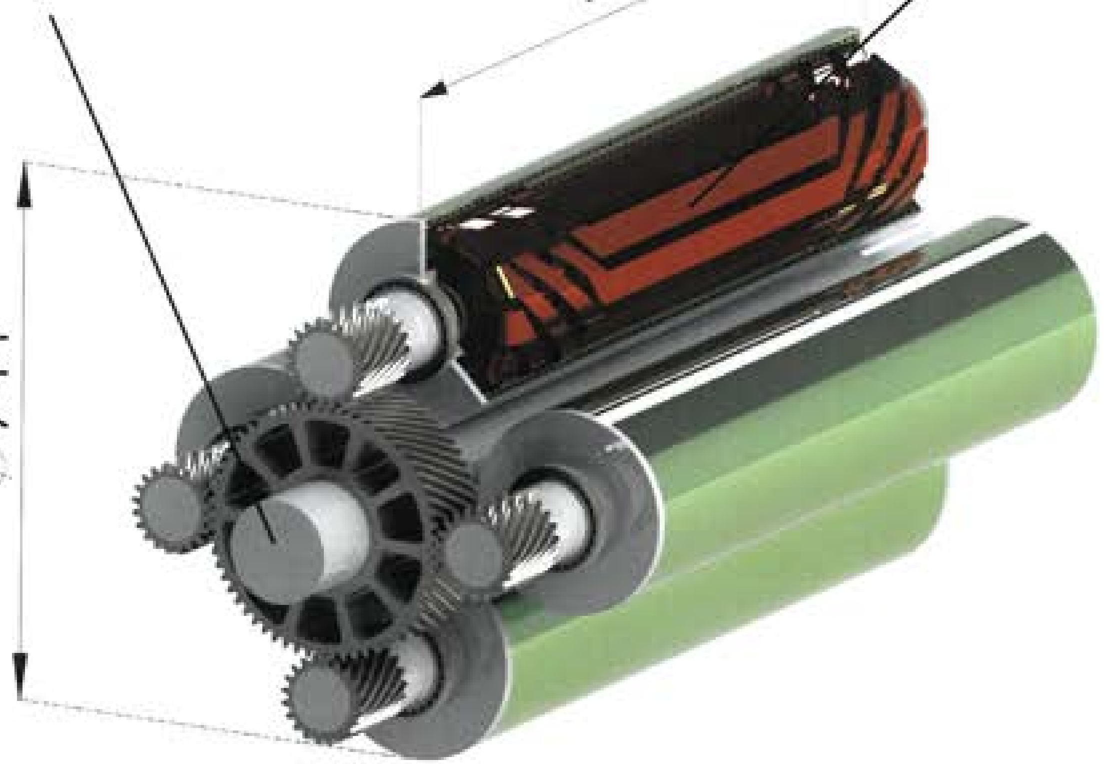


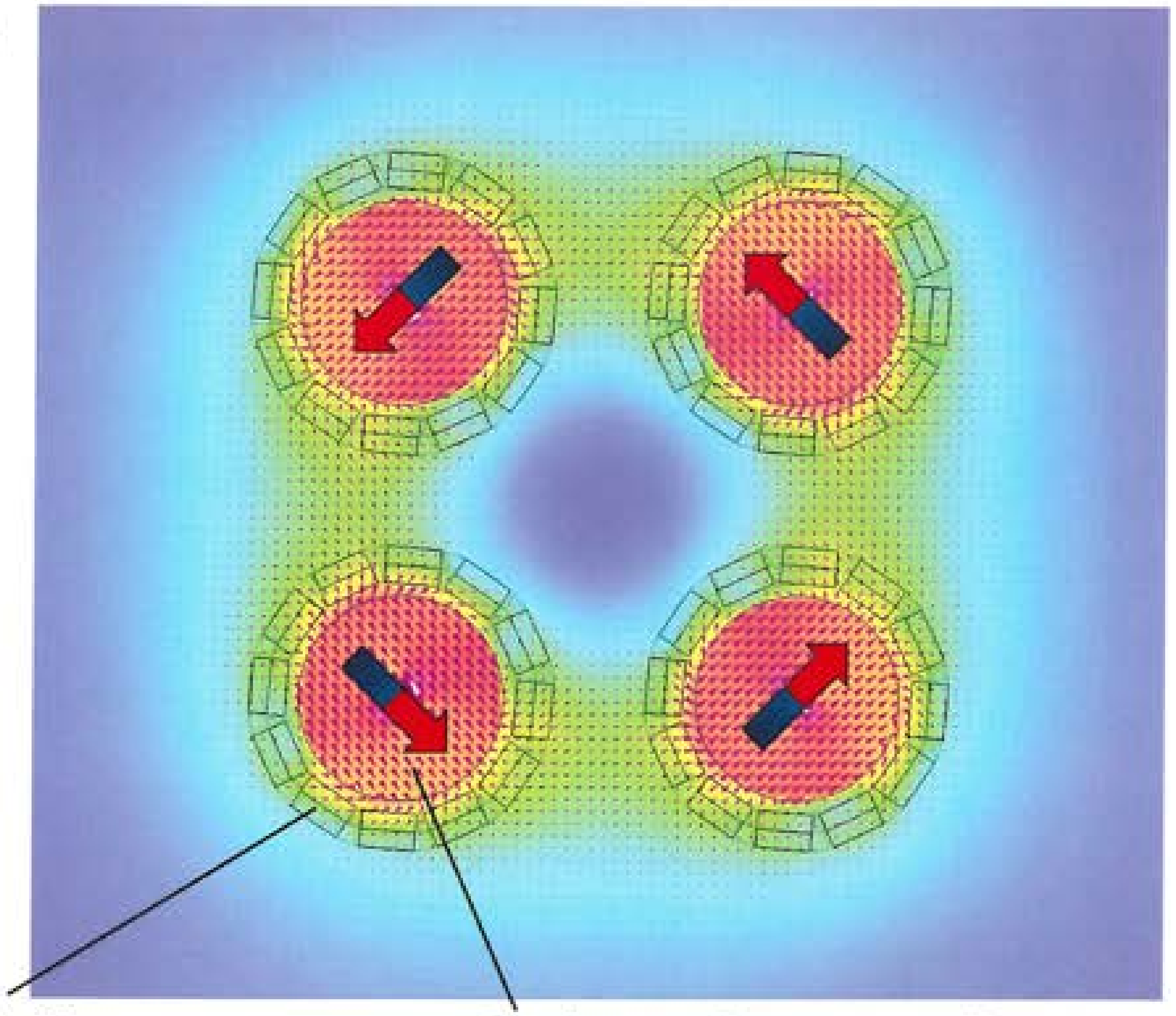



The addition of 20mm laminated steel shielding to the 6 Rotor Toroidal PM machine increases the power by an additional 7-8%. The steel laminations follow the outer contours of the device.

The laminated steel shielding further contains the stray field within the machine.

# Toroidal Permanent Magnet Motor/Generator
# 4 Rotor, 3:1 Gearbox, 30 MW High Speed

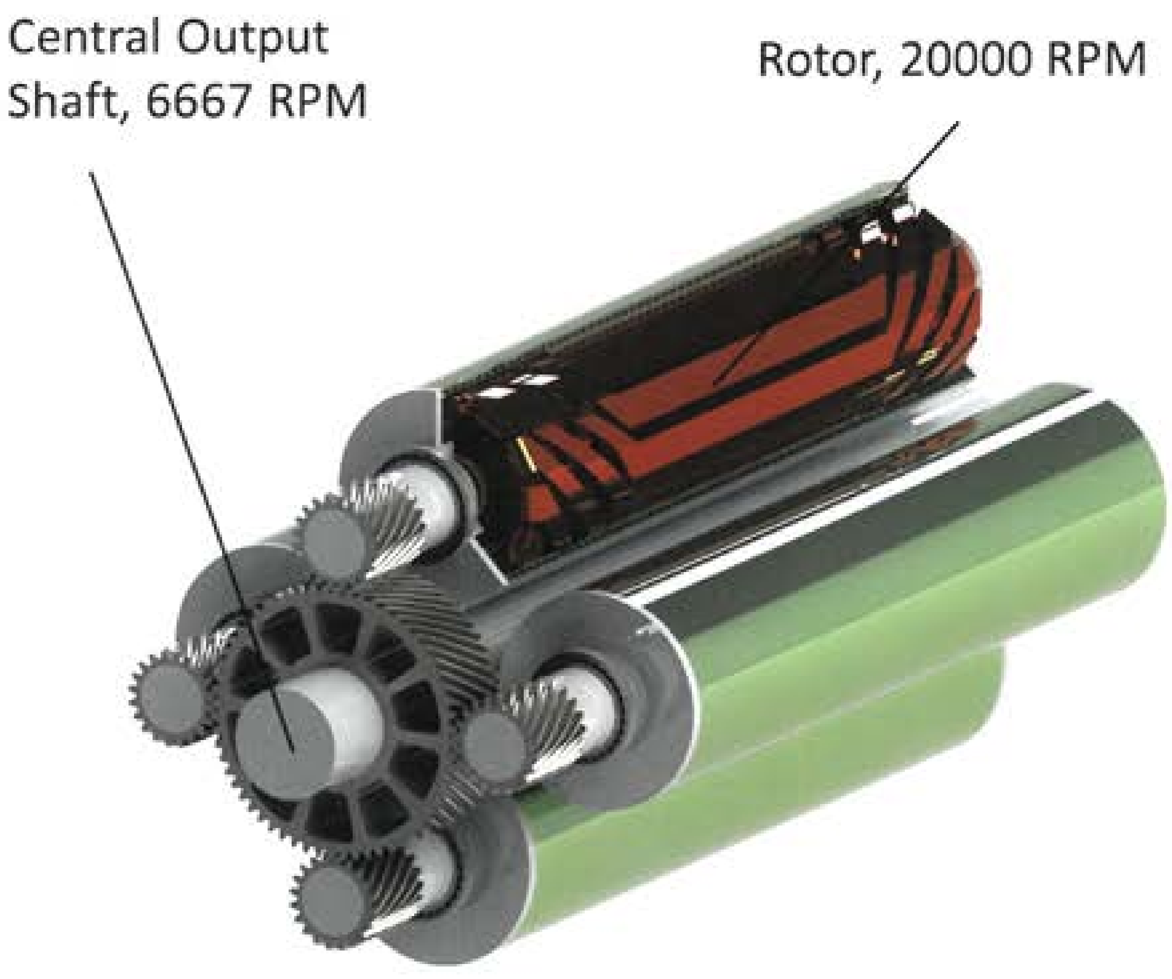


# GUINA'S PM TOROIDAL TECHNOLOGY

## 4 Rotor - 3:1 Gearbox - 30 MW High Speed

| | |
|---|---|
| Power (MW) | **30** |
| Rated Central Shaft Speed (RPM) | **6667** |
| No. of Rotor Assemblies | **4** |
| Rotor Current Density A/cm$^2$ | **1000** |
| Rated Rotor Shaft Speed (RPM) | **20000** |
| Rotor Diameter (mm) | **280** |
| No. of Independent Rotor Windings | **6** |
| Rotor Material | **Oxygen Free Copper Wire** |
| Rotor Wire Packing Factor | **0.7** |
| Rotor Winding Weight Estimate (kg) | **413** |
| Stator Material | **Neodymium N45SH** |
| Stator Diameter (mm) | **170** |
| Stator Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **412** |
| Cooling | **Pumped Liquid** |

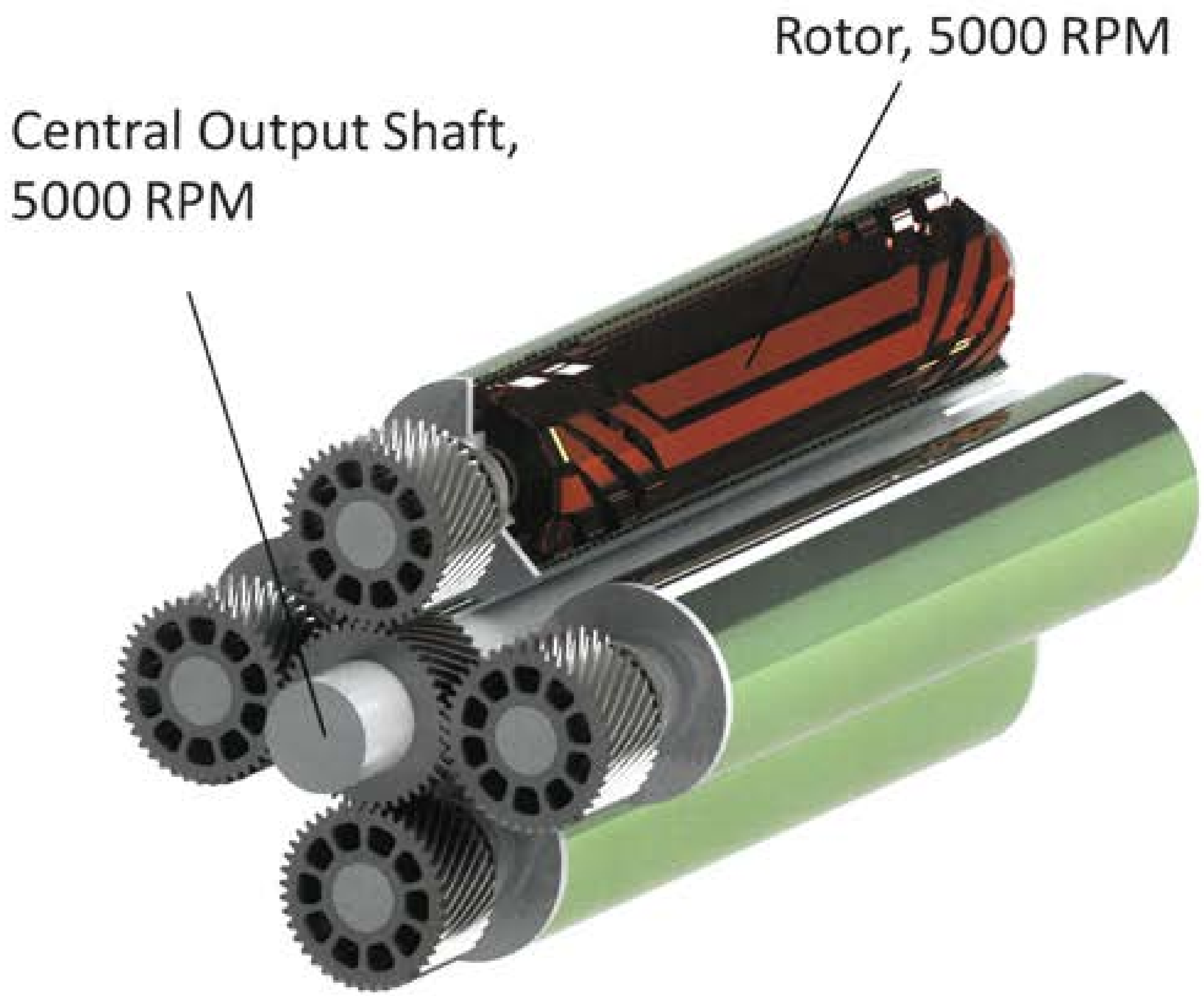


# GUINA'S PM TOROIDAL TECHNOLOGY

GUINA ENERGY GROUP

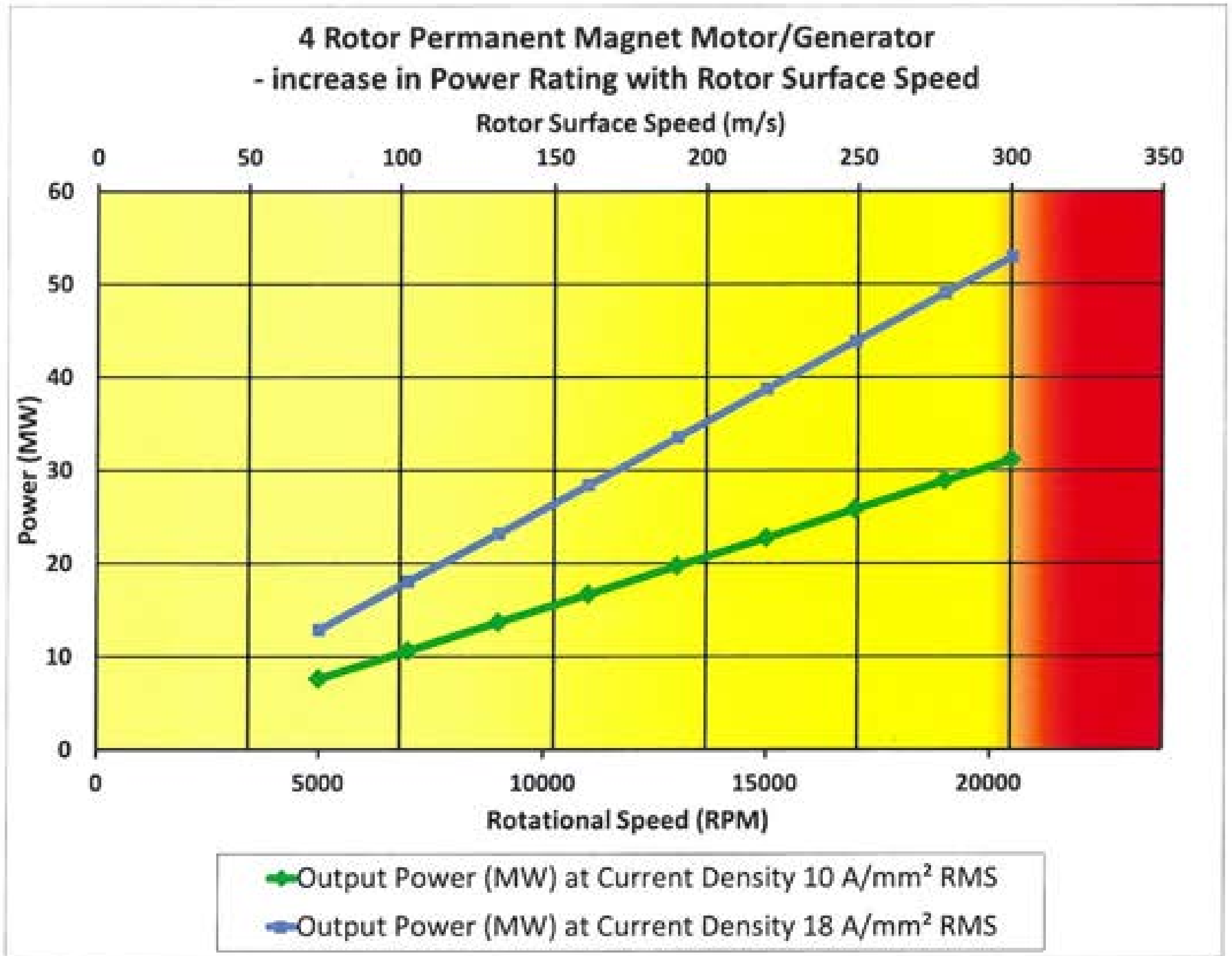
## 4 Rotor - 1:1 Gearbox - 7.6 MW High Speed

| | |
|---|---|
| Power (MW) | **7.6** |
| Rated Central Shaft Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **4** |
| Rotor Current Density A/cm$^2$ | **1000** |
| Rated Rotor Shaft Speed (RPM) | **5000** |
| Rotor Diameter (mm) | **280** |
| No. of Independent Rotor Windings | **6** |
| Rotor Material | **Oxygen Free Copper Wire** |
| Rotor Wire Packing Factor | **0.7** |
| Rotor Winding Weight Estimate (kg) | **413** |
| Stator Material | **Neodymium N45SH** |
| Stator Diameter (mm) | **170** |
| Stator Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **412** |
| Cooling | **Pumped Liquid** |

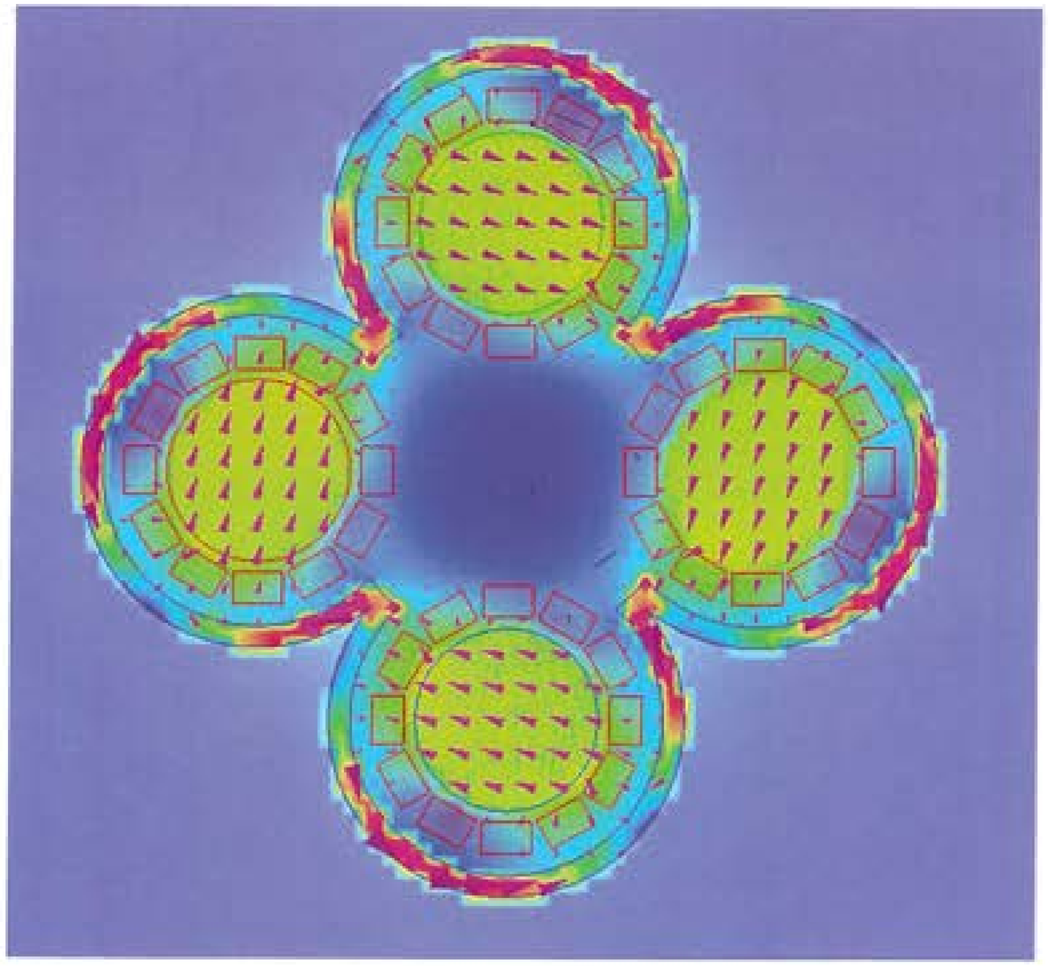


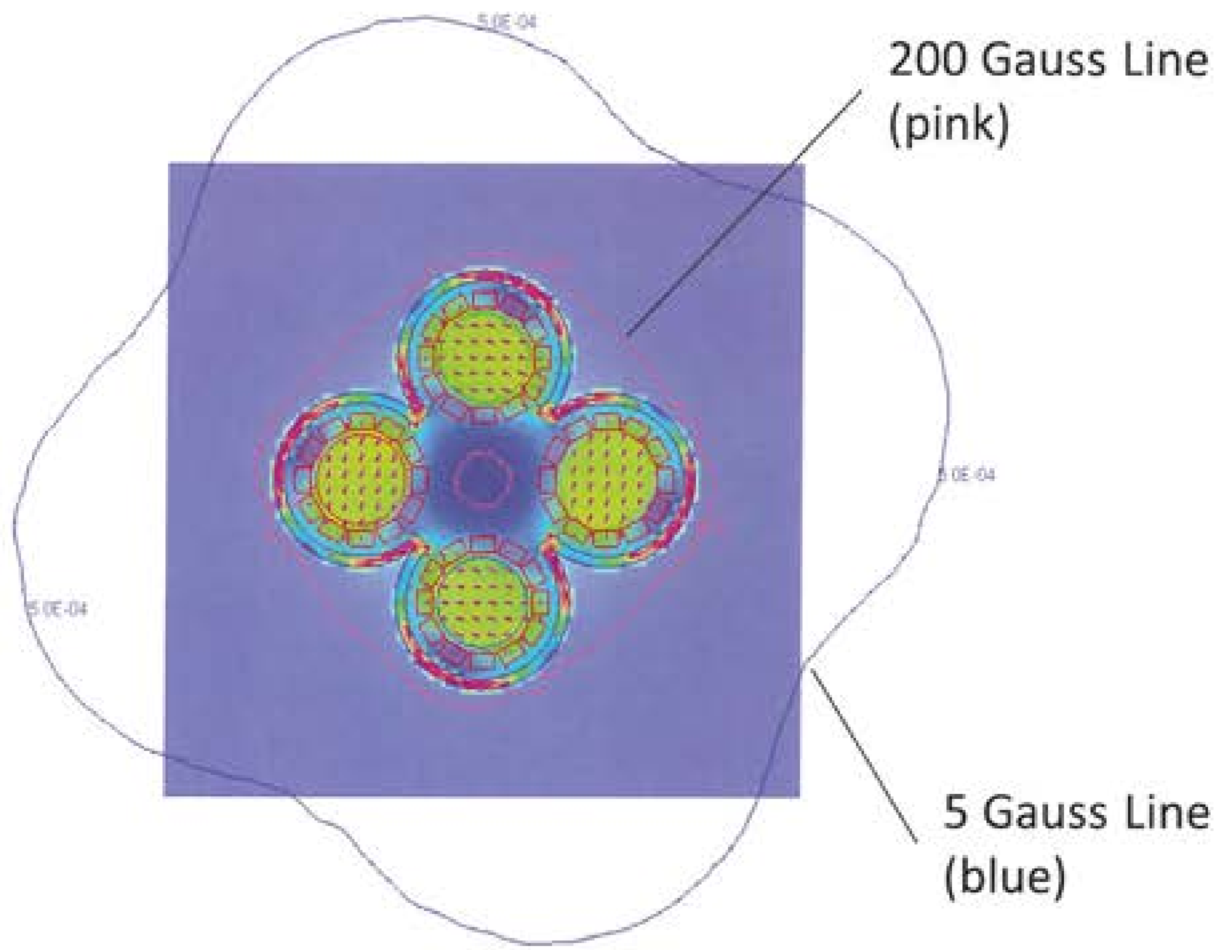
GUINA'S PM TOROIDAL TECHNOLOGY

# 4 Rotor - Power Scalability and Overall Dimensions




# 4 Rotor with Shielding





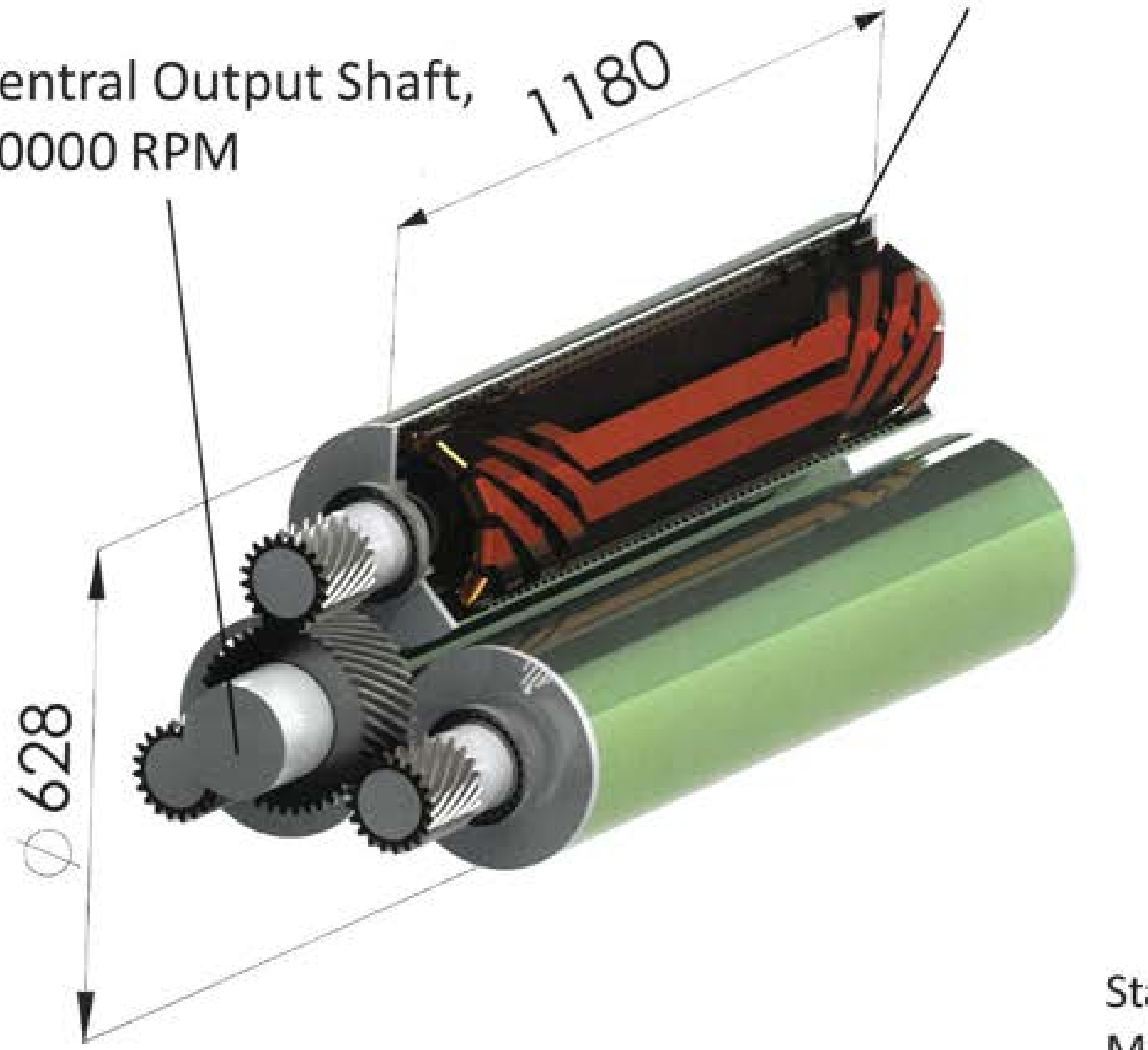

The addition of 20mm laminated steel shielding to the 4 Rotor Toroidal PM machine increases the power by an additional 16-17%. The steel laminations follow the outer contours of the device.

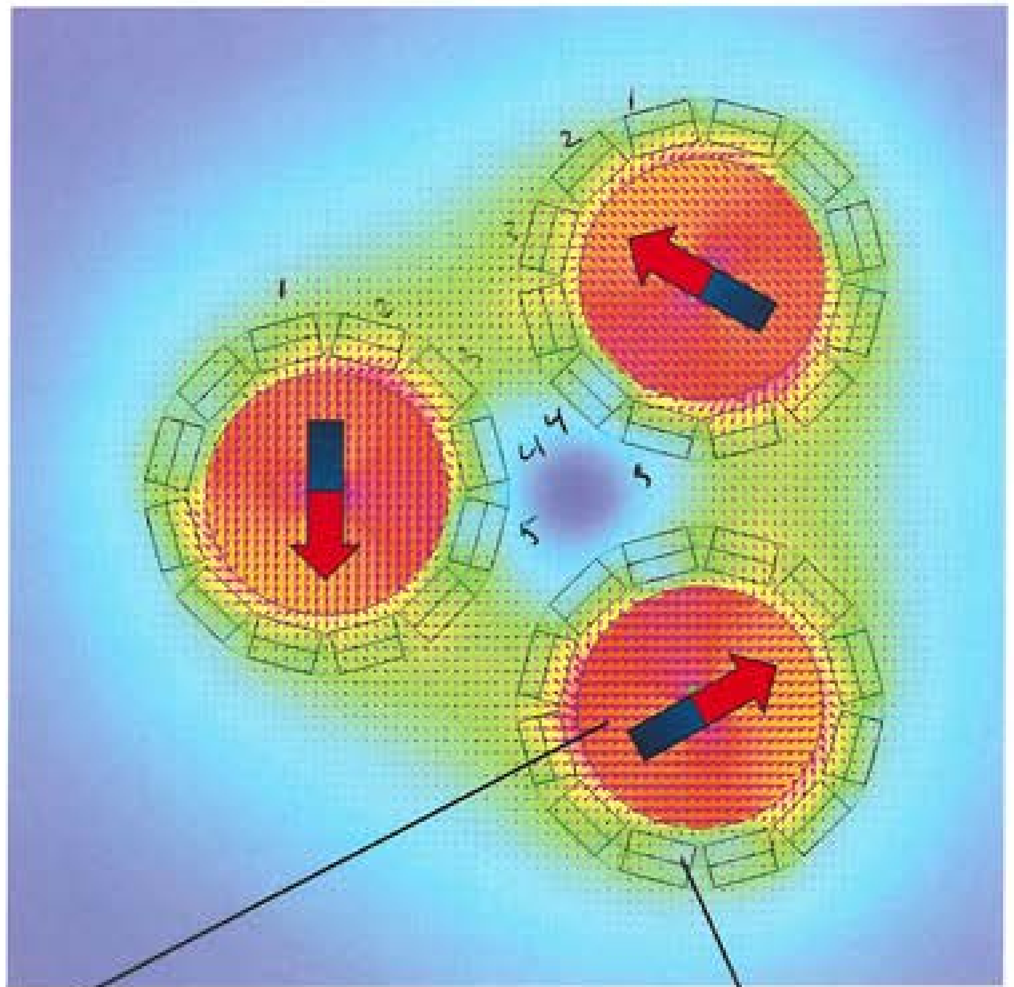
The laminated steel shielding further contains the stray field within the machine.

# Toroidal Permanent Magnet Motor/Generator
# 3 Rotor, 2:1 Gearbox, 22.8 MW High Speed

Rotor, 20000 RPM

Central Output Shaft,
10000 RPM



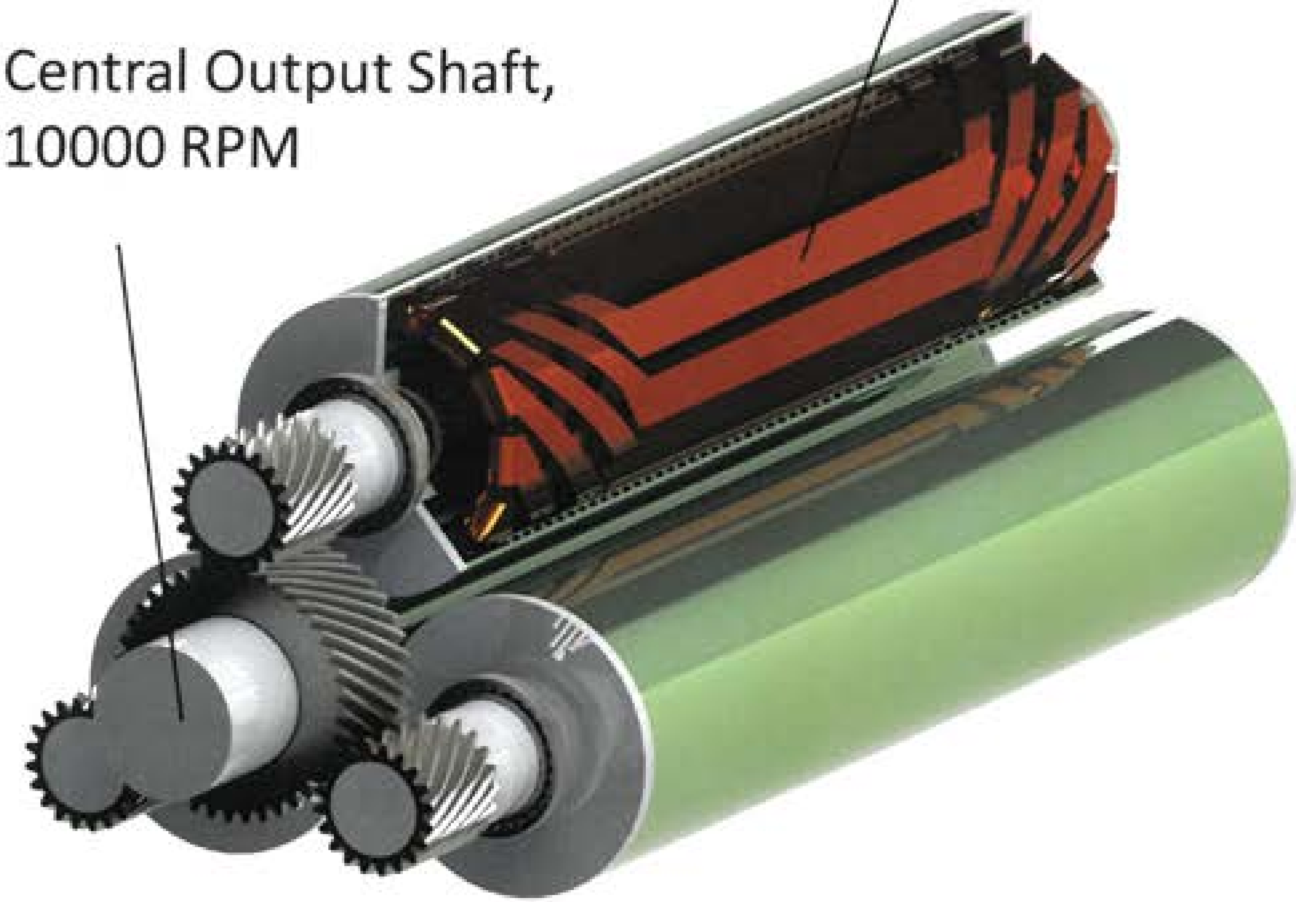
Stationary Permanent Magnet

Rotating Windings

# GUINA'S PM TOROIDAL TECHNOLOGY

## 3 Rotor - 2:1 Gearbox - 22.8 MW High Speed

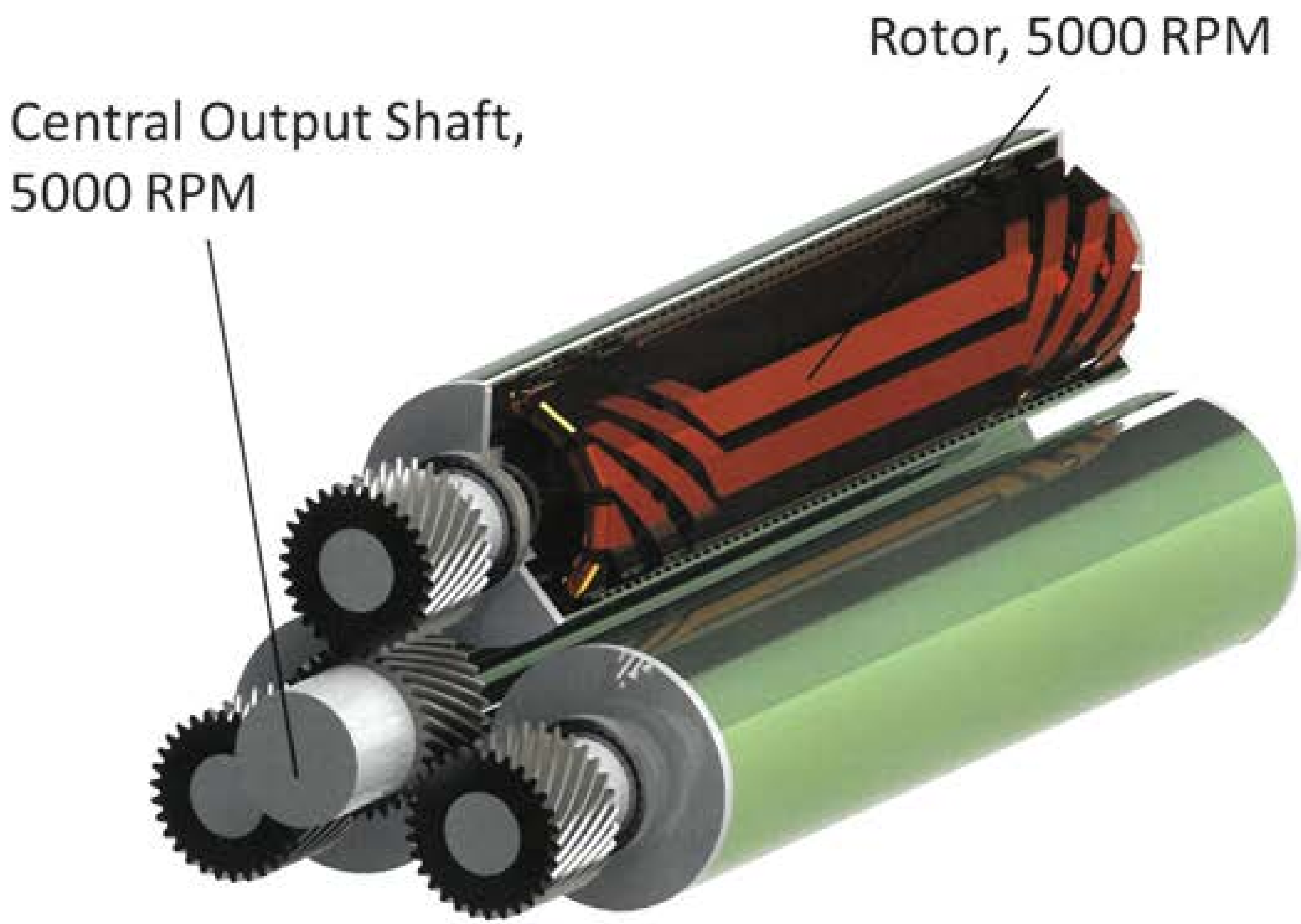
| | |
|---|---|
| Power (MW) | **22.8** |
| Rated Central Shaft Speed (RPM) | **10000** |
| No. of Rotor Assemblies | **3** |
| Rotor Current Density A/cm² | **1000** |
| Rated Rotor Shaft Speed (RPM) | **20000** |
| Rotor Diameter (mm) | **280** |
| No. of Independent Rotor Windings | **6** |
| Rotor Material | **Oxygen Free Copper Wire** |
| Rotor Wire Packing Factor | **0.7** |
| Rotor Winding Weight Estimate (kg) | **309** |
| Stator Material | **Neodymium N45SH** |
| Stator Diameter (mm) | **170** |
| Stator Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **308** |
| Cooling | **Pumped Liquid** |



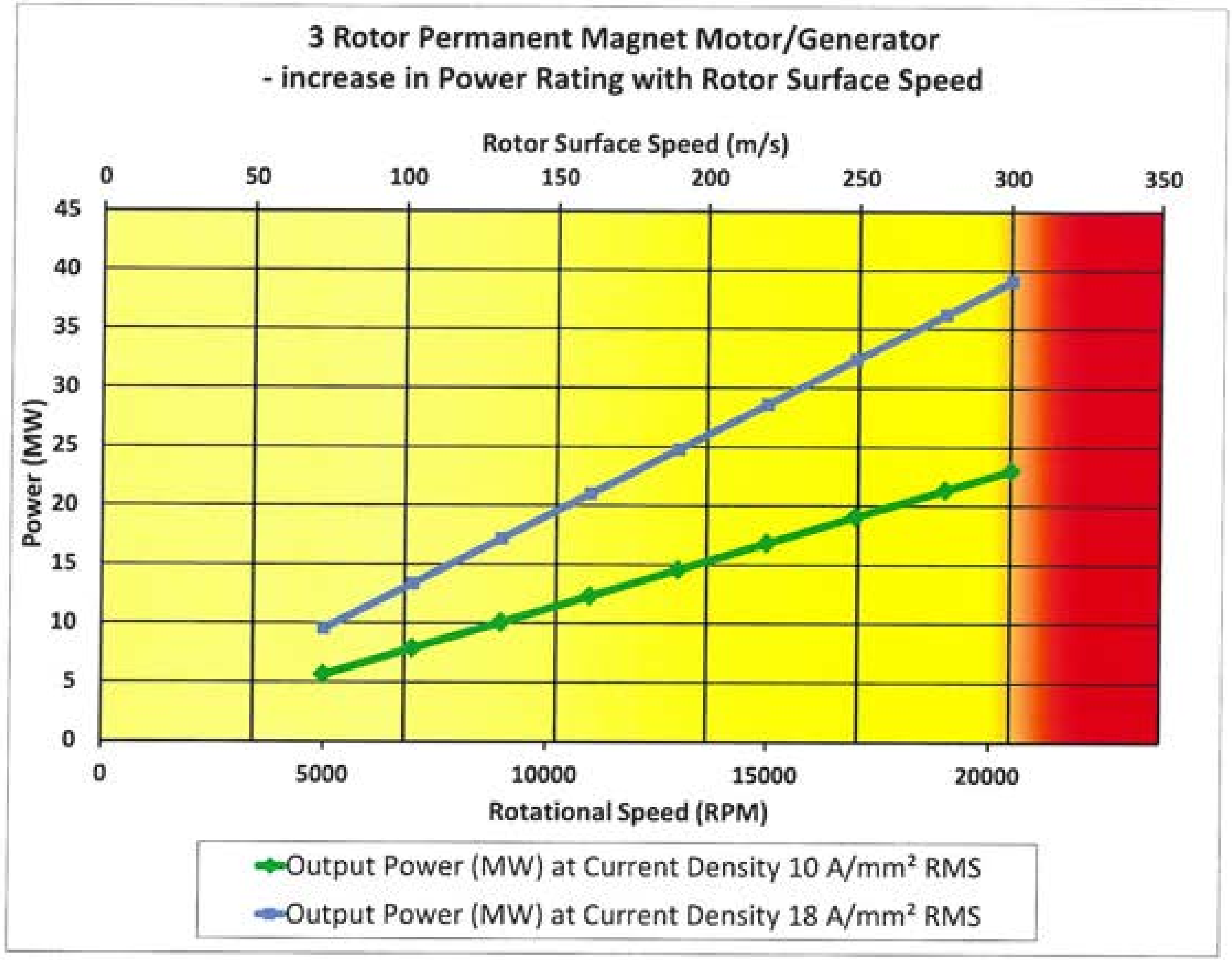
## GUINA'S PM TOROIDAL TECHNOLOGY

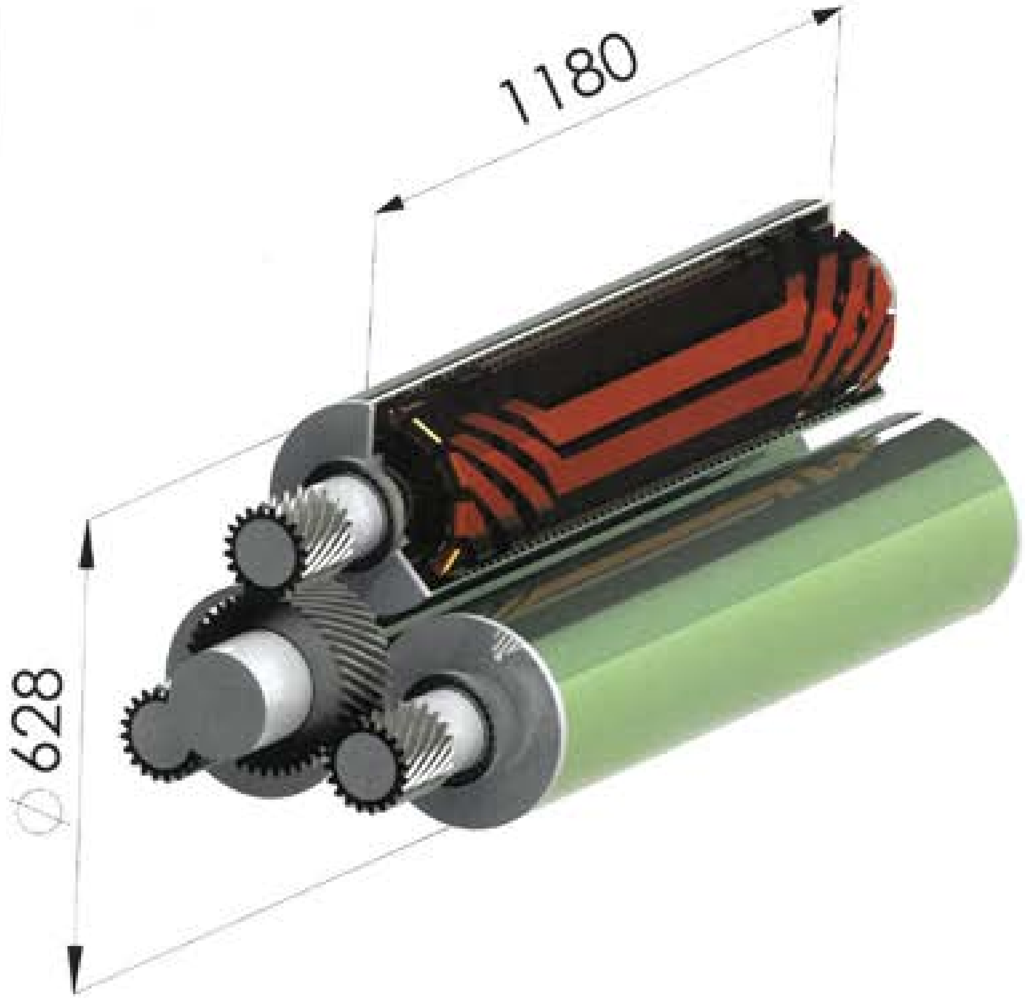
# 3 Rotor - 1:1 Gearbox - 5.7 MW High Speed

| | |
|---|---|
| Power (MW) | **5.7** |
| Rated Central Shaft Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **3** |
| Rotor Current Density A/cm² | **1000** |
| Rated Rotor Shaft Speed (RPM) | **5000** |
| Rotor Diameter (mm) | **280** |
| No. of Independent Rotor Windings | **6** |
| Rotor Material | **Oxygen Free Copper Wire** |
| Rotor Wire Packing Factor | **0.7** |
| Rotor Winding Weight Estimate (kg) | **309** |
| Stator Material | **Neodymium N45SH** |
| Stator Diameter (mm) | **170** |
| Stator Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **308** |
| Cooling | **Pumped Liquid** |



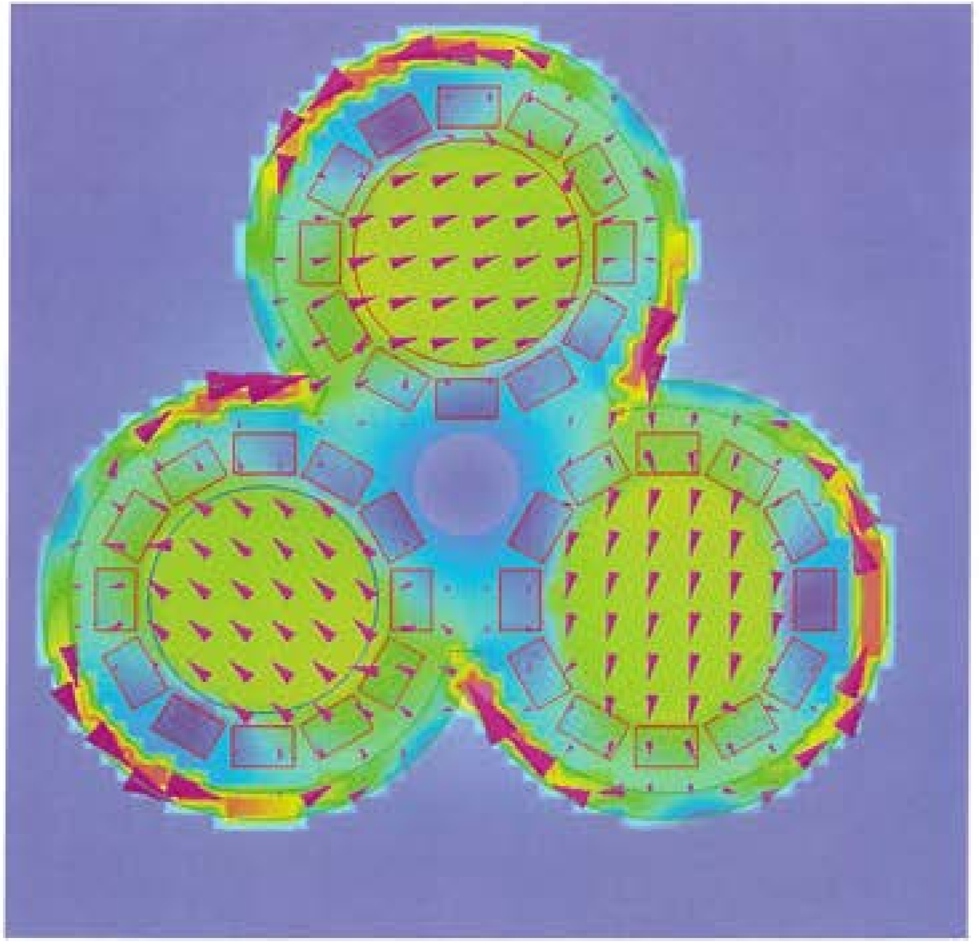
# 3 Rotor - Power Scalability and Overall Dimensions

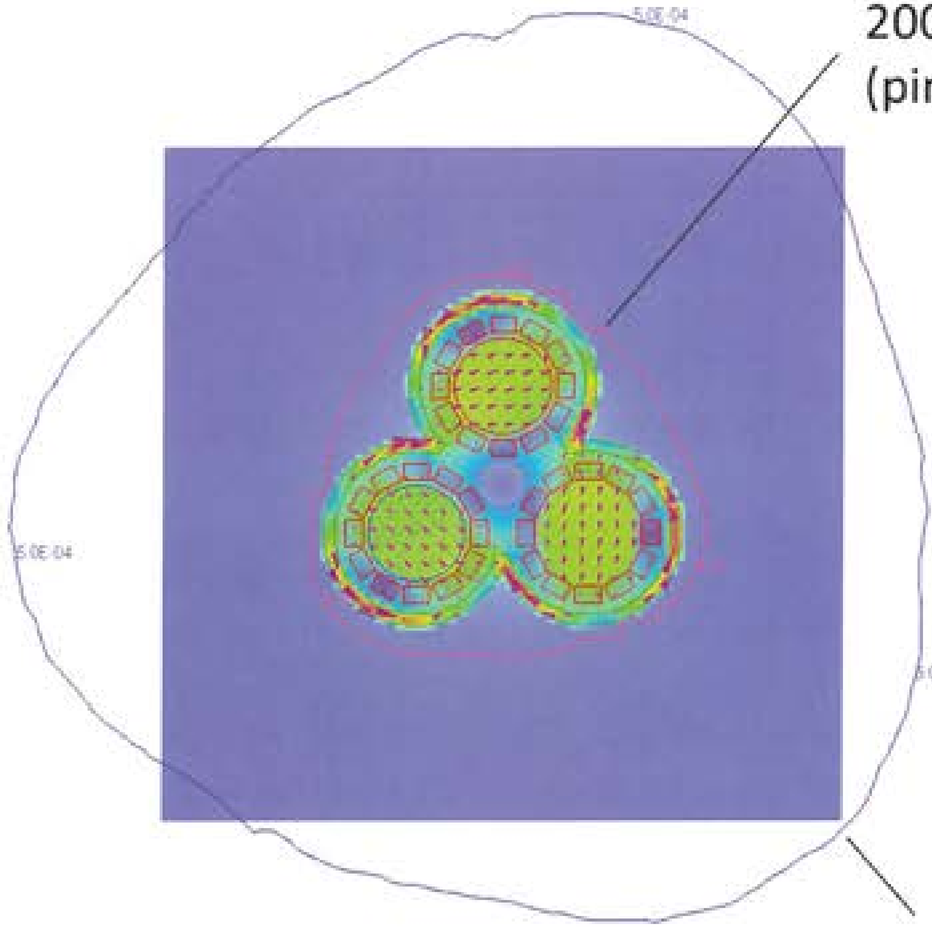


GUINA'S PM TOROIDAL TECHNOLOGY

# 3 Rotor with Shielding






The addition of 20mm laminated steel shielding to the 3 Rotor Toroidal PM machine increases the power by an additional 17-18%. The steel laminations follow the outer contours of the device.

The laminated steel shielding further contains the stray field within the machine.

# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

Our Brushless Permanent Magnet Cluster Technology uses rotating permanent magnets and stationary windings. The arrangement of the two pole cylindrical permanent magnets significantly reduces output torque ripple (below 1% for the cases presented) while also reducing the amount of steel shielding required by around 50%.

The technology shown has been extensively modelled and simulated using Vector Fields and Solidworks modelling software.

There are many possible variations in the arrangement of the permanent magnetic rotors and steel shielding.

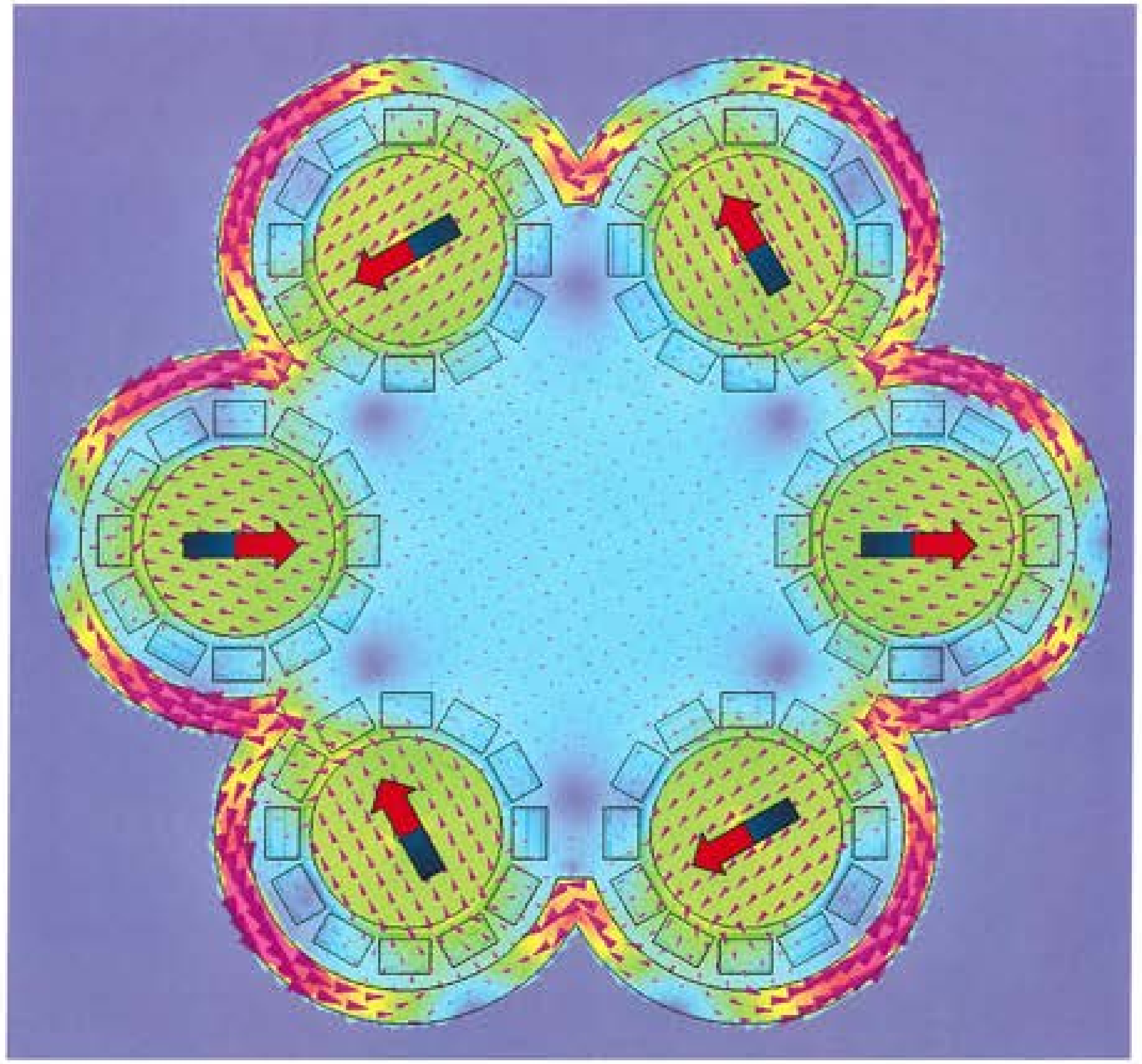
The quoted power levels of the devices presented are based on 10 A/mm$^2$ RMS sinusoidal AC current in the windings. The devices can be constructed with 3 or more phases. The steel shielding used includes a lamination fill factor of 95%.

Our Brushless Permanent Magnet Cluster Technology features permanent magnets that rotate inside a set of independent windings which remain stationary.

The following pages show the arrangement of successive magnetic poles within the cluster assembly. These inter-pole relationships produce low torque ripple while requiring a minimum of shielding.

# Key Technology Advantages

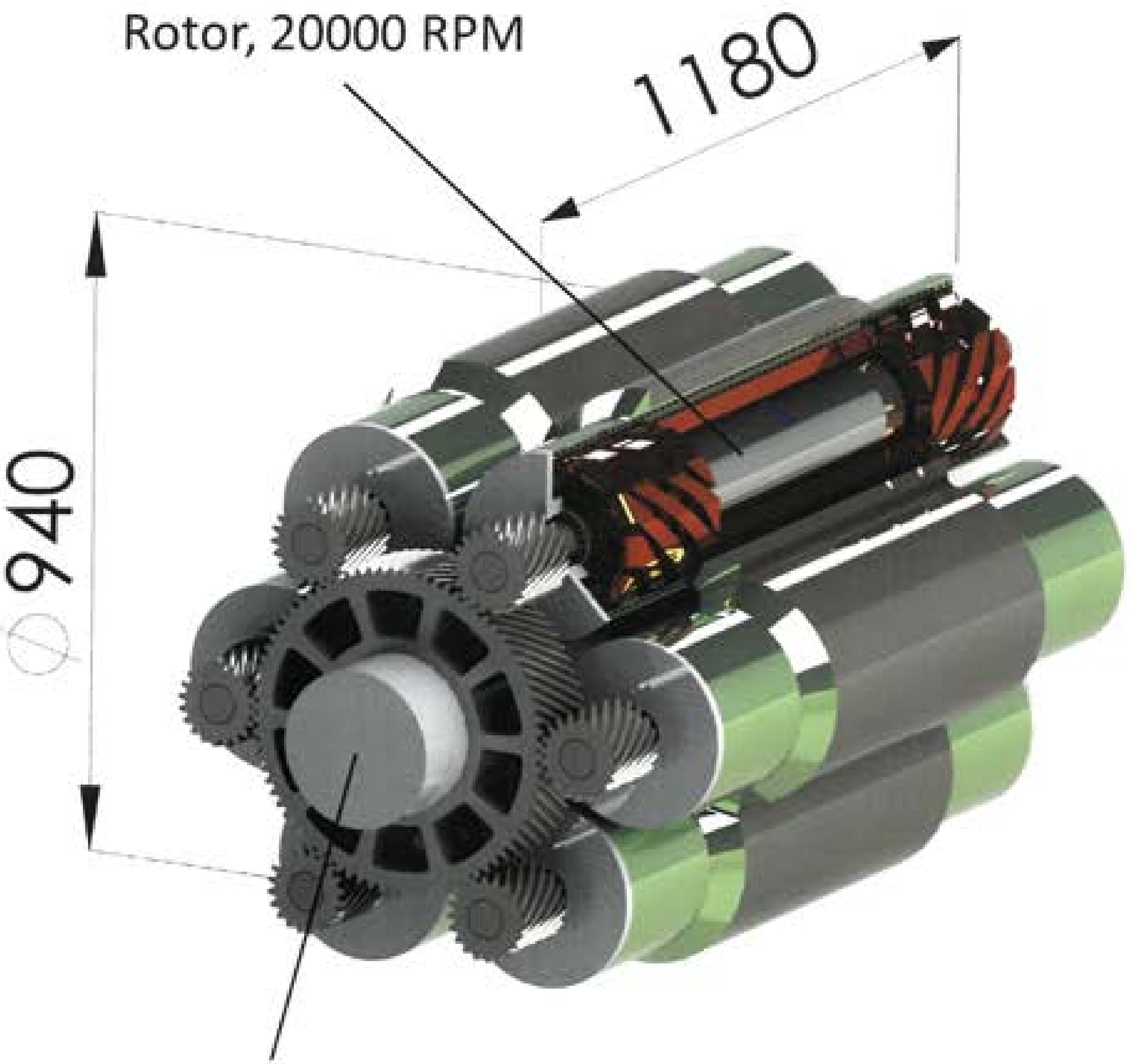
- Brushless
- Low torque ripple (<1%) due to phase cancelling magnet orientations
- Configurable number of independent rotor windings
- Configurable number of rotor assemblies. More assemblies results in improved field containment.
- High power to weight ratios
- Significantly less shielding steel required in comparison with the Brushless PM Technology

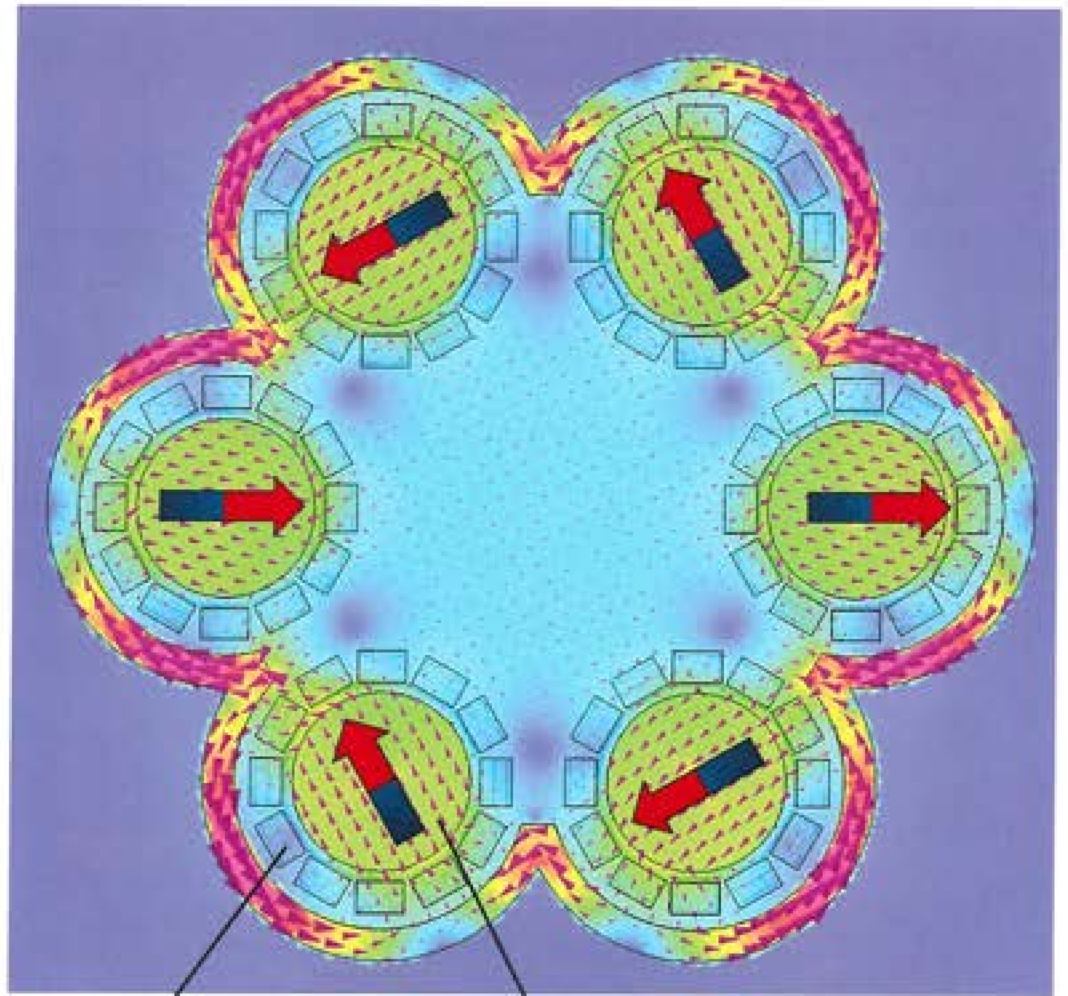


# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

GUINA ENERGY GROUP

## 6 Rotor – 47.6 MW High Speed



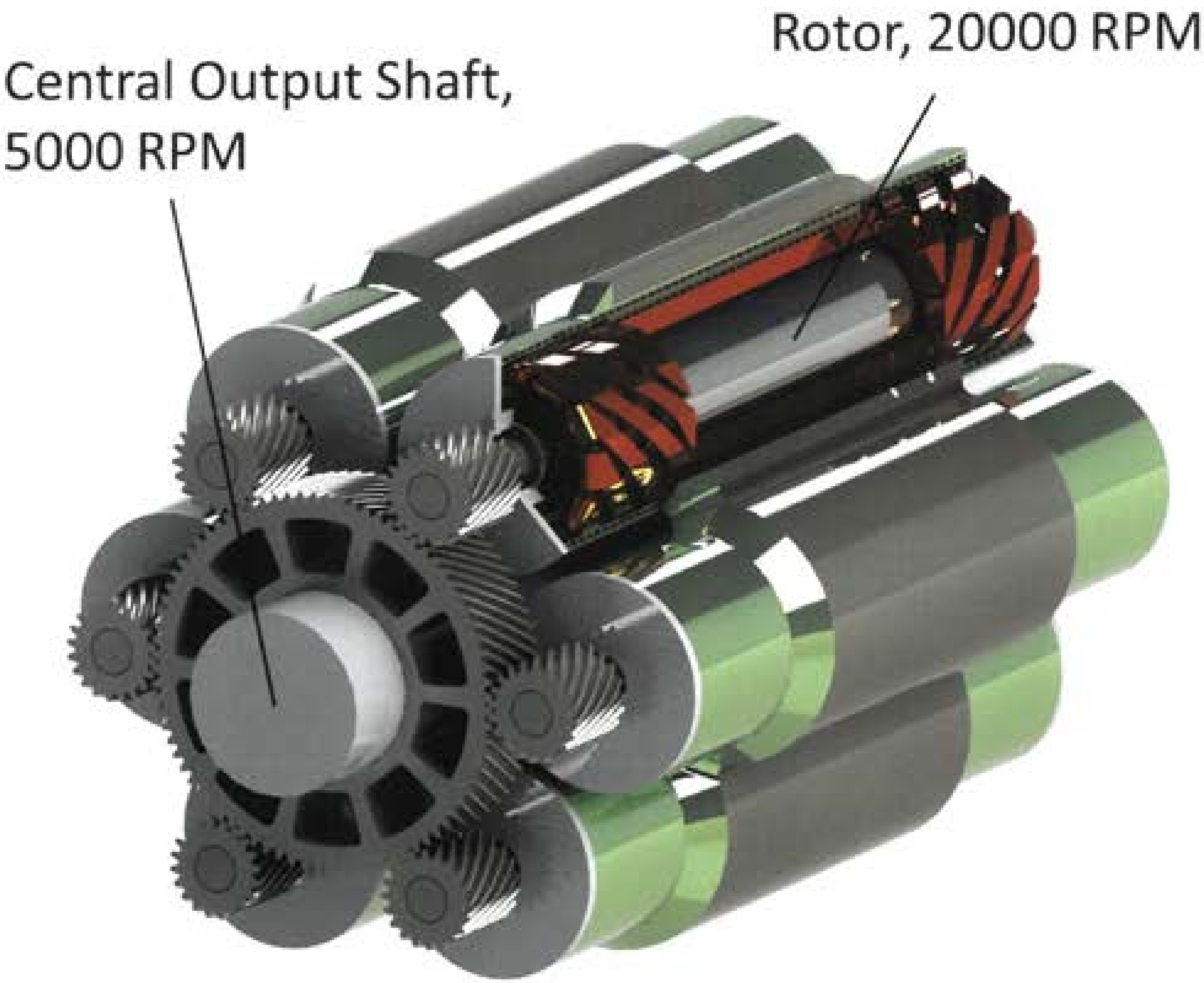

Arrows indicate relative direction of magnetisation

# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

GUINA ENERGY GROUP

## 6 Rotor - 4:1 Gearbox - 47.6 MW High Speed

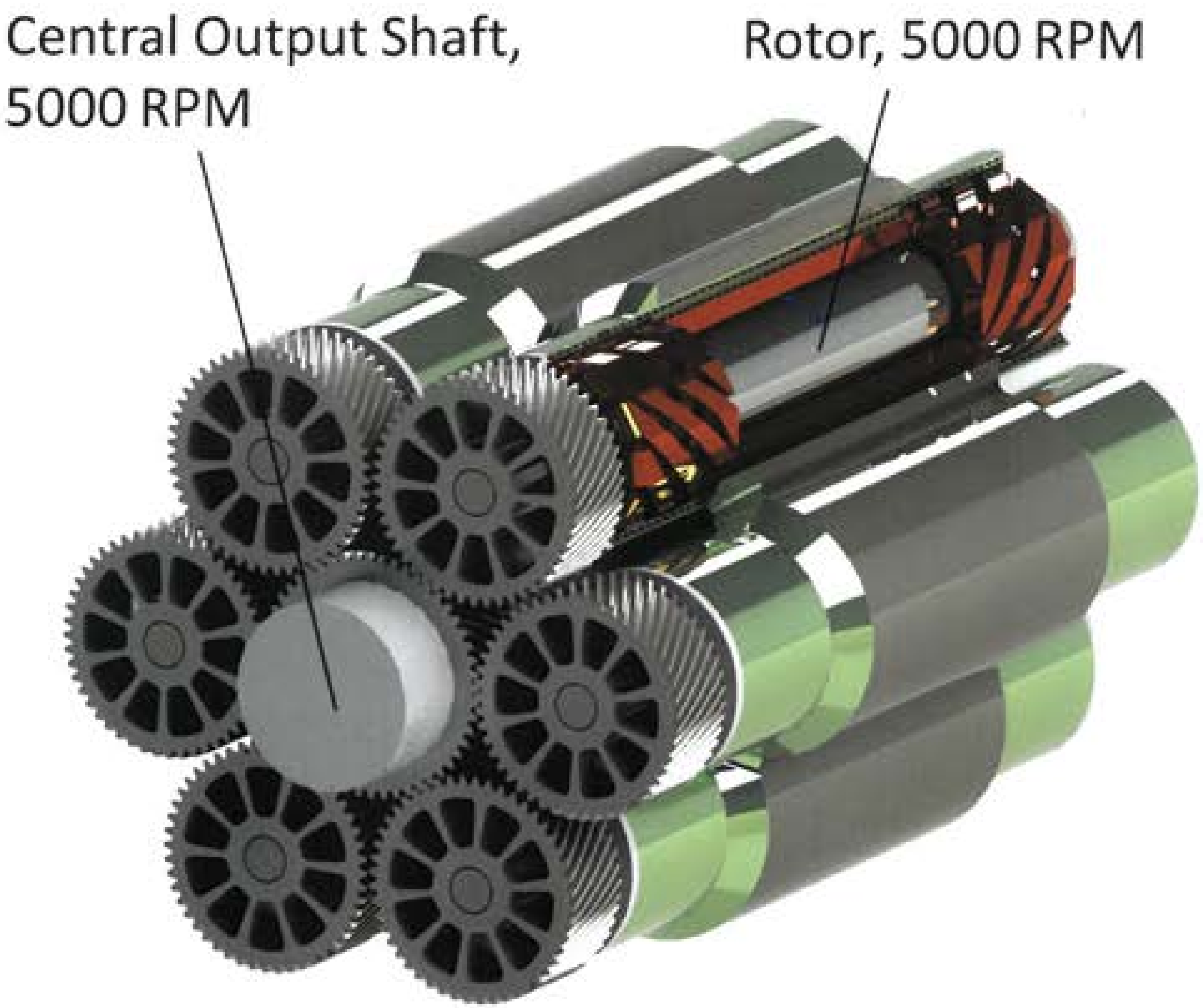
| | |
|---|---|
| Power (MW) | **47.6** |
| Rated Speed (RPM) | **20000** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **80.9** |
| No. of Rotor Assemblies | **6** |
| Stator Current Density ($A/cm^2$ RMS) | **1000** |
| Stator Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **619** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **618** |
| Steel Shield Weight (kg) | **451** |
| Cooling | **Pumped Liquid** |



# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

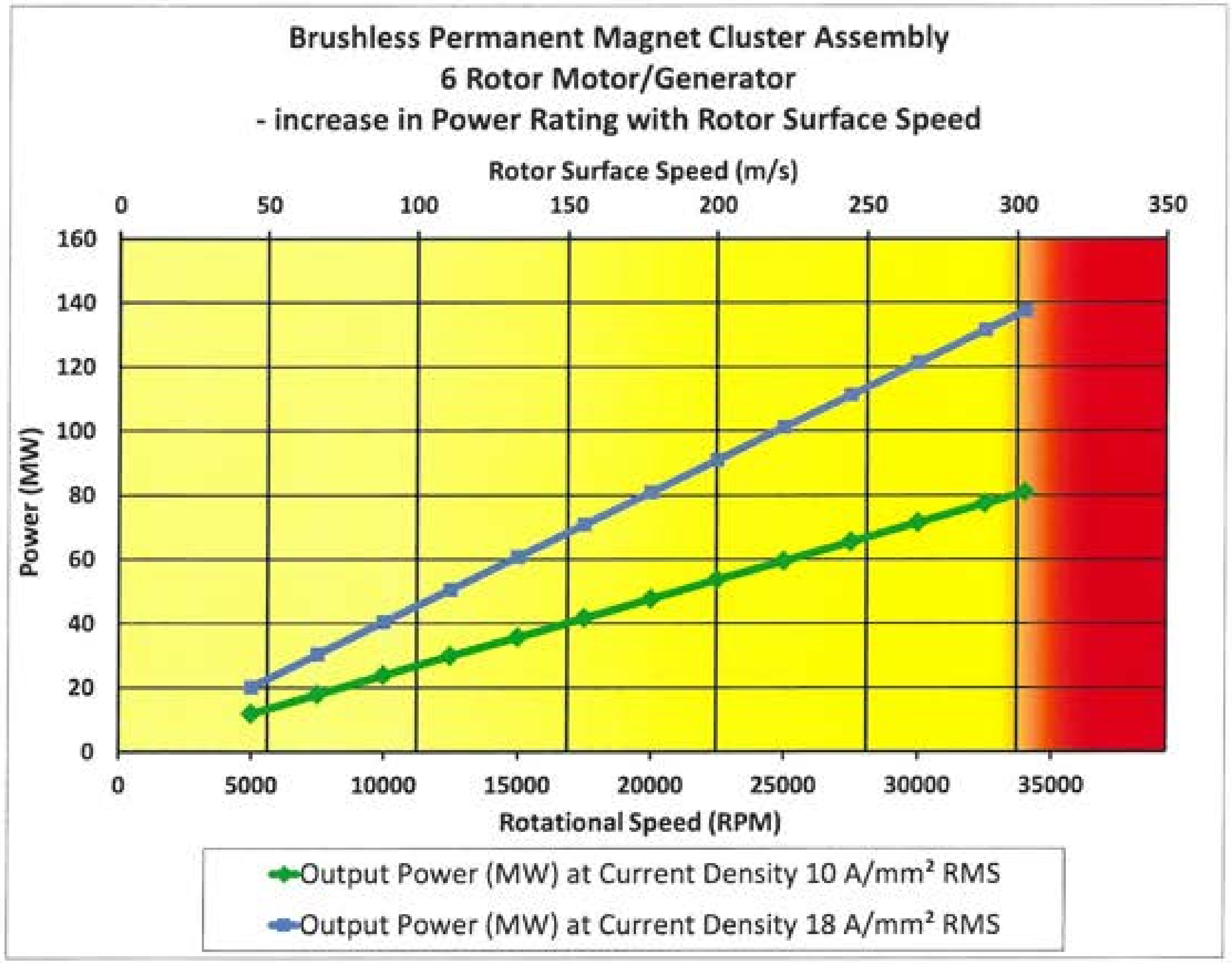
## 6 Rotor - 1:1 Gearbox - 11.9 MW High Speed

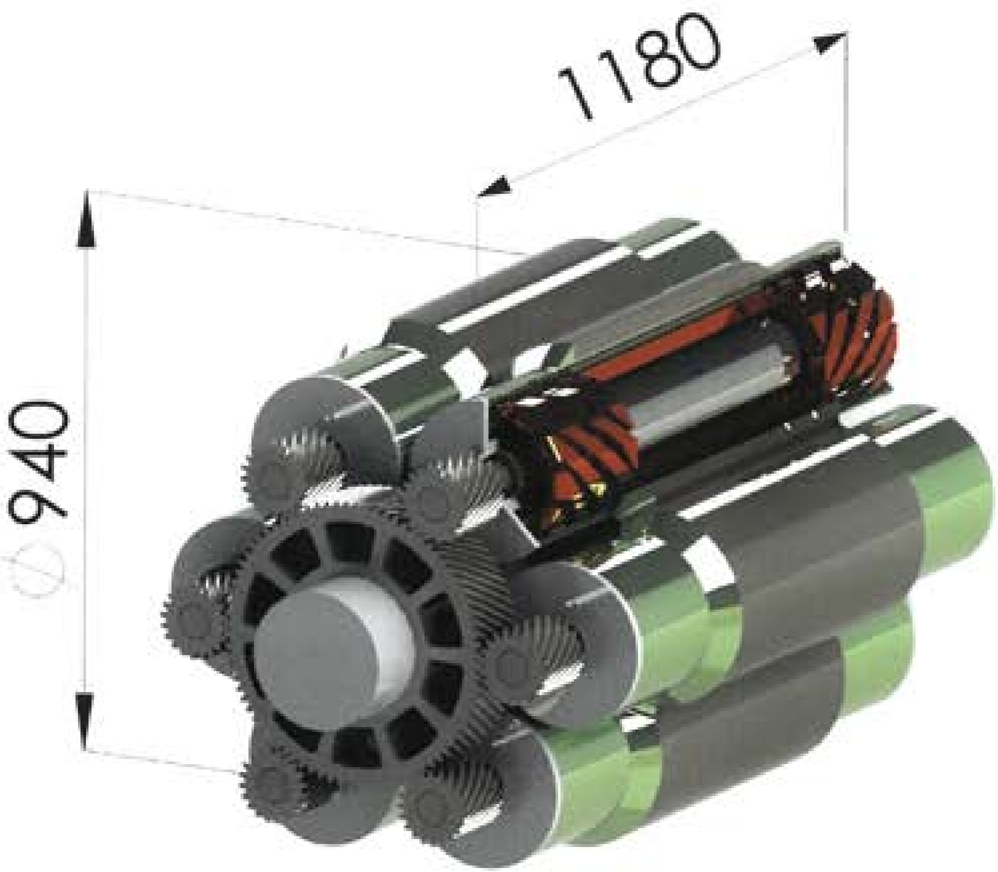
| | |
|---|---|
| Power (MW) | **11.9** |
| Rated Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **6** |
| Stator Current Density (A/cm² RMS) | **1000** |
| Stator Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **619** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **618** |
| Steel Shield Weight (kg) | **451** |
| Cooling | **Pumped Liquid** |



# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

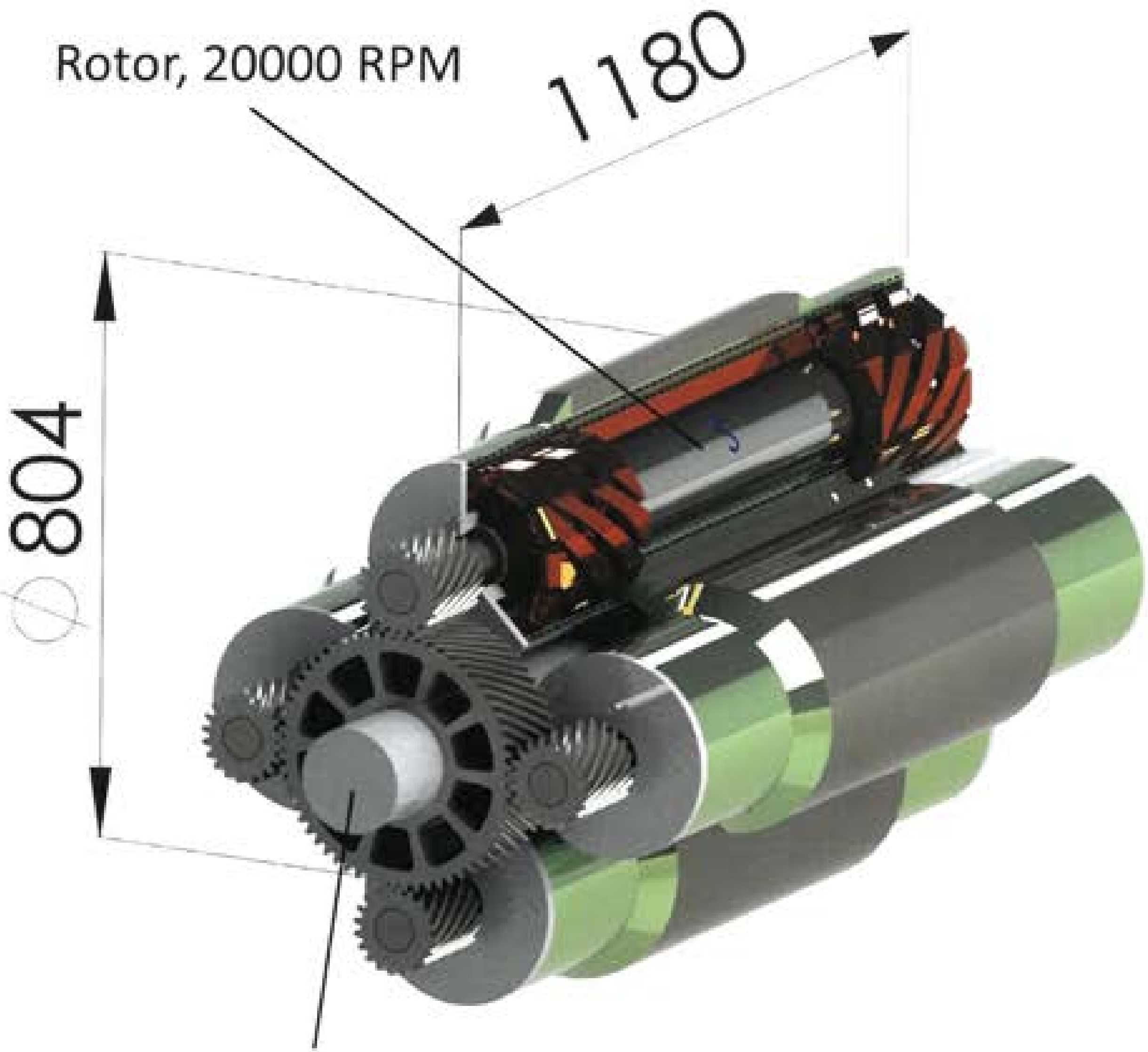
## 6 Rotor - Power Scalability and Overall Dimensions

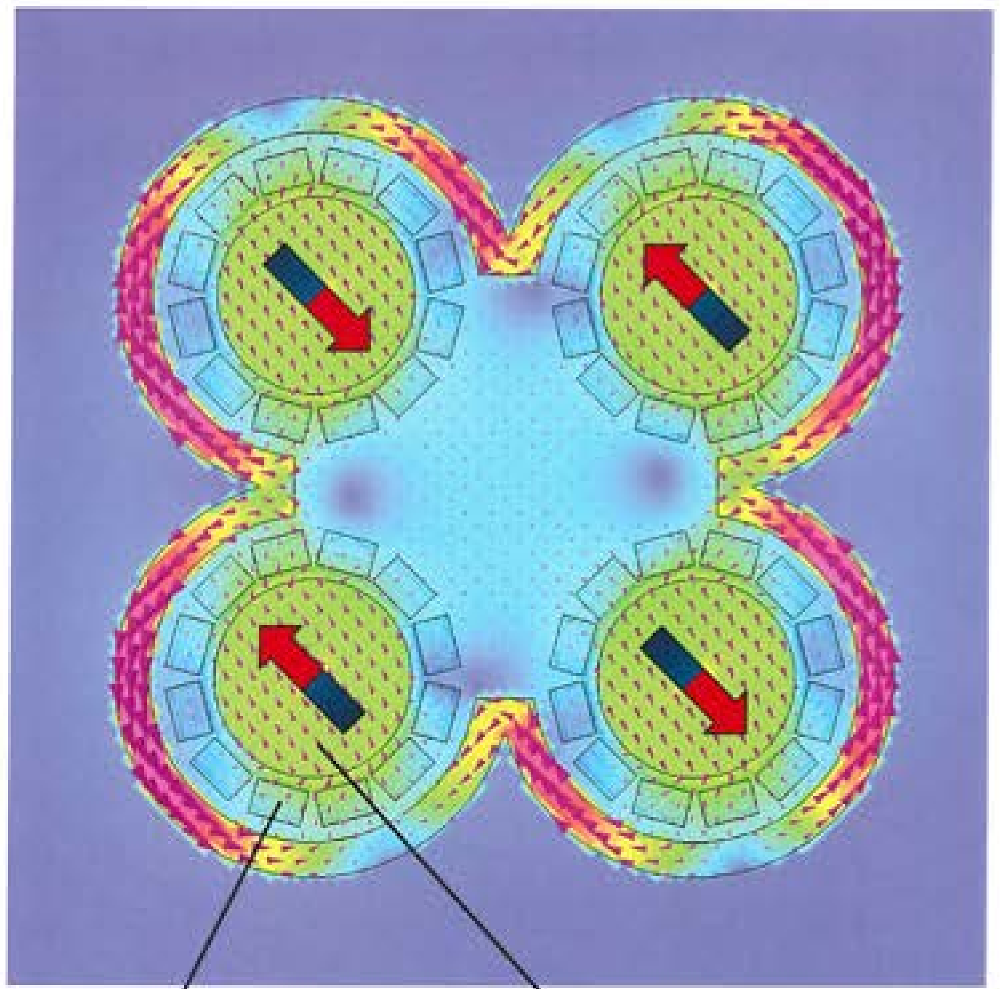


# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

## 4 Rotor – 33.2 MW High Speed



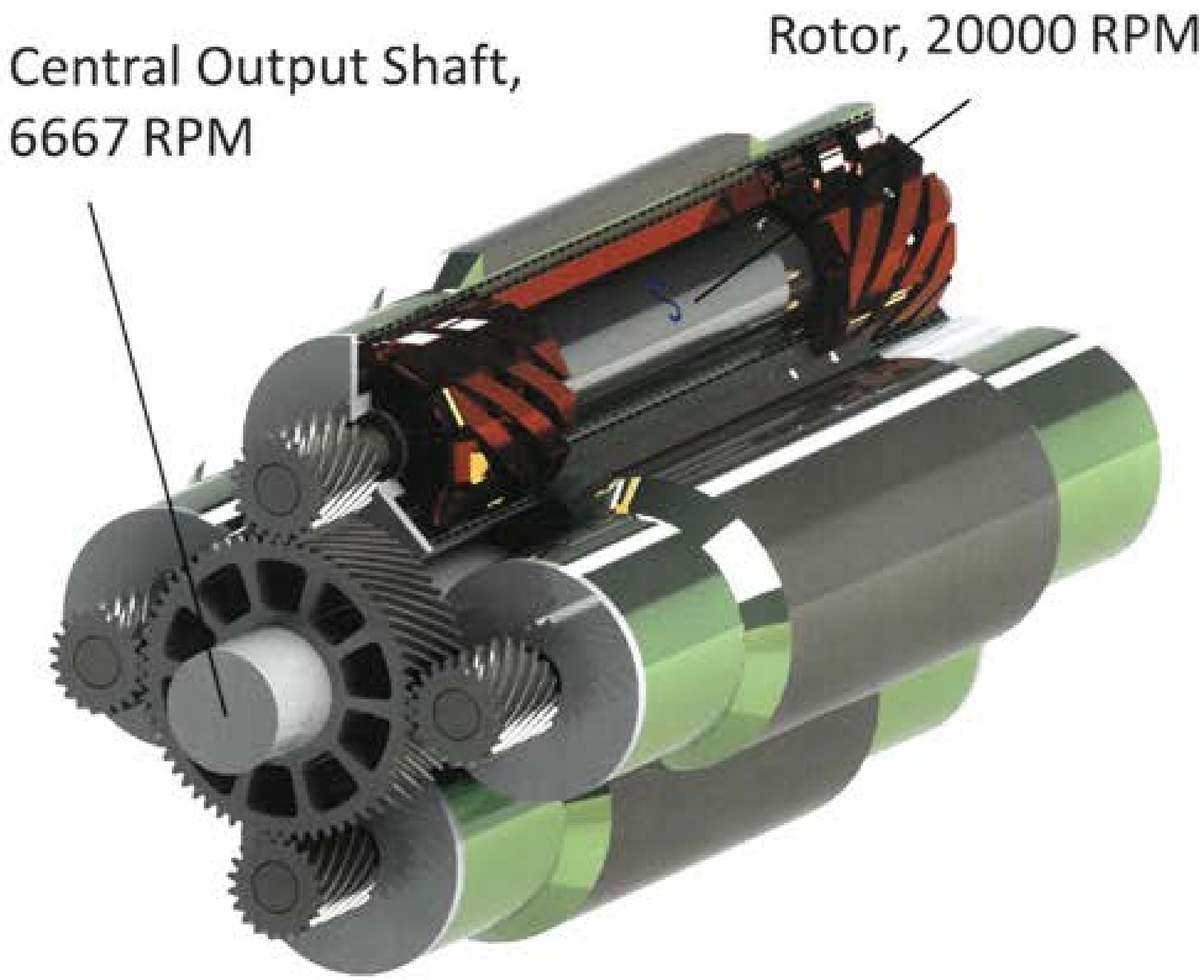




Arrows indicate relative direction of magnetisation

# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

## 4 Rotor - 3:1 Gearbox - 33.2 MW High Speed

| | |
|---|---|
| Power (MW) | **33.2** |
| Rated Speed (RPM) | **20000** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **56.4** |
| No. of Rotor Assemblies | **4** |
| Stator Current Density (A/cm$^2$ RMS) | **1000** |
| Stator Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **413** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **412** |
| Steel Shield Weight (kg) | **381** |
| Cooling | **Pumped Liquid** |

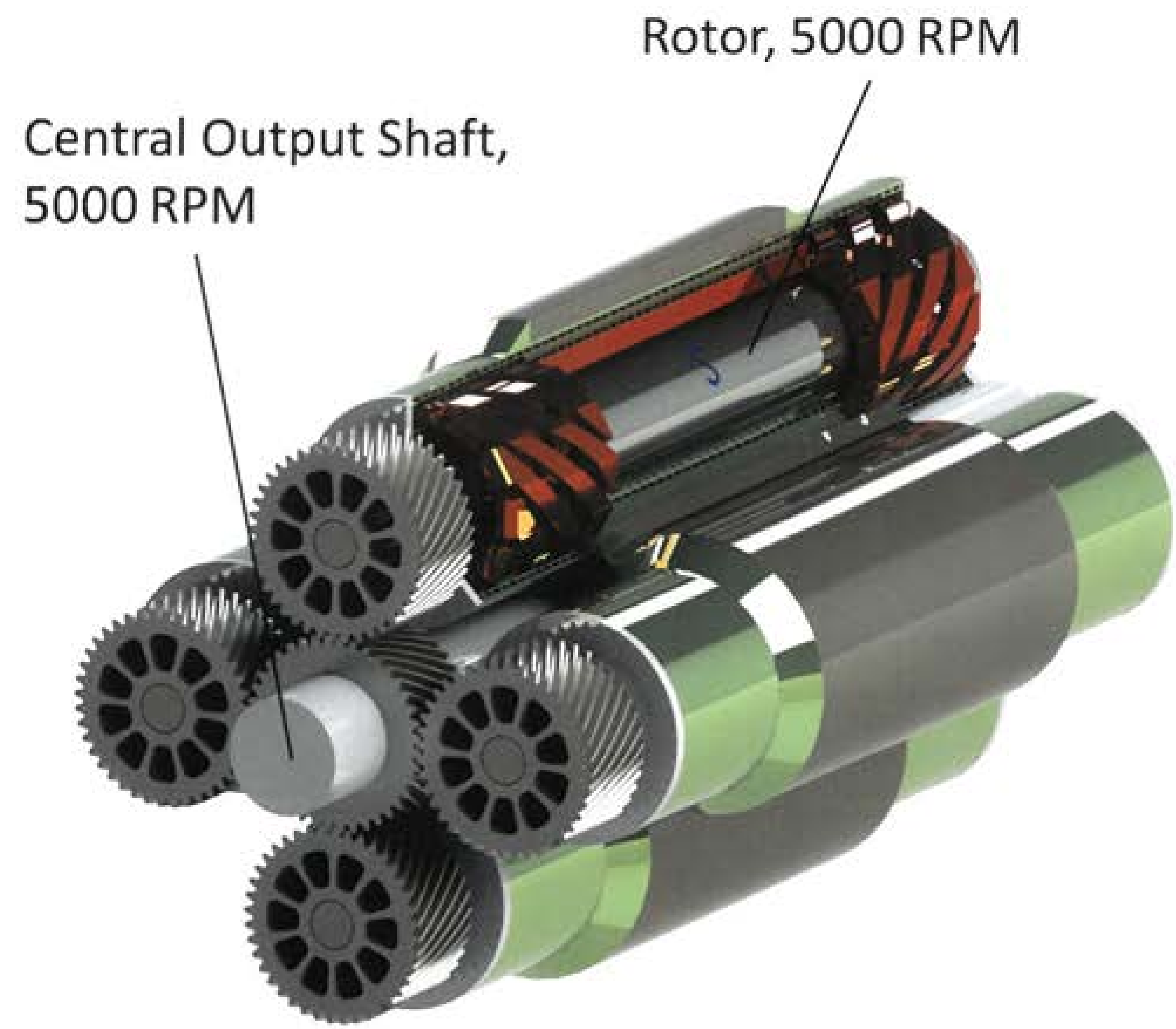


# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

GUINA ENERGY GROUP

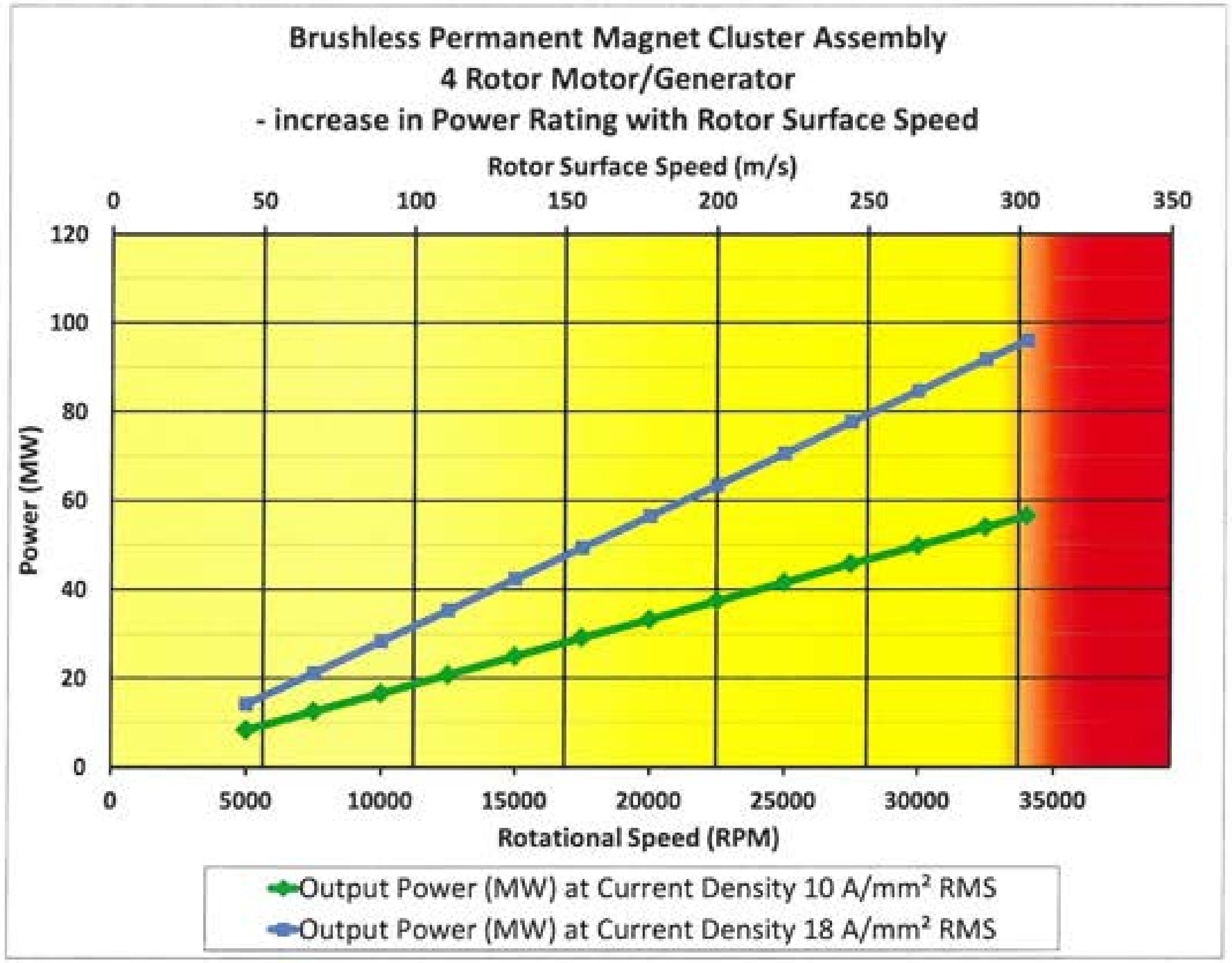
## 4 Rotor - 1:1 Gearbox - 8.3 MW High Speed

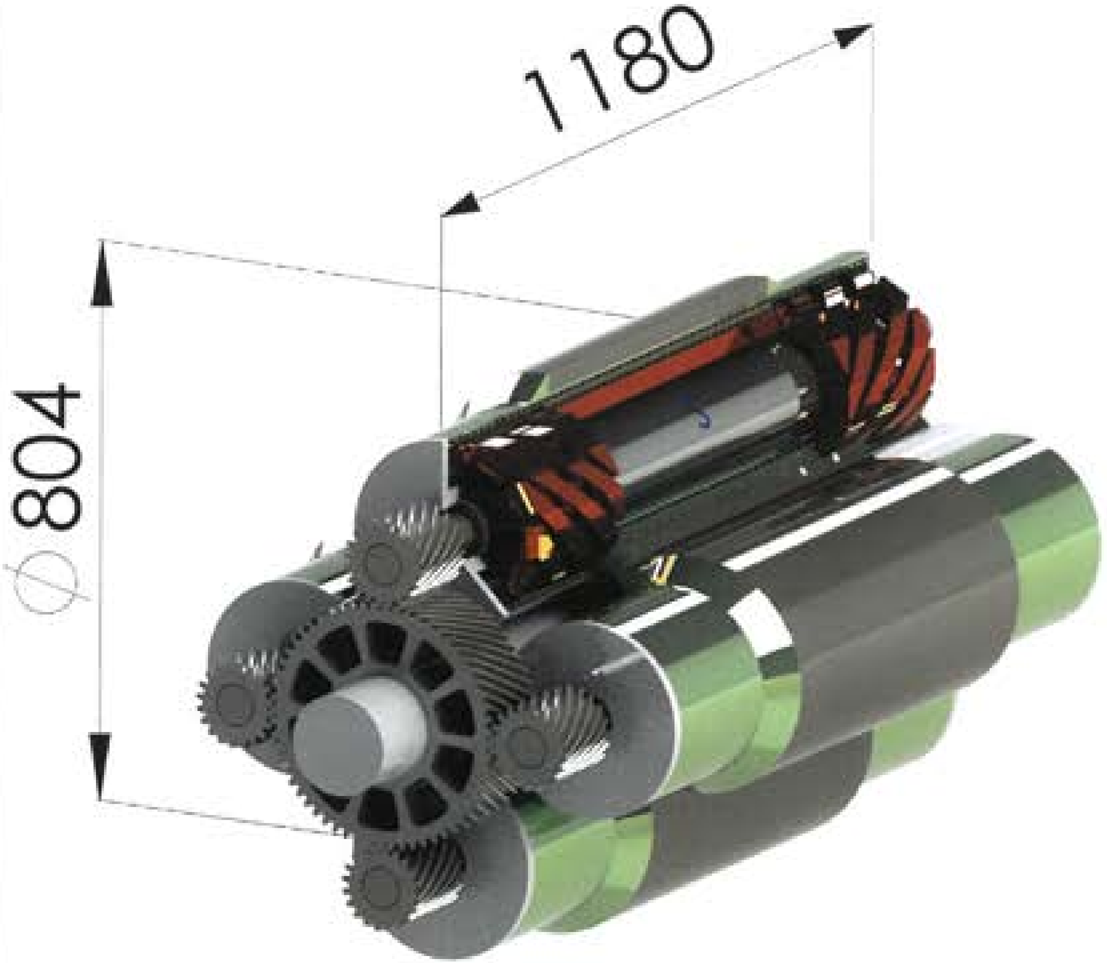
| | |
|---|---|
| Power (MW) | **8.3** |
| Rated Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **4** |
| Stator Current Density ($A/cm^2$ RMS) | **1000** |
| Stator Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **413** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **412** |
| Steel Shield Weight (kg) | **381** |
| Cooling | **Pumped Liquid** |



# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

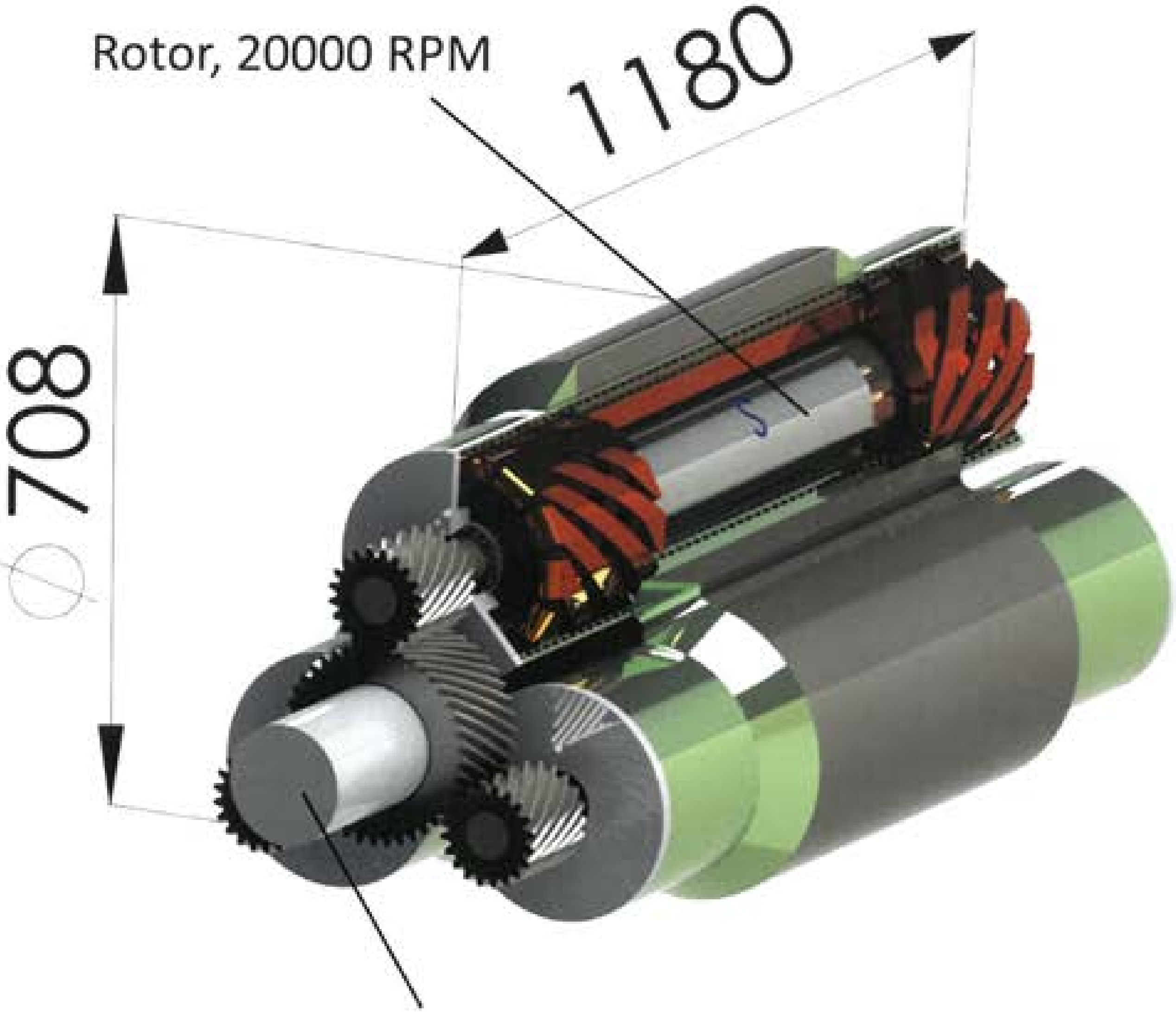
## 4 Rotor - Power Scalability and Overall Dimensions

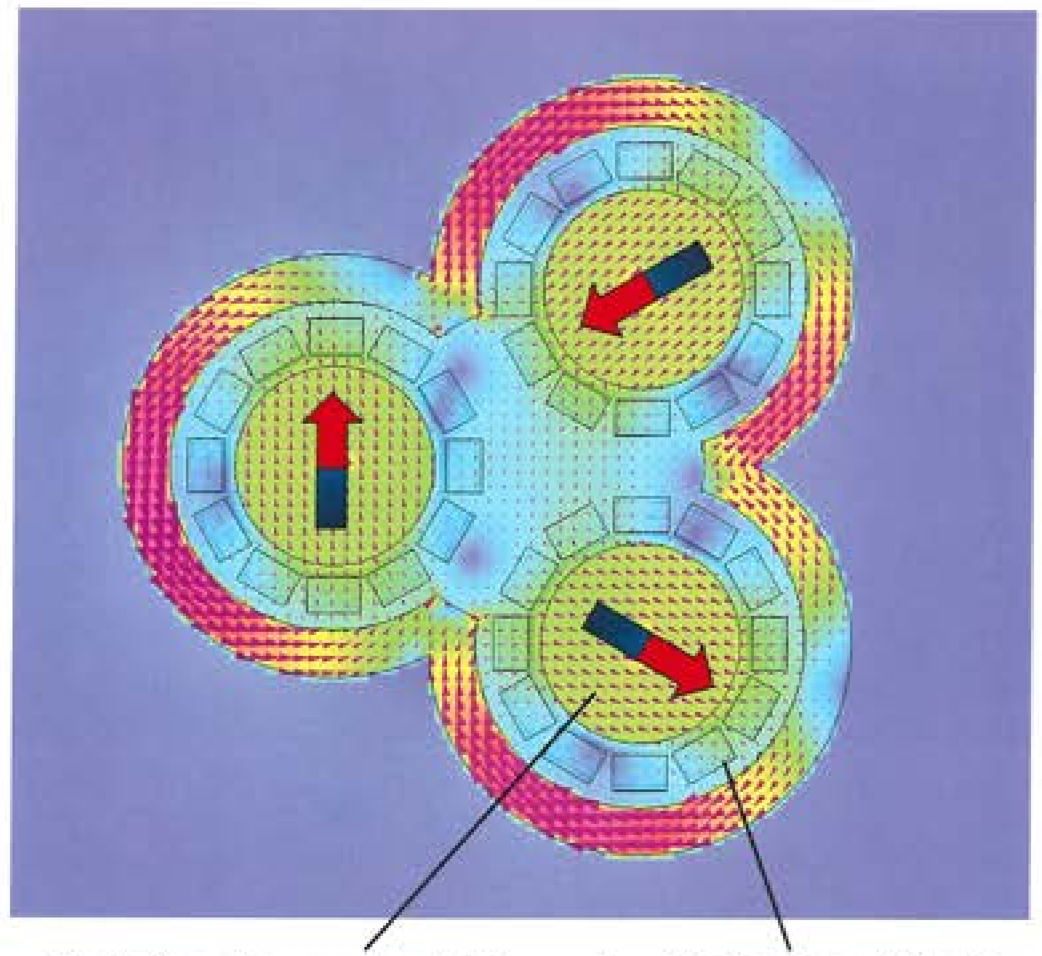


# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

## 3 Rotor – 26.8 MW High Speed



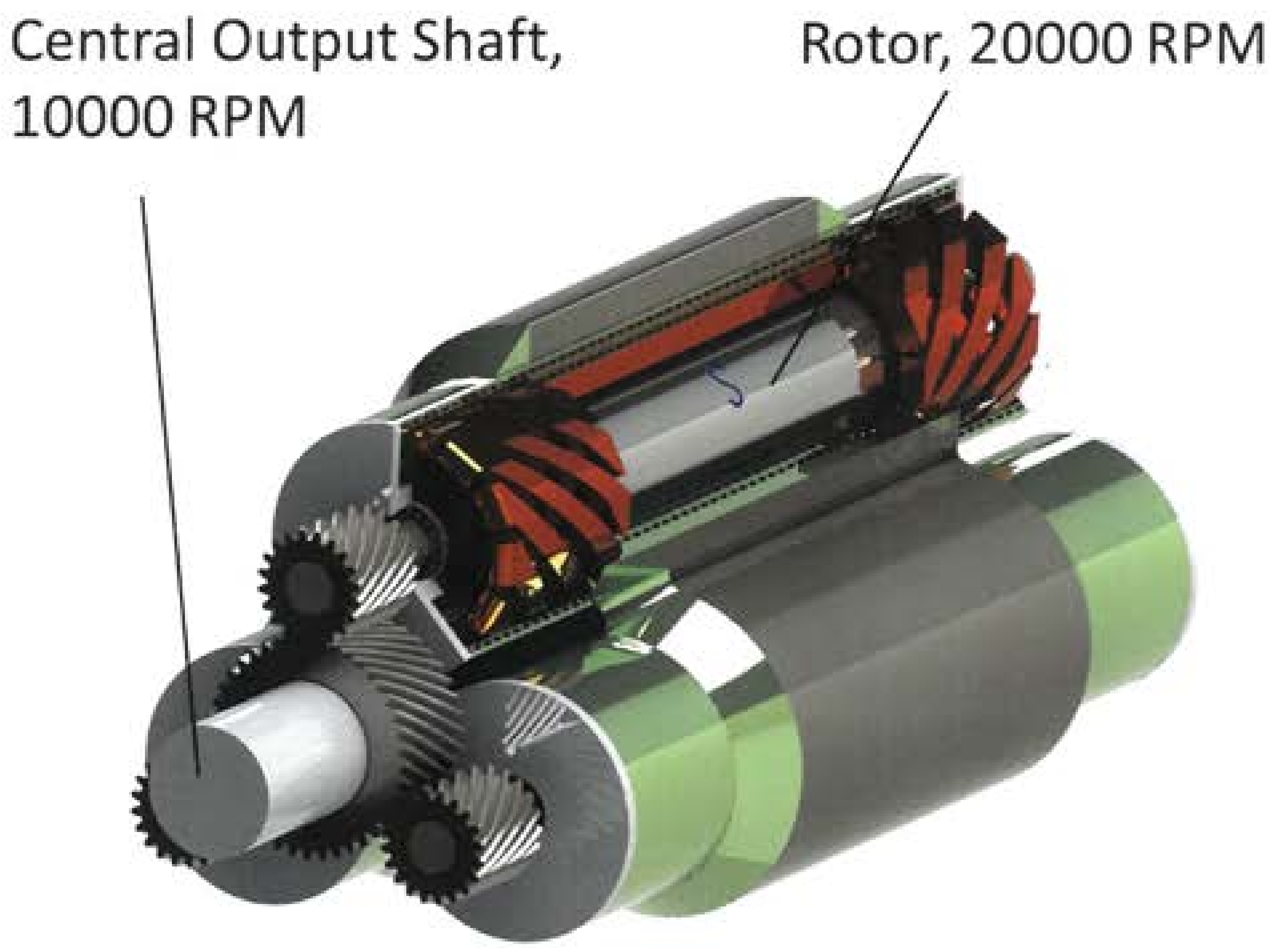
Rotating Permanent Magnet Stationary Windings

Arrows indicate relative direction of magnetisation

# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

## 3 Rotor - 2:1 Gearbox - 26.8 MW High Speed

| | |
|---|---|
| Power (MW) | **26.8** |
| Rated Speed (RPM) | **20000** |
| Max. RPM @ 300m/s Rotor Surface Speed | **34000** |
| Power @ Max RPM. (MW) | **35.6** |
| No. of Rotor Assemblies | **3** |
| Stator Current Density (A/cm² RMS) | **1000** |
| Stator Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **309** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **180** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **308** |
| Steel Shield Weight (kg) | **387** |
| Cooling | **Pumped Liquid** |

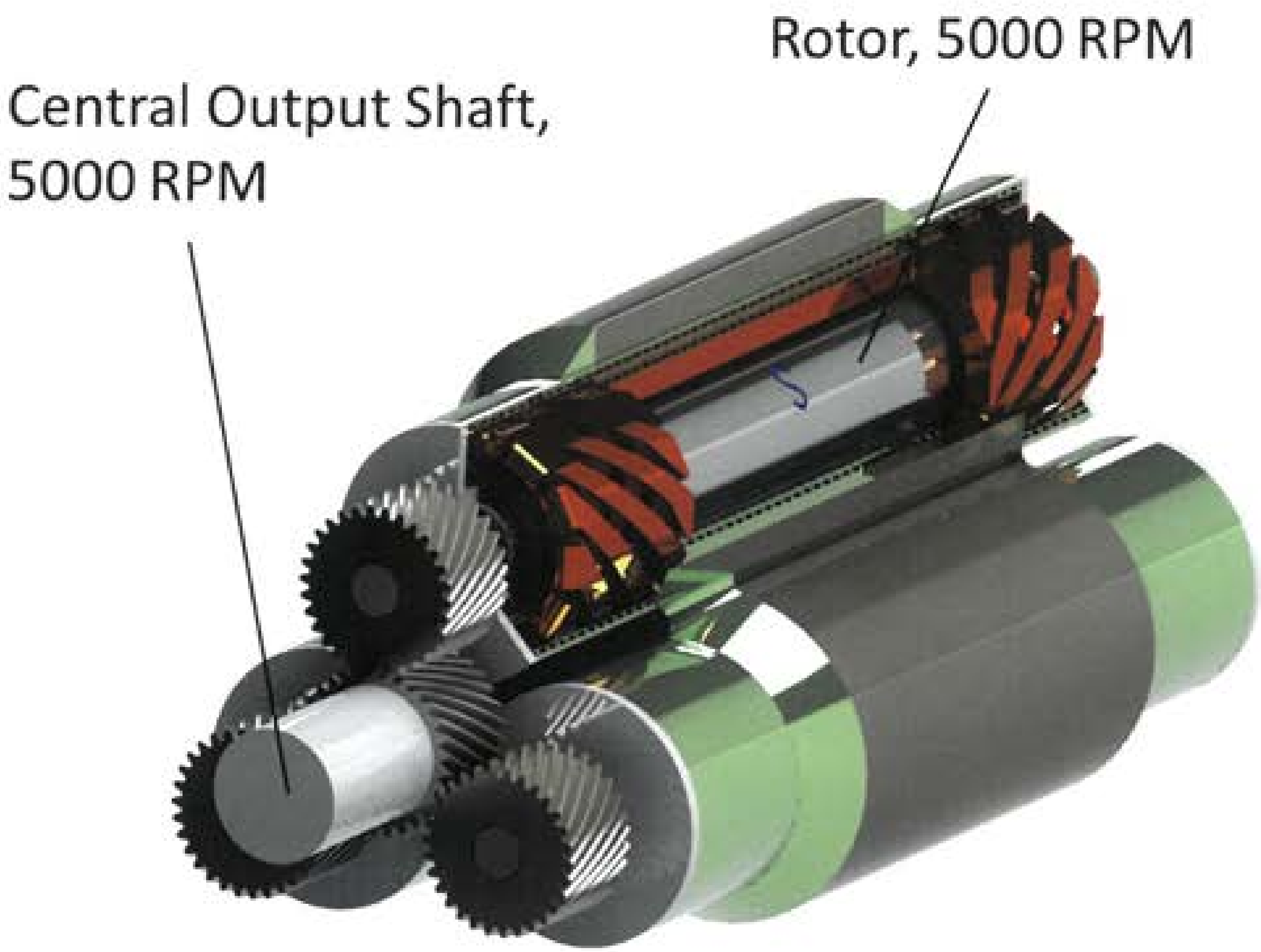


# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

GUINA ENERGY GROUP

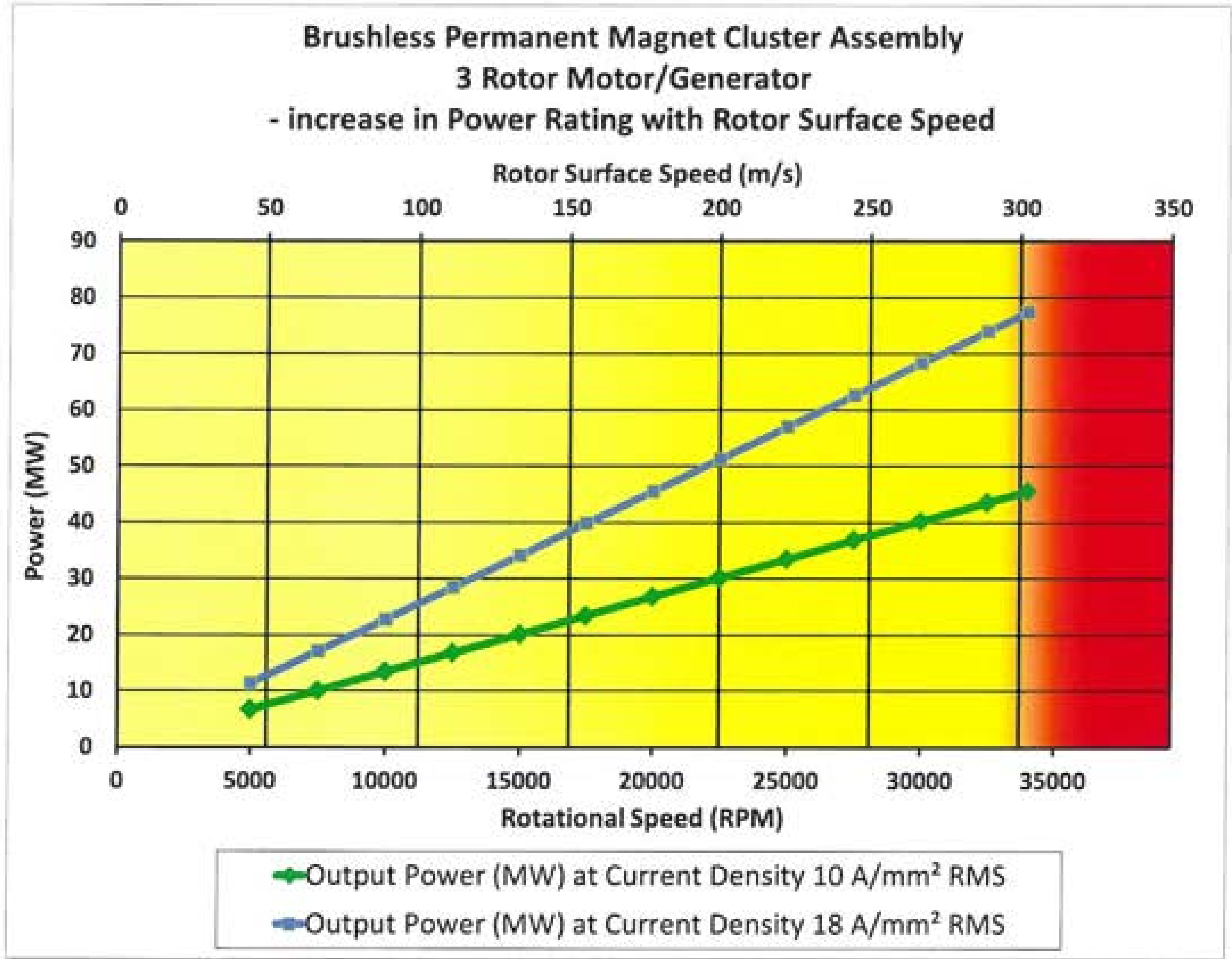
## 3 Rotor - 1:1 Gearbox - 6.7 MW High Speed

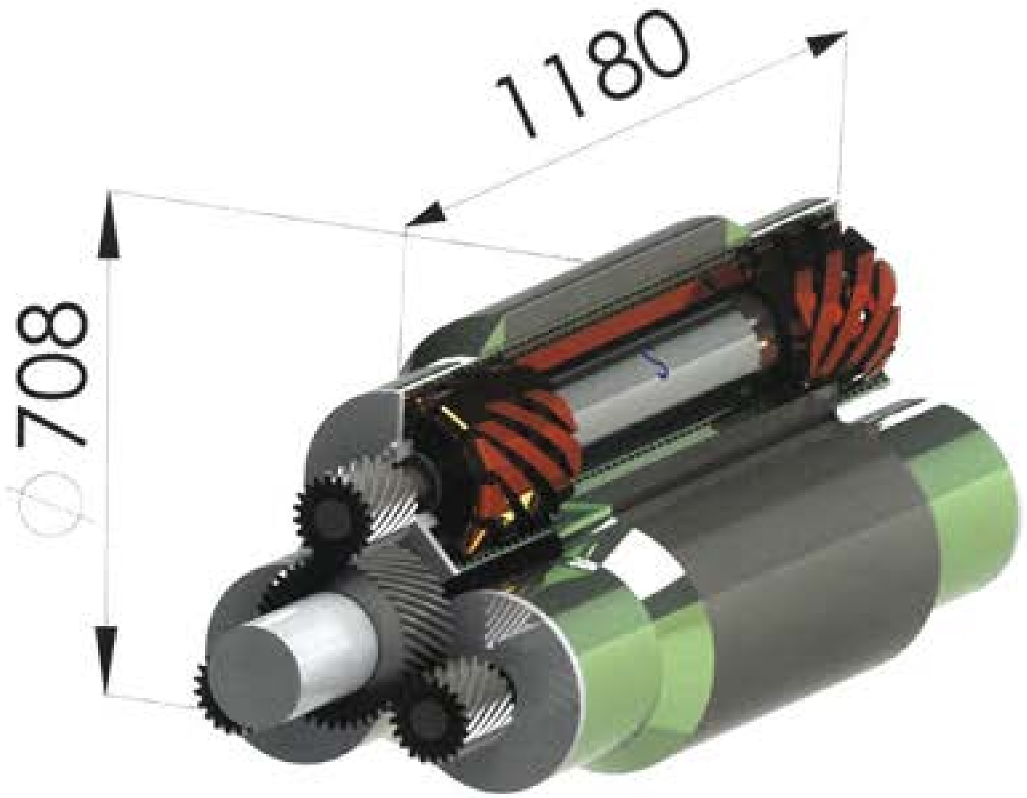
| | |
|---|---|
| Power (MW) | **6.7** |
| Rated Speed (RPM) | **5000** |
| No. of Rotor Assemblies | **3** |
| Stator Current Density (A/cm² RMS) | **1000** |
| Stator Diameter (mm) | **280** |
| No. of Independent Stator Windings | **6** |
| Stator Material | **Oxygen Free Copper Wire** |
| Stator Wire Packing Factor | **0.7** |
| Stator Winding Weight Estimate (kg) | **309** |
| Rotor Material | **Neodymium N45SH** |
| Rotor Surface Speed (m/s) | **45** |
| Rotor Diameter (mm) | **170** |
| Rotor Length (mm) | **600** |
| Permanent Magnet Weight (kg) | **308** |
| Steel Shield Weight (kg) | **387** |
| Cooling | **Pumped Liquid** |



# GUINA'S BRUSHLESS PM CLUSTER TECHNOLOGY

## 3 Rotor - Power Scalability and Overall Dimensions



# TECHNOLOGICAL AND APPLICATION SUMMARY

# TECHNOLOGY SUMMARY

## Homopolar

- Highest efficiency.
- No AC superconducting loss.
- High and Very Low Speed operation using Electromagnetic Converter Technology.

## Superconducting DC Toroidal

- DC superconducting toroidal field.
- Inherent stray magnetic field containment.
- Highest Power to Weight.

## Permanent Magnet Toroidal

- Non-superconducting – no cryostat needed.
- Inherent stray magnetic field containment.
- Suited to higher speeds.

## Permanent Magnet Cluster

- Non-superconducting – no cryostat needed
- Brushless while still retaining low (<1%) torque ripple
- Suited to higher speeds.

## Brushless Permanent Magnet

- Simplest construction
- Non-superconducting – no cryostat needed
- Brushless with low ripple.
- Suited to higher speeds.

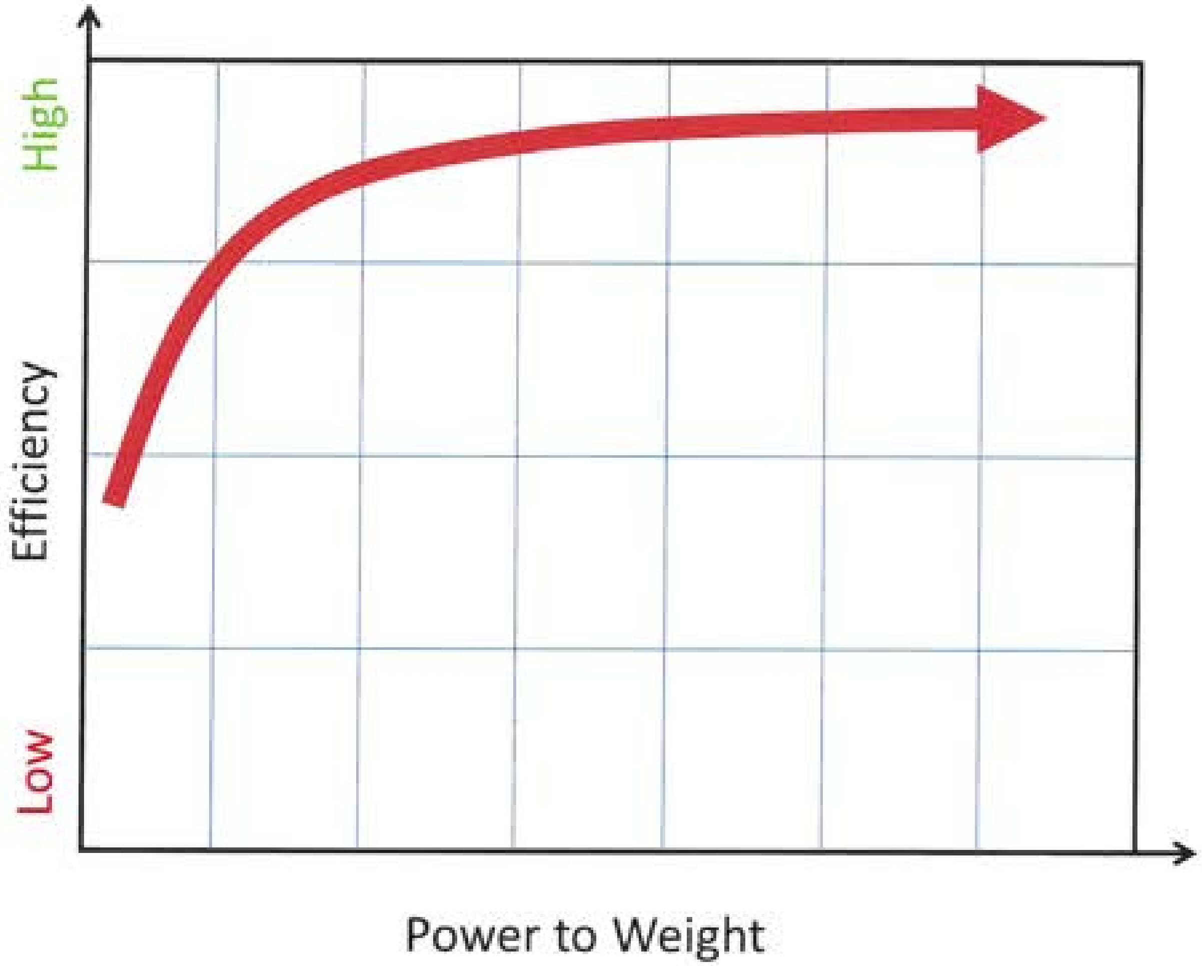
# TECHNOLOGY SUMMARY

GUINA ENERGY GROUP

## Permanent Magnet Technology


- Power to weight is largely determined by winding current density.
- High current density increases copper heat losses.
- Increases in power to weight due to rotor fields is limited by the peak strength of the permanent magnets.

## Homopolar Technology




- Power to weight can be substantially increased by increasing the driving B-field of the device.
- Increased B-field does not result in rapid increase of the losses due to the utilisation of a DC superconducting magnet.

# LOSSES IN PM TECHNOLOGY

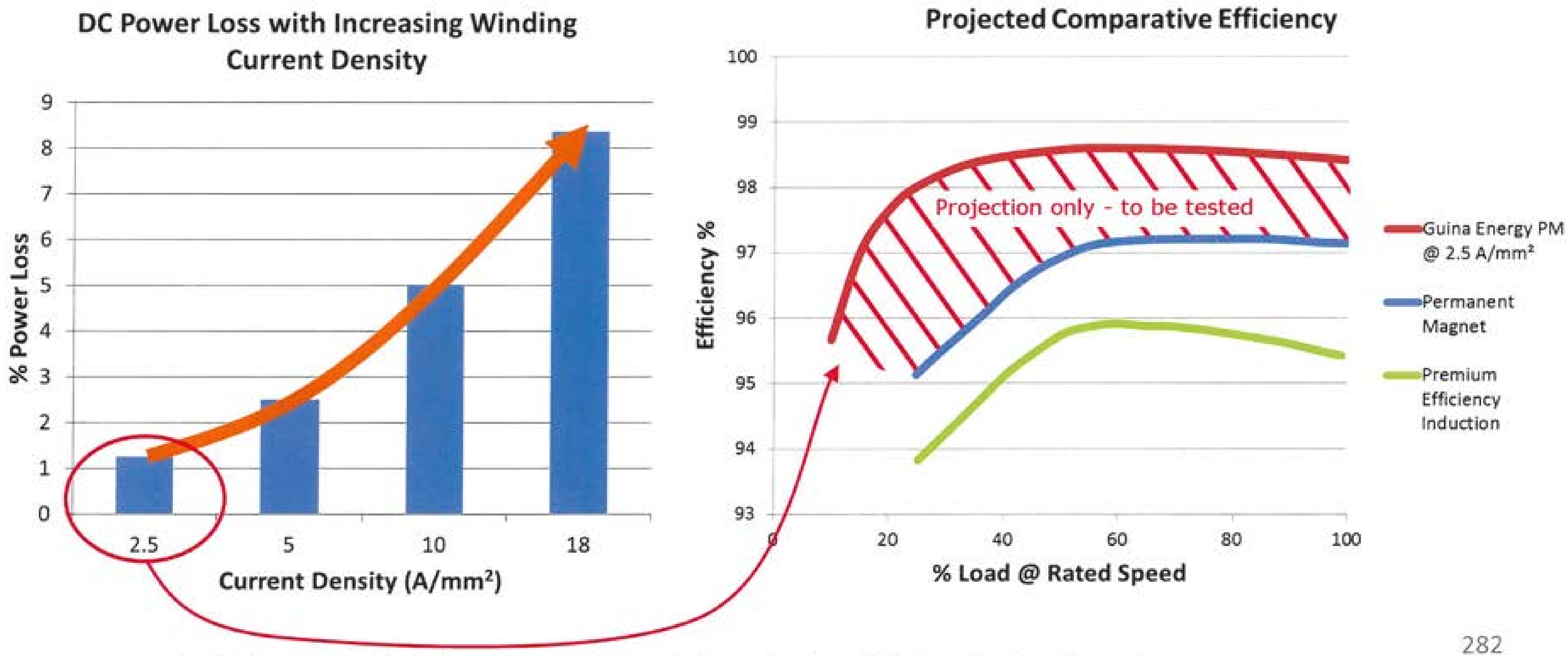
GUINA ENERGY GROUP

Some Key Equations for PM Technology:

- High Power Density, Smaller Size = Lower efficiency.
- High Efficiency = Larger Size and Lower Power Density.

HOWEVER...

**Guina Energy's PM Technology is readily configurable for either High Power Density or High Efficiency.**






Note: The figures presented in this document are calculations and projections based on available data and may be subject to change.

# EFFICIENCY & POWER DENSITY CONSIDERATIONS

GUINA ENERGY GROUP

We believe that the efficiency of our high power density homopolar machines can be >10% higher than that of our high power density permanent magnet machines due to the following factors:

- Lower resistive heat loss at high power levels due to the utilisation of a DC superconducting stator coil.
- Elimination of any mechanical gearbox.
- Reduction in the complexity of associated power electronics.

# HOMOPOLAR MOTOR

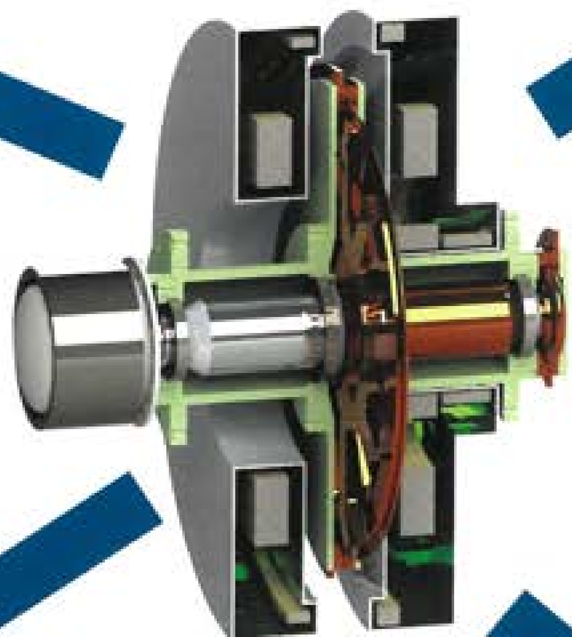
GUINA ENERGY GROUP

## Transportation Electrification

## High torque, low speed & compact design


Marine

Trains



Heavy Vehicles

Aviation

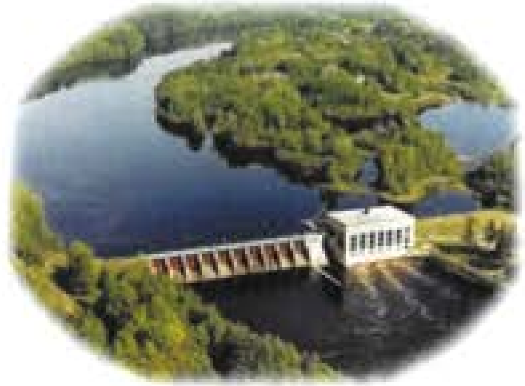
Public Transportation

# HOMOPOLAR GENERATOR

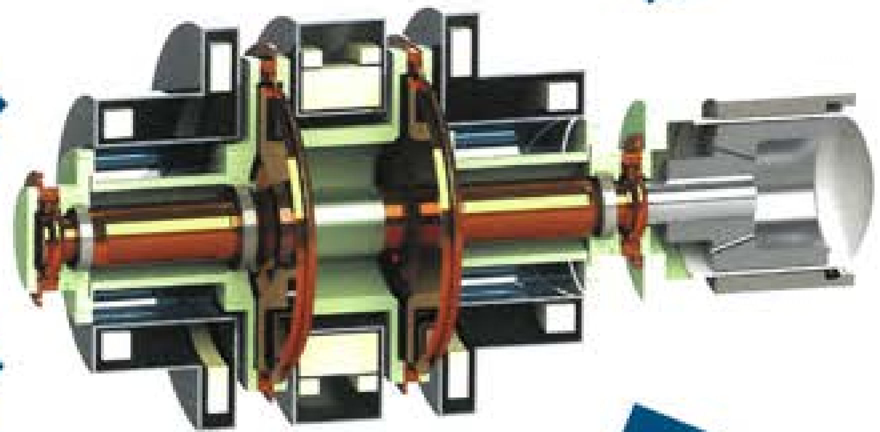
**Renewable Energy**

**High power, low to intermediate speed & high torque**

Wind



Hydro



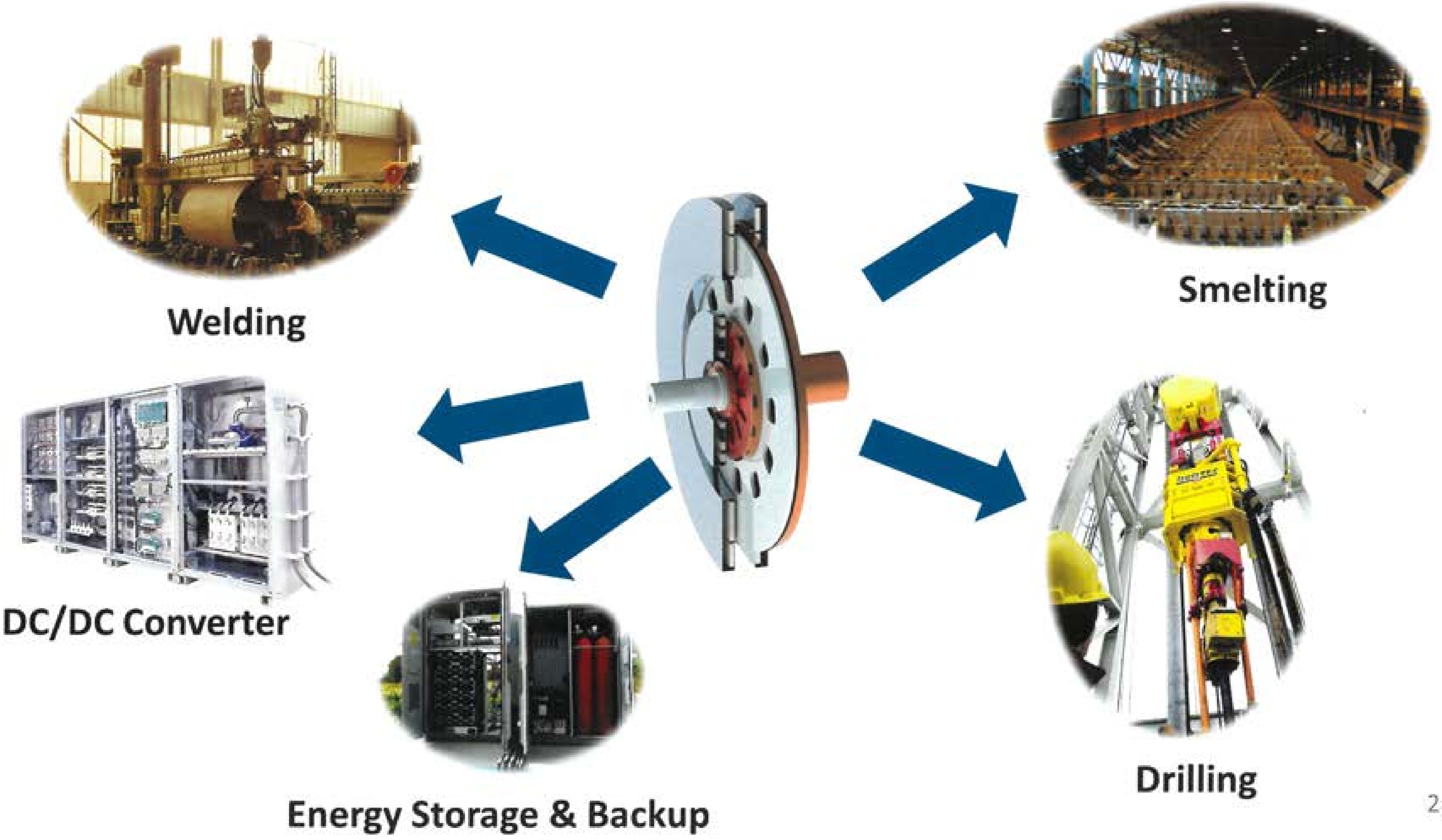
Wave

Tide

# ELECTROMAGNETIC POWER CONVERTERS

## Industry

## High current, DC power & Gearing



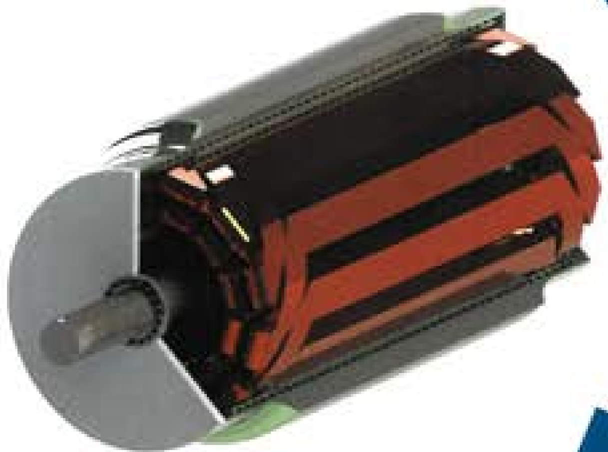
# PERMANENT MAGNET MACHINES

**Wide Range of Applications**

**Increasing Power-to-Weight**

**Electric Motorcycles**

**Electric Cars**



**Light or Heavy Rail**

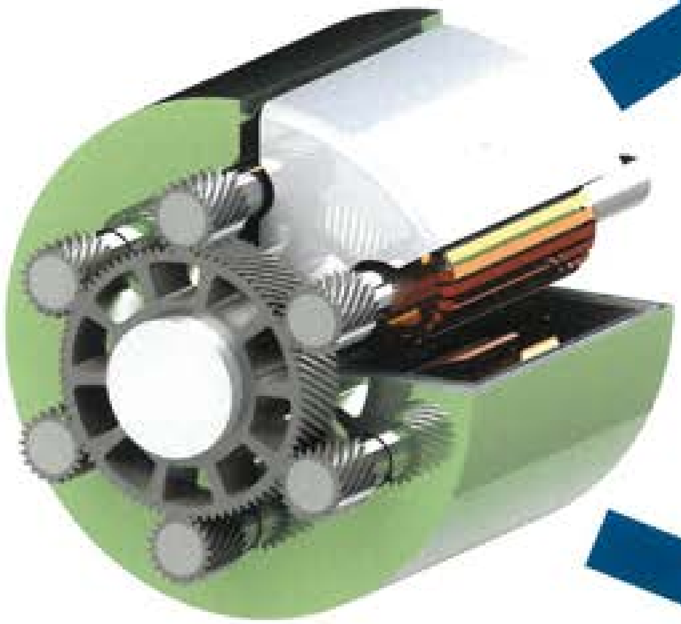
**The sky is the limit!!**

# TOROIDAL MACHINES

**High torque, high power & minimum stray field**

**Wind**

**Aviation**



**Marine**

**Trains**

Our designs challenge existing technology through the implementation of the innovations developed by Guina Energy Group. These innovations stem from thinking about traditional problems in a new way to produce advanced Green Energy solutions. Our technology utilises the power of high magnetic fields and superconducting magnet technology to produce high power to weight and highly efficient devices and systems.

For more information please email us at
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