THE UNIVERSITY of EDINBURGH
School of Engineering
Institute for Energy Systems

C-GEN Direct Drive Generator

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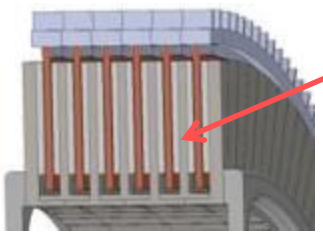
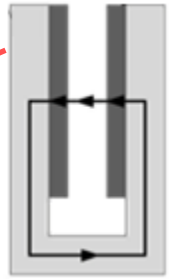
Project Plan

- C-GEN Technology
- Lab Prototypes
- 1MW Demonstrator
- Unique Selling Points & Benefits

C-GEN Technology



Adjacent C-Cores



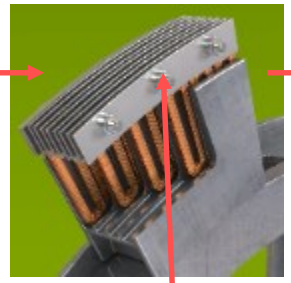
Single C-Core

Auxiliary Cooling:
Specifically designed air cooling system, with alternatives being researched and prototyped

Mechanical Integration:
Adaptable to new and known configurations and topologies, with ability to meet individual turbine requirements

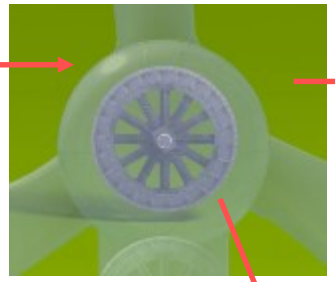
Permanent Magnet Rotor Module

Radial Flux Generator Composed of Several C-Cores

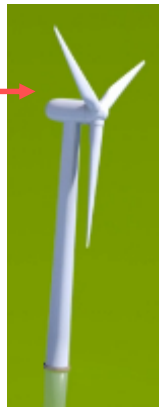


Stator Module

Generator Rotor



Assembled Generator



Stacked Generators For Higher Ratings

Core Patent: Generator and Magnetic Flux Conducting Unit
Granted: USA, China, Japan, Canada, Australia
Pending: Europe

Generator and Converter Circuits:
Each stacked PMG is electrically and magnetically independent

- Dedicated power converter per PMG
- Few or all generator modules connected to a single converter
- Circuit to suit wind conditions for maximum yield

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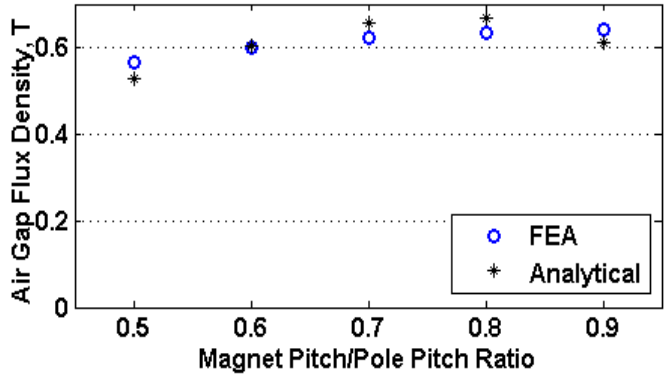
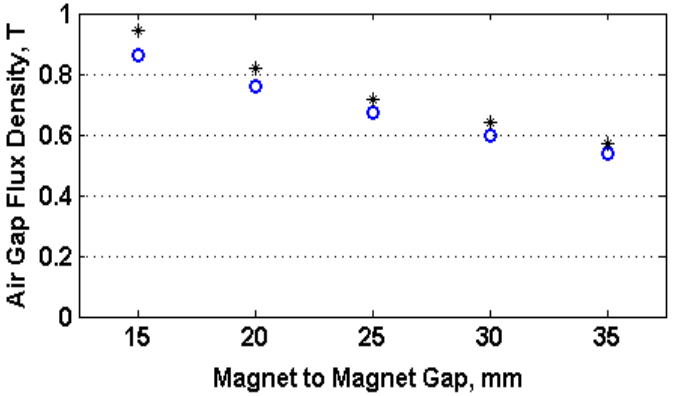
Lab Prototype Development

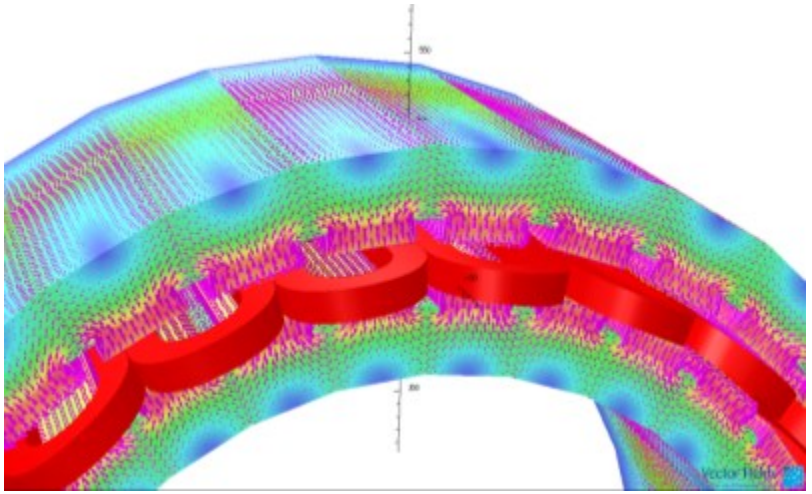
- Objectives:
  - To prove the fundamental engineering principles
  - To verify design tools and procedures
  - To demonstrate manufacture and assembly techniques
  - To show high level of performance in terms of efficiency
  - To build confidence in developing a 1MW demonstrator

Prototype 1: 20kW radial-flux

Test aim: does analytical design tool (*left*) match with numerical modelling (Finite Element model, *right*), e.g. airgap flux density.



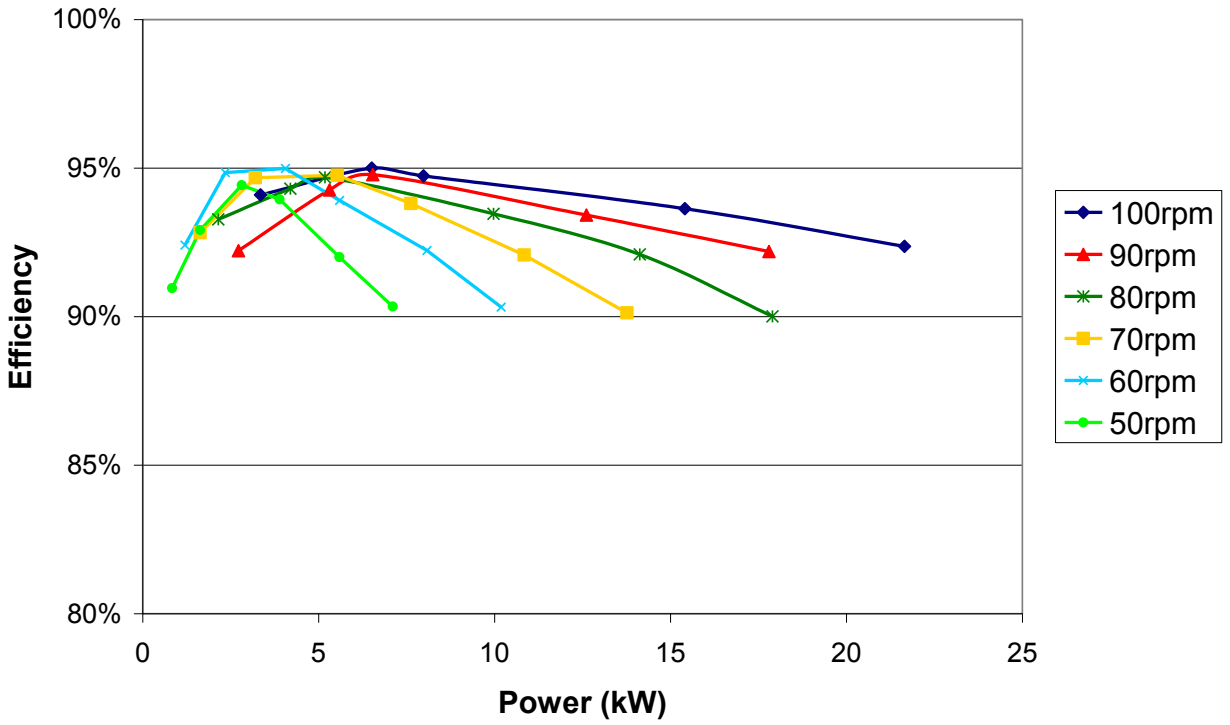




Broad agreement between design tool and numerical tools.✓

Prototype 1: 20kW radial-flux

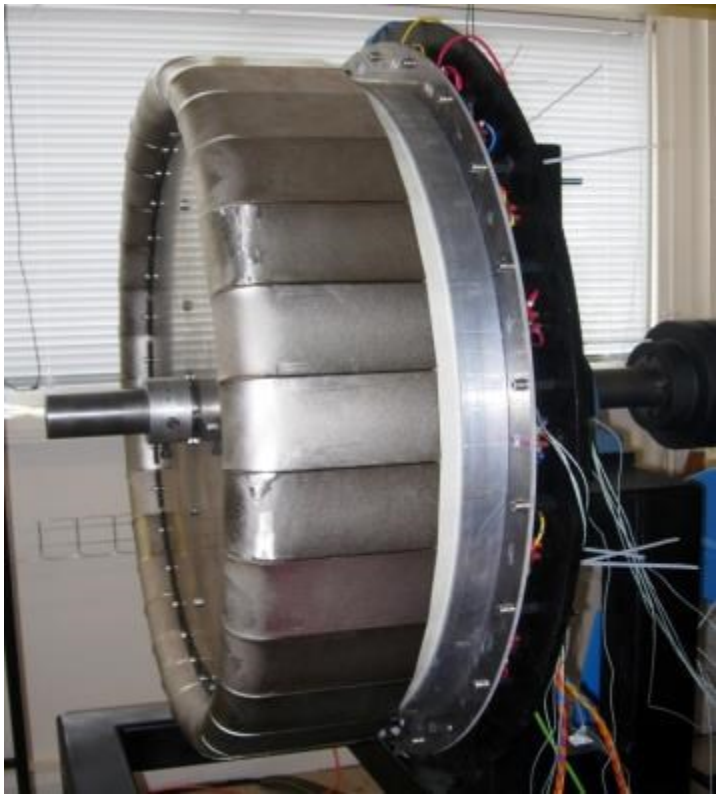
Test aim: Can the generator produce power efficiently over a broad range of loads and speeds?

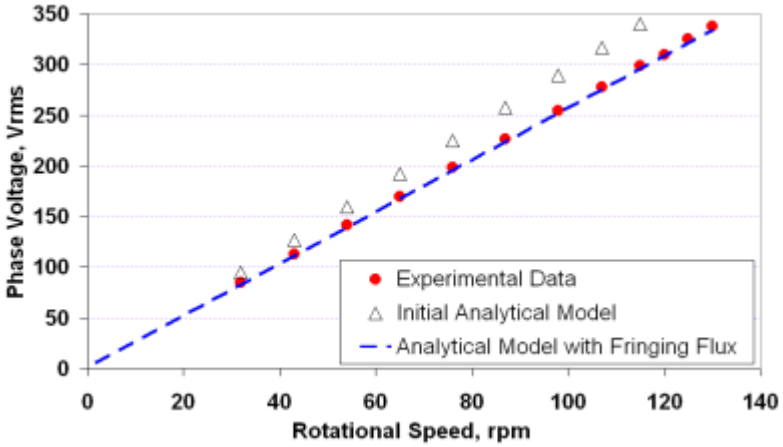


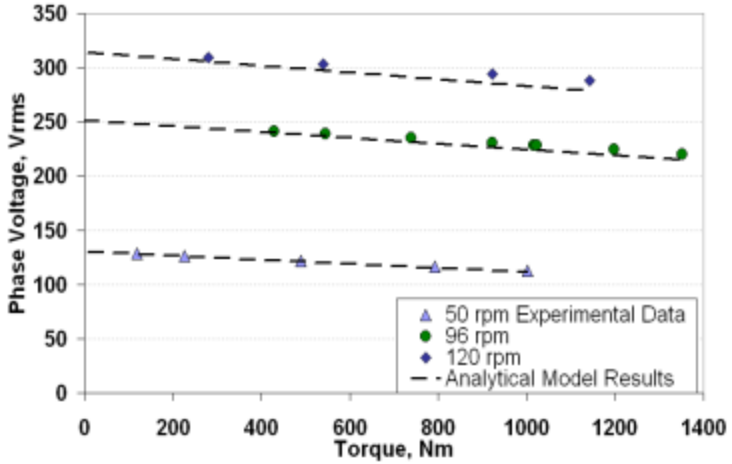
High efficiency over a range of speeds and loads.✓

Prototype 2: 15kW radial-flux

Test aim: compare analytical design model and experimental results, e.g. voltages



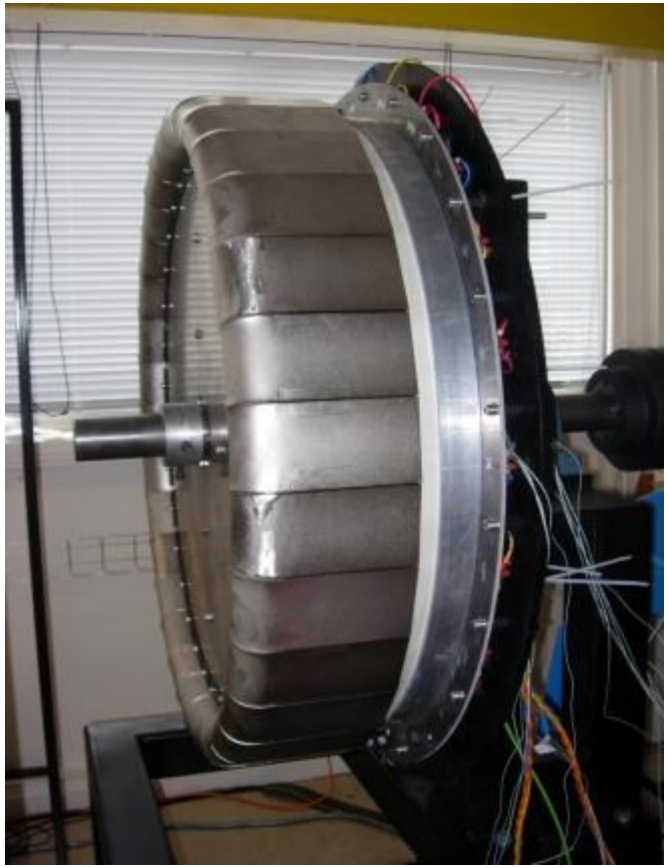


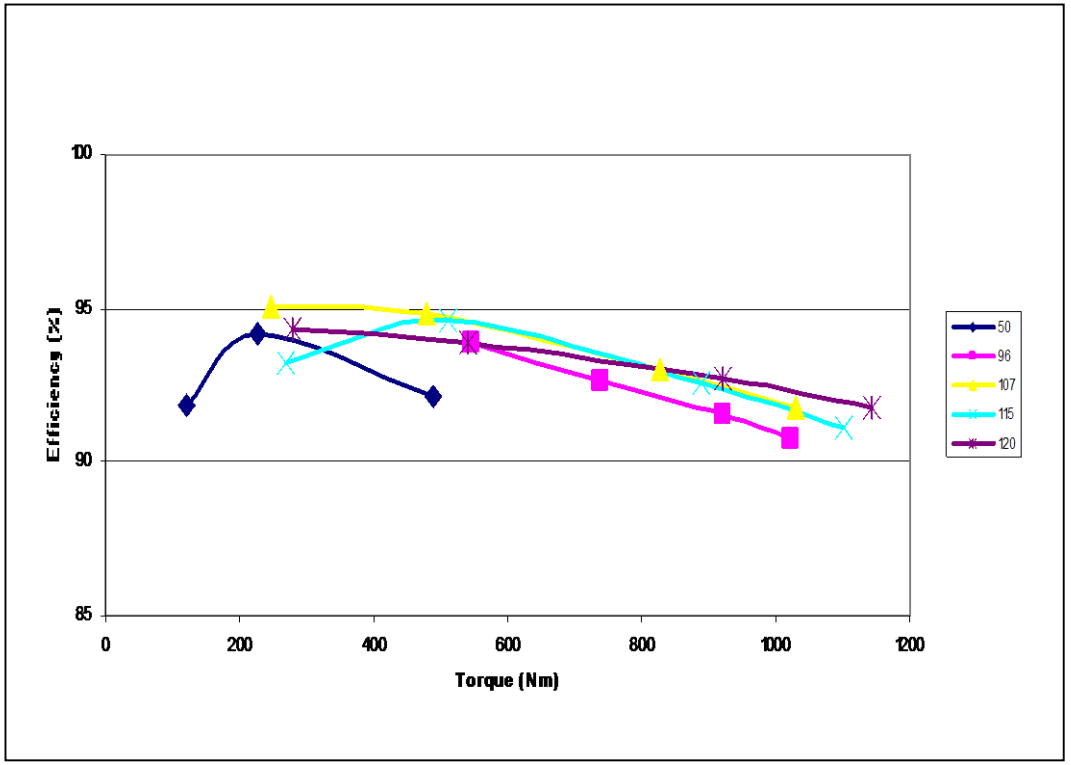


Analytical models match up with experimental results.✓

Prototype 2: 15kW radial-flux

Test aim: Can the generator produce power efficiently over a broad range of loads and speeds?

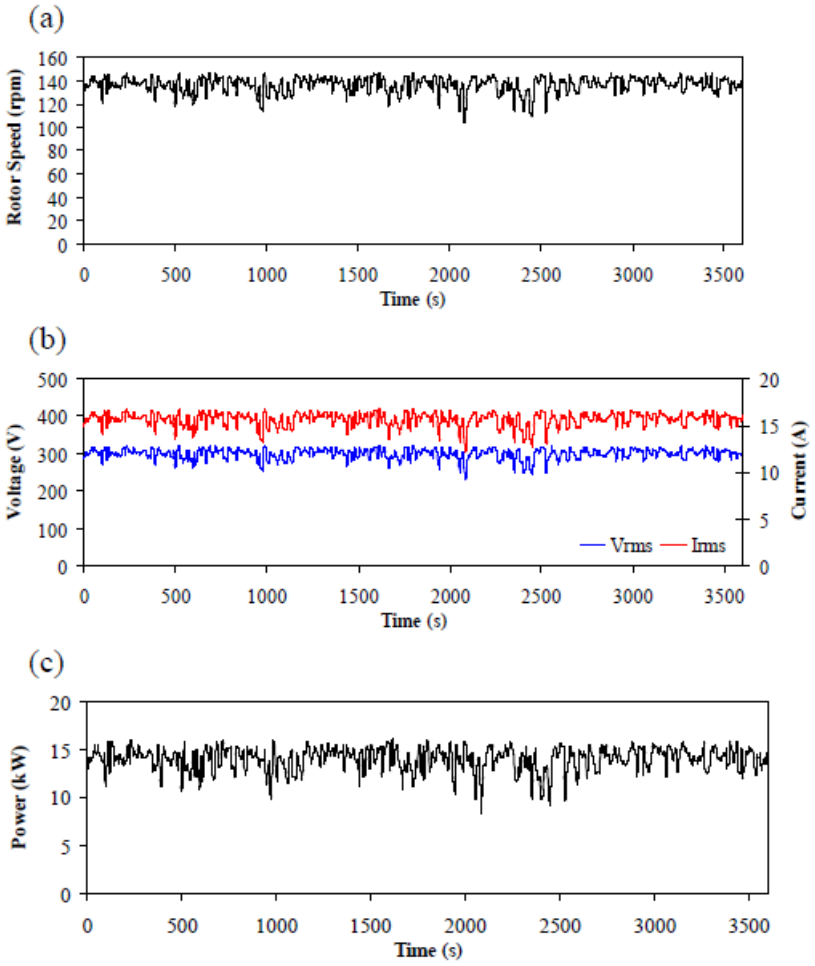




High efficiency over a range of speeds and loads.✓

Prototype 2: 15kW radial-flux

Test aim: Can C-GEN technology safely produce power when mounted to a wind turbine?

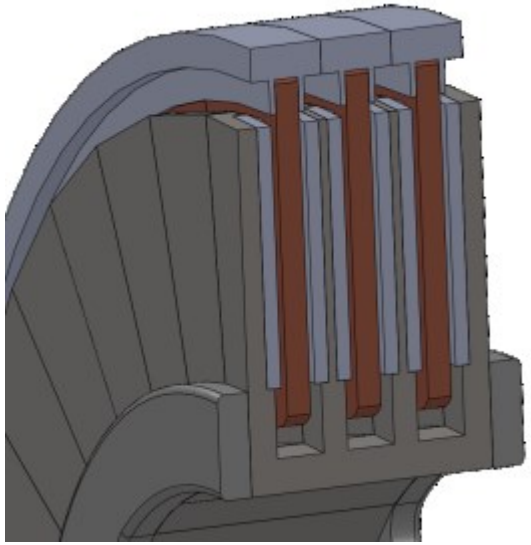


Power results on a 15kW wind turbine. ✓

Prototype 3: 25kW axial-flux

Aims:

- Can we build an axial-flux version? ✓
- Can we build a multi-stage version? ✓
- Can we build a modular version? ✓
- Can we cast rotor modules? ✓



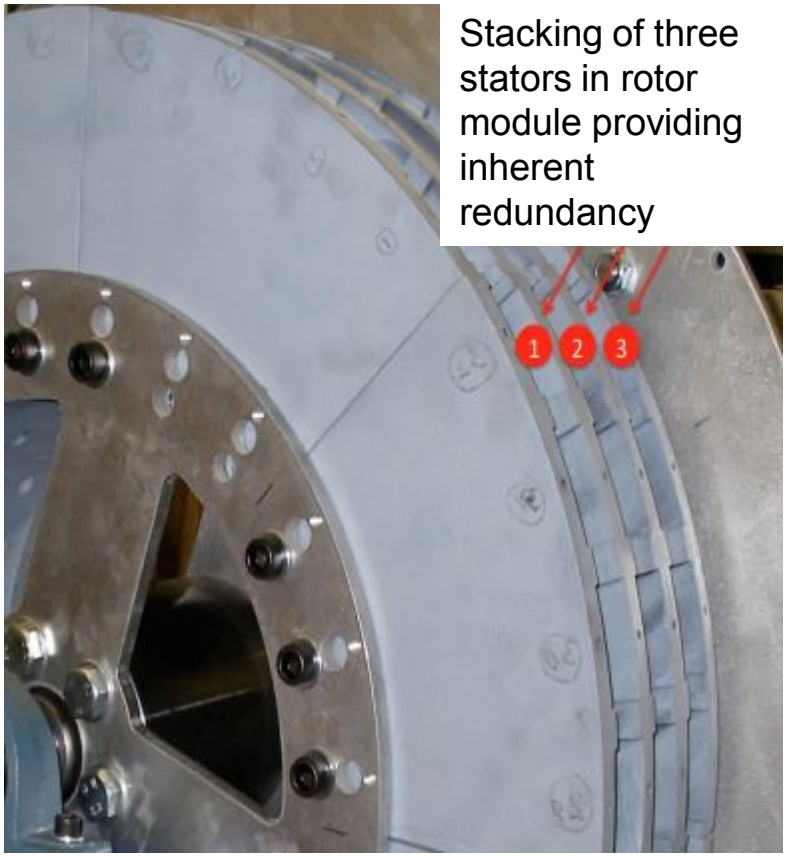
Multi-stage Axial Flux C-GEN

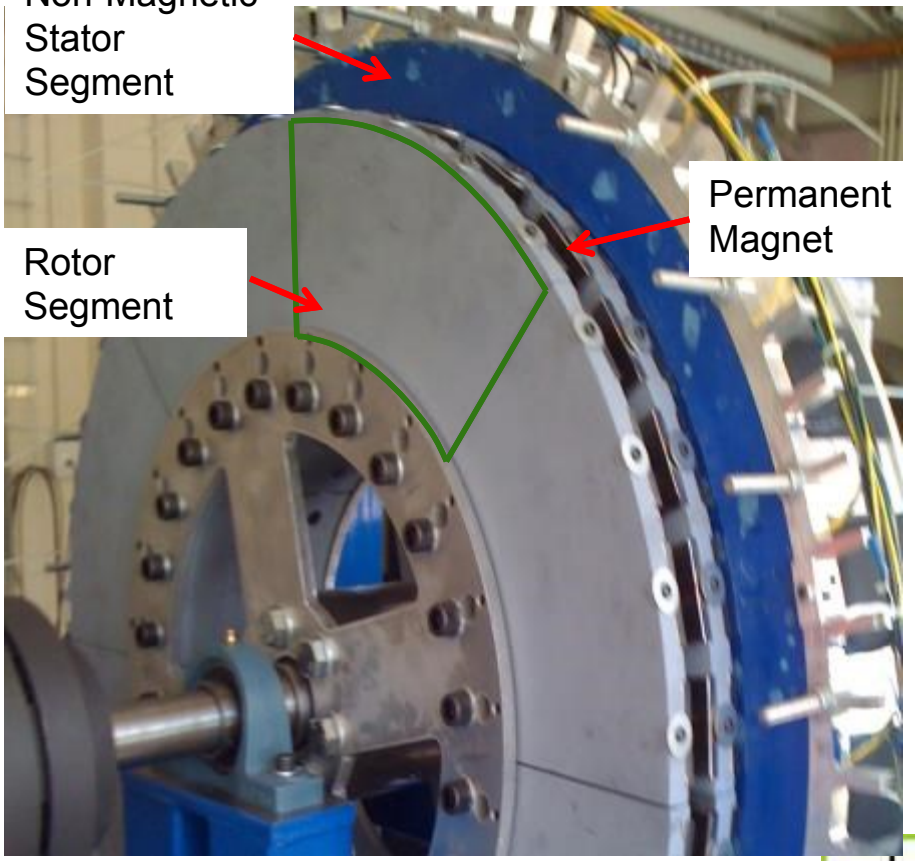
- Rotor Construction

Stator Construction

C-GEN Design Validation

Satisfactory Testing of initial demonstrators
Full validation of design tools & models





1MW Demonstrator

NGenTec 1MW Prototype Technical Characteristics

- Demonstrate technology at high power
- Four equal stages (250kW) – any combination of stages can be satisfactorily run (One, Two, Three or Four stages)

- Power = 1MW
- Output voltage Un=690 V
- Speed circa. 12 rpm
- Single stack of potential 6MW machine
- Insulation / Temperature rise Class F

1MW Prototype Detailed Test Results

Pre-assembly Tests

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Early stage demonstration validation

Pre-assembly Thermal Tests

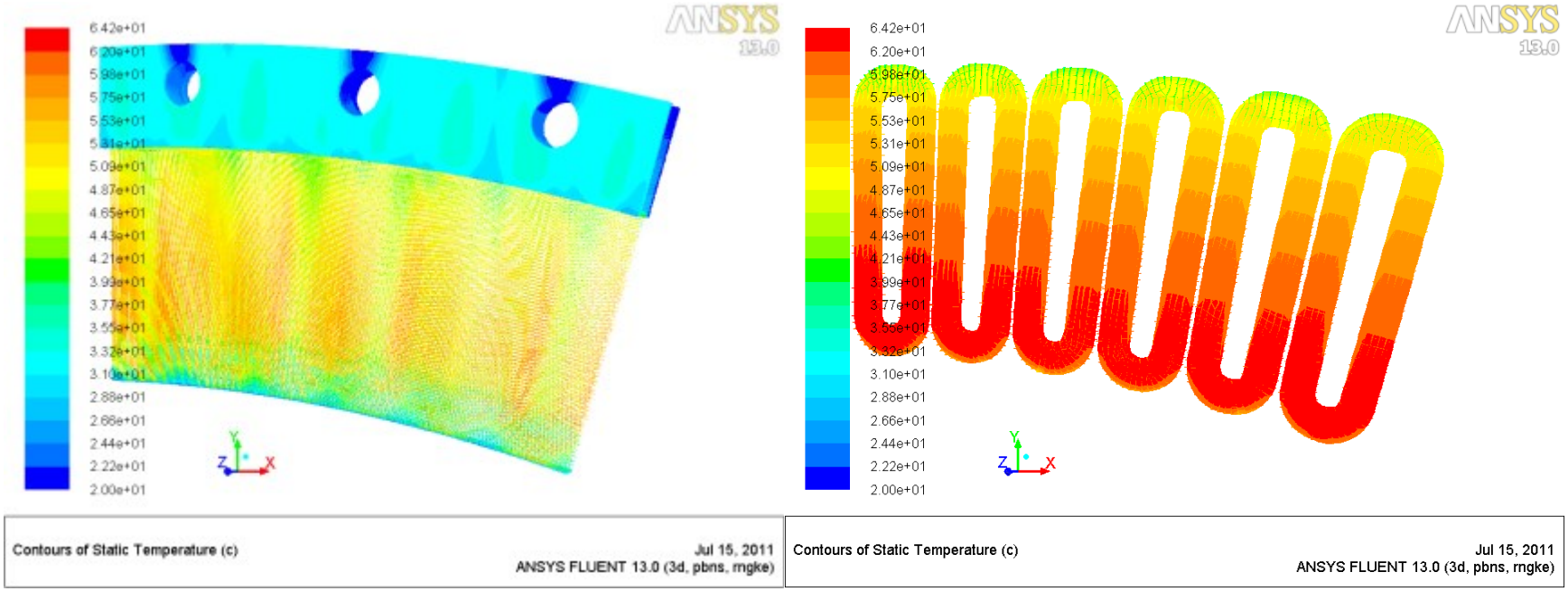
Full Scale Test Module

- Single rotor module with stator module
- 4 stages
- Test rig allows worst case thermal scenario (no rotation but with electrical losses)

Early stage demonstration validation

Pre-assembly Thermal Tests

Test aim: Experimentally validate CFD and other thermal modelling



Maximum coil temperatures for 51kW electrical losses from experimentation is 60°C; from CFD (above) it is 64°C ✓

1MW Prototype Test Results

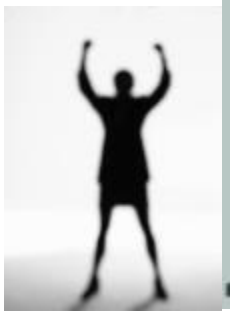
1MW PMG Overview

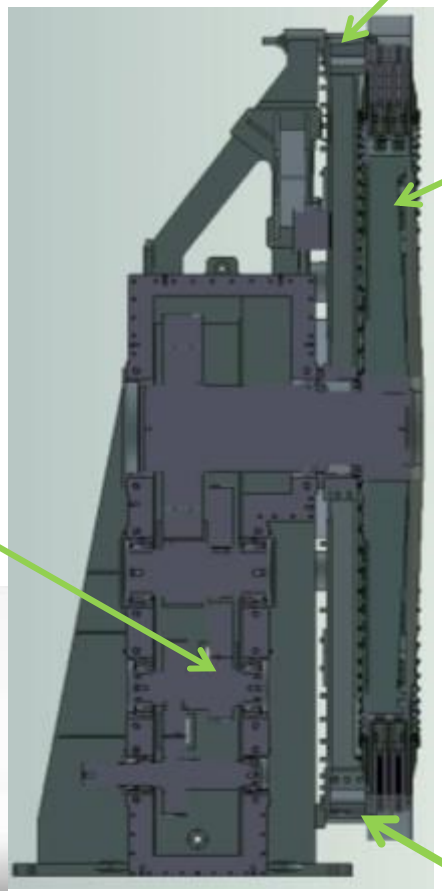
Stator Structure

Rotor Modules

Rotor Structure

Test Gearbox to provide required generator speed and support structures

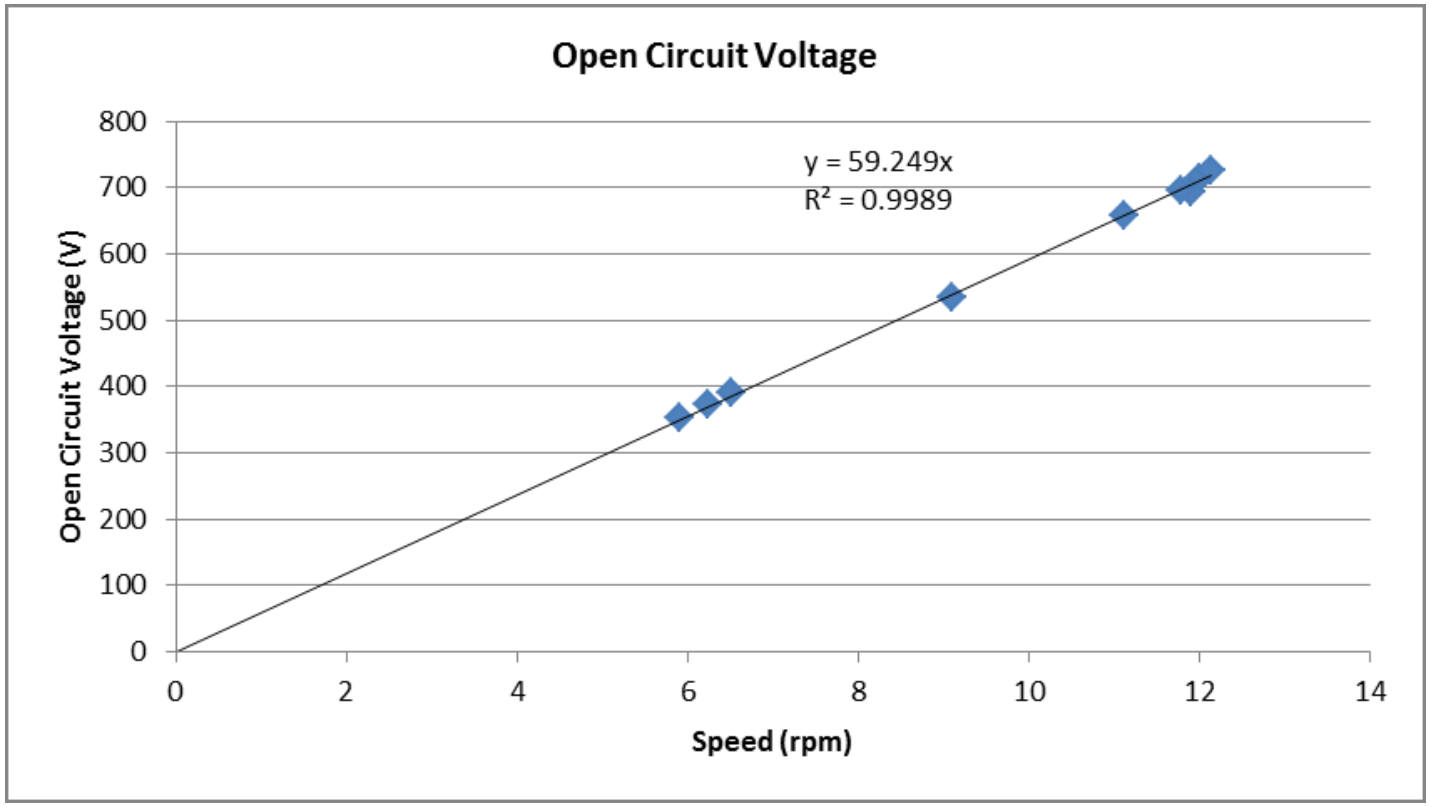




Stator Modules

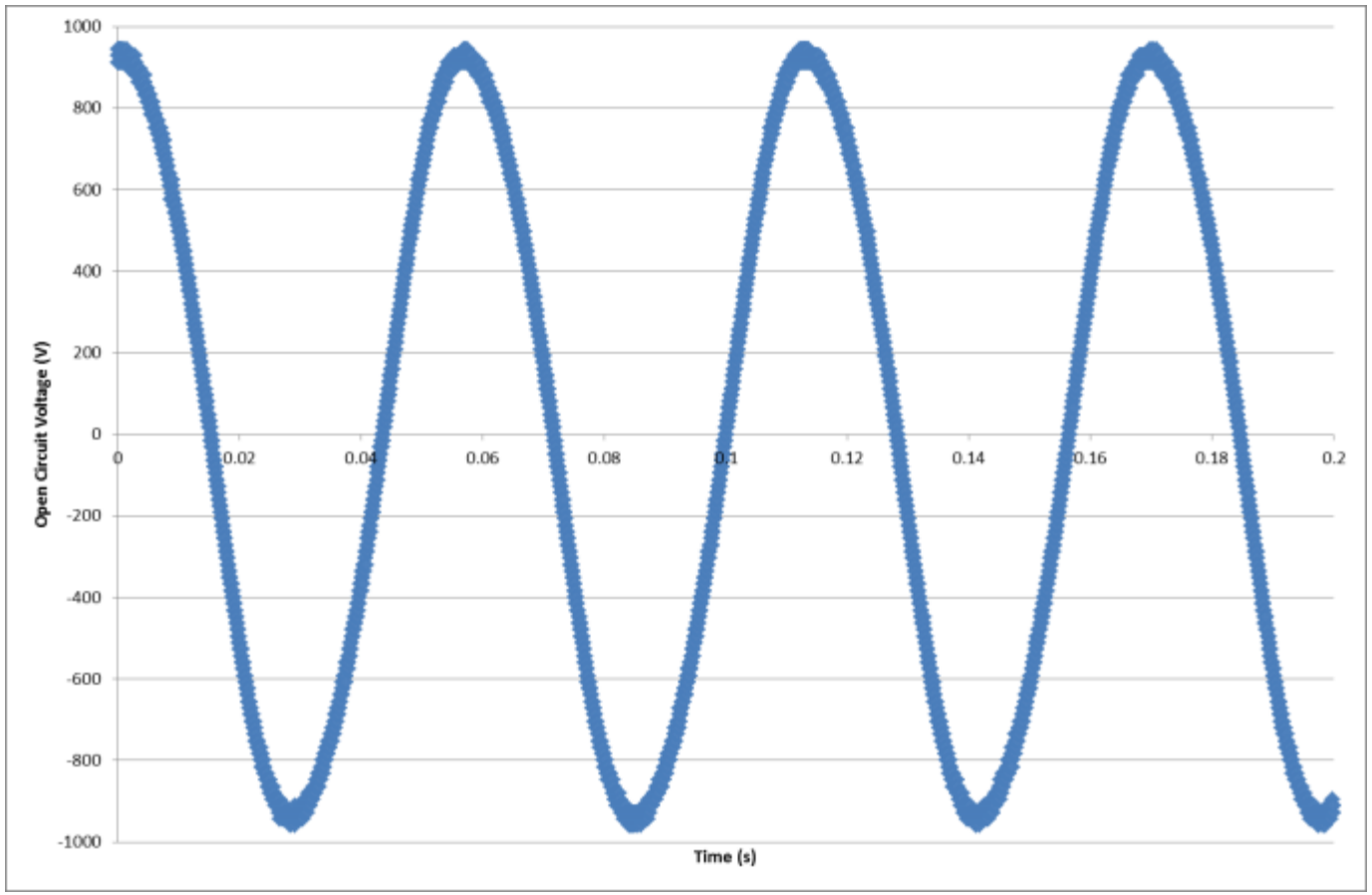
No Load Voltage

- All generator stages well balanced
- Demonstrating accurate design and manufacturing



Waveform Analysis

UL-L from digital oscilloscope. Stage 1, Phase 3



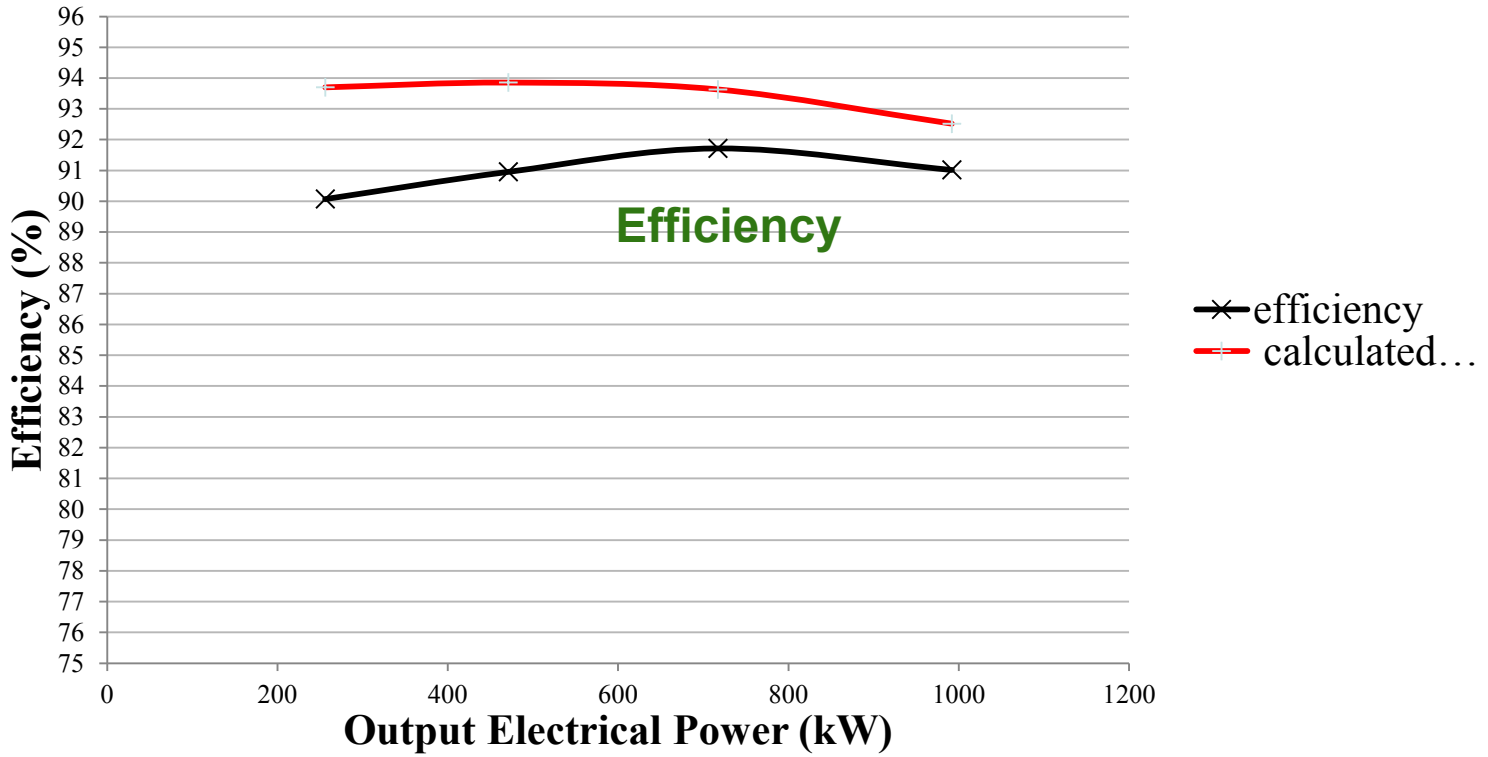
Full Load – All Stages

- Good correlation between initial design and measured temperature rise
- Not more than 15% temperature variation from the mean temperature rise
- Less than 4% difference Vs CFD

Speed (rpm)	Torque (kNm)	**Output Power (kW)**	Line Current (Amp)	Phase Current (Amp)	**Temp Rise – max (^{O}C)**	Coil Block no	**Temp Rise – min (^{O}C)**	Coil Block no	Cooling (m^3/s)
13.3	791	**1101**	202	116.6	**54.70**	S3-F	**41.69**	S1-0	6.3

Efficiency

- Efficiency measurements well understood
- Design work in hand to demonstrate higher values for future machines



Unique Selling Points Demonstrated

C-GEN Technology provides the following benefits:

- High reliability and availability
- Reduced Levelised Cost of Energy
- High efficiency across full operating range
- Standardised components
- Built in redundancy
- Zero cogging torque
- Reduced weight and size
- Cost competitive