

a) Double air gap axial-flux topology, 4 rotor discs    b) 4 x 3-phase phase modular wound radial-flux topology

Figure 1. Axial-flux and radial-flux electrical machine topologies considered

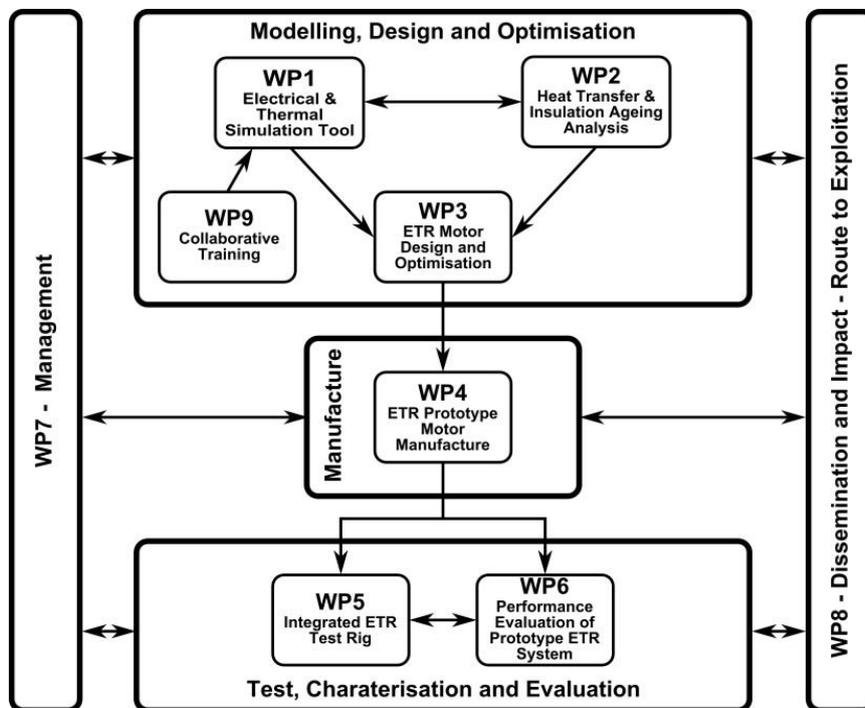


Figure 2 Project work package structure

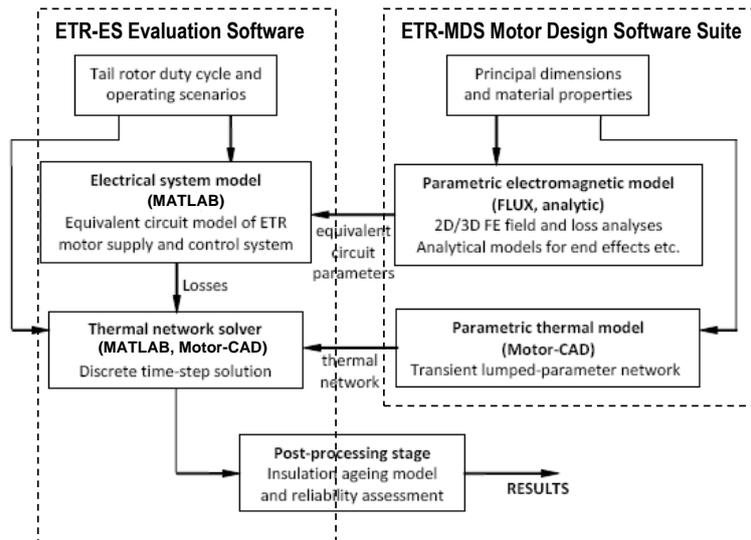
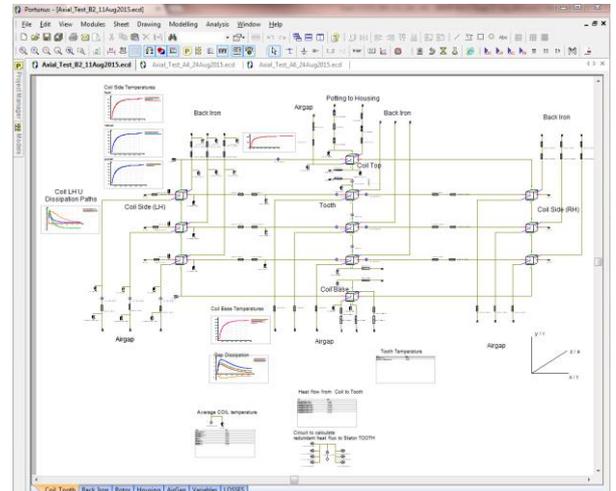
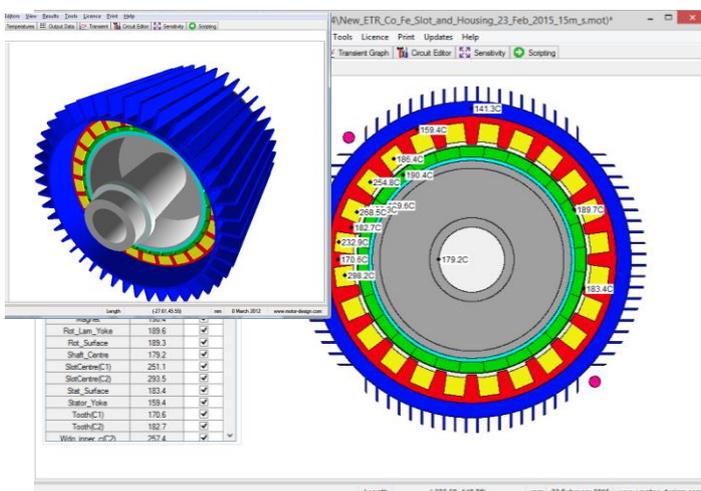


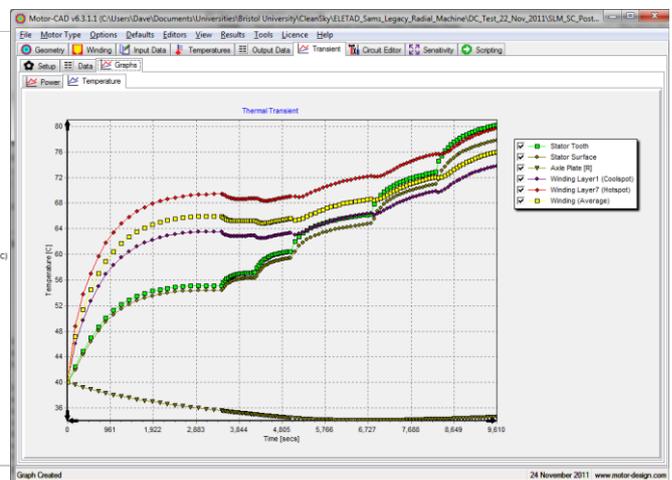
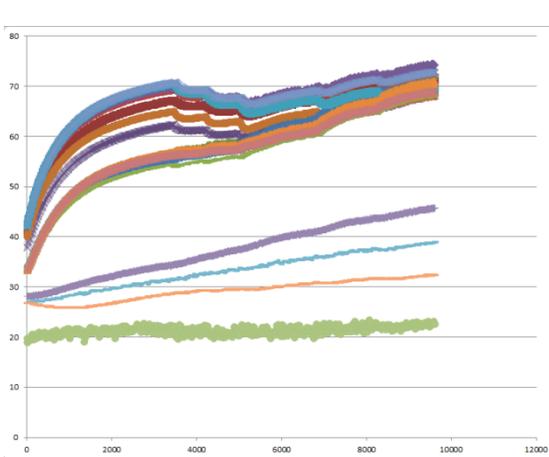
Figure 3 Software suite sub-elements and interactions



a) Radial-flux topology model in MOTORCAD software

b) Axial-flux topology thermal analysis tool

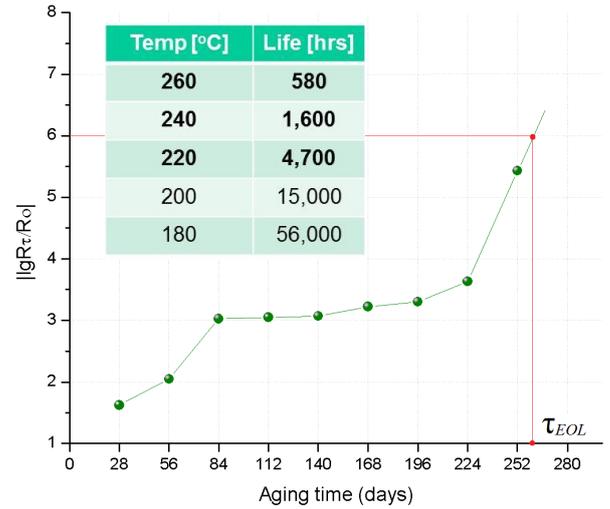
Figure 4 Developed lumped parameter thermal models for fault-tolerance electrical machine topologies considered



a) Experiment

b) Model

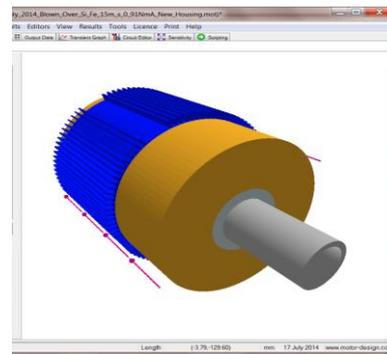
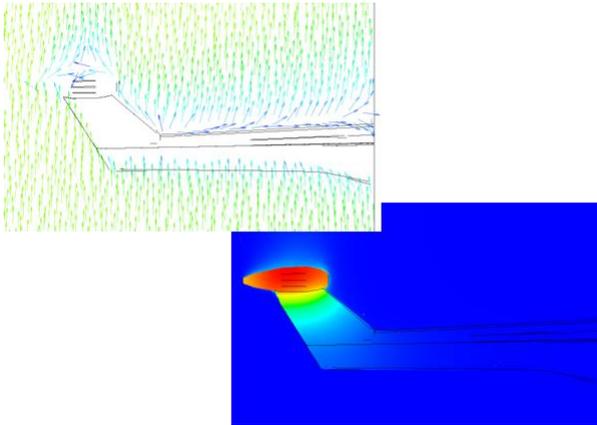
Figure 5 Initial validation of modelling software against test data from a fault tolerant machine



a) Example test motorettes used, before and after life testing

b) End of life criteria established from accelerated ageing tests

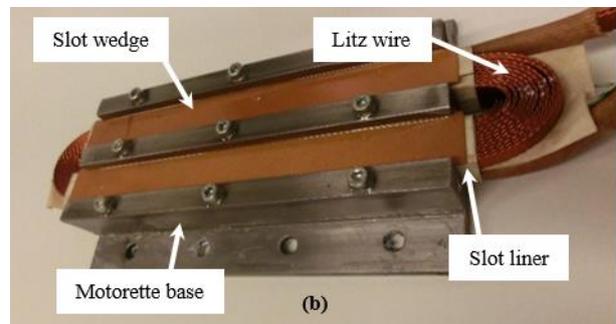
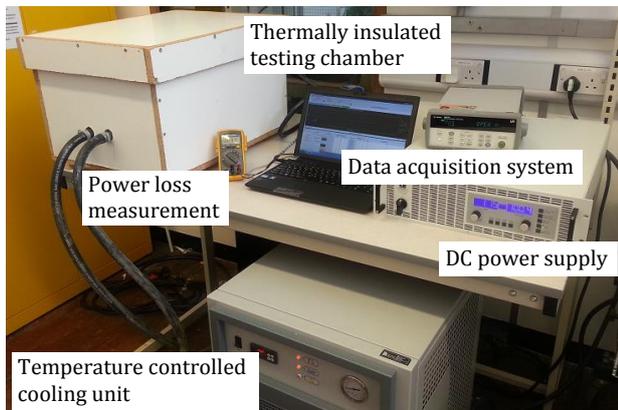
Figure 6 Accelerated ageing testing of high temperature class insulation systems



a) Investigation of tail rotor cooling

b) Cooling fin profile optimisation

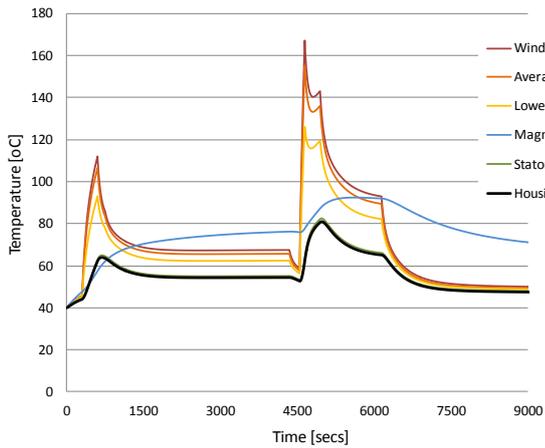
Figure 7 Computational fluid dynamics studies used to analyse convective heat transfer



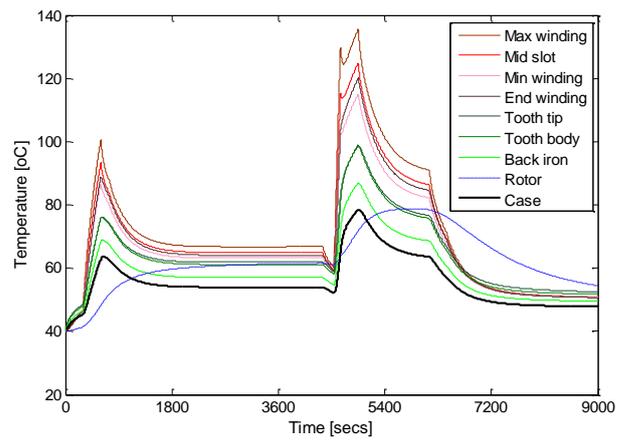
a) Heat transfer test bench

b) Example winding assembly used in thermal tests

Figure 8 Experimental investigation of conductive heat transfer from the winding



Peak temperatures		Losses	
Winding	Magnet	Peak	Average
167°C	93°C	18.1kW	3.2kW

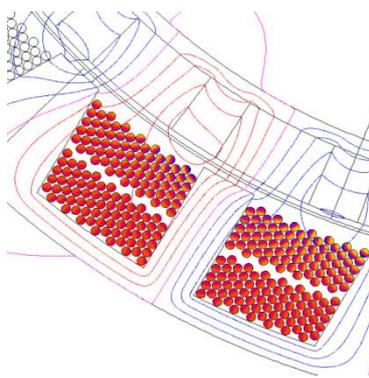


Peak temperatures		Losses	
Winding	Magnet	Peak	Average
136°C	80°C	10.2kW	1.9kW

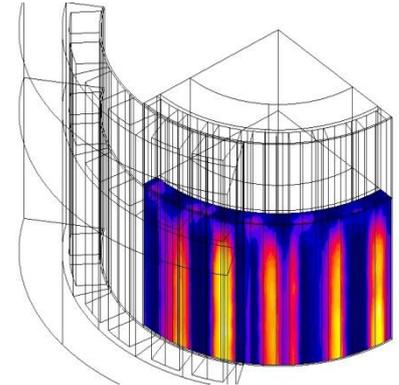
Figure 9 Example model based comparison of axial-flux and radial-flux designs over a mission cycle



a) Flux model

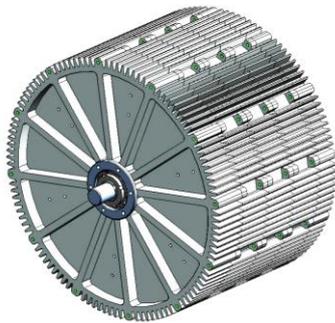


b) Winding AC loss study

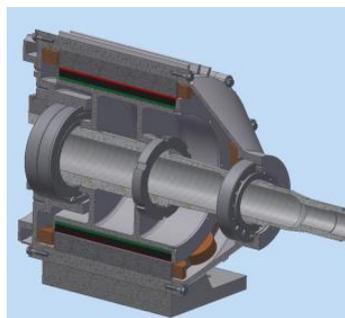


c) Rotor eddy current loss study

Figure 10 Example electro-magnetic finite element analyses undertaken during the design development



a) Axial-flux housing



b) Radial-flux assembly

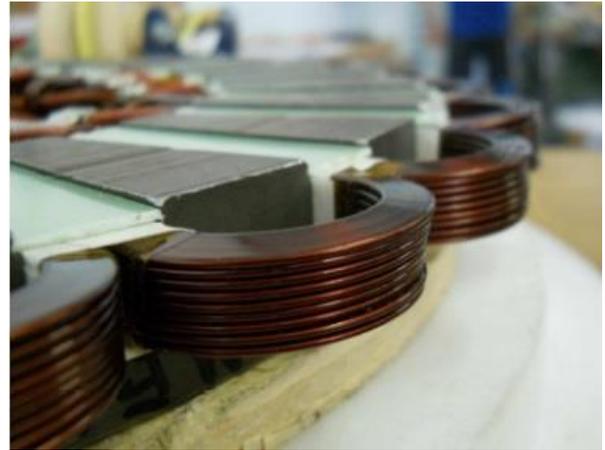
TABLE I PERCENTAGE WEIGHT BREAKDOWN OF ACTIVE MATERIAL USED IN THE TWO PROTOTYPE DESIGNS

Active component	Axial-flux	Radial-flux
Stator core	40 %	34 %
Winding copper	36 %	32 %
Permanent magnet	24 %	25 %
Rotor back iron	N/A	9 %

Figure 11 Axial-flux and radial-flux motor concepts

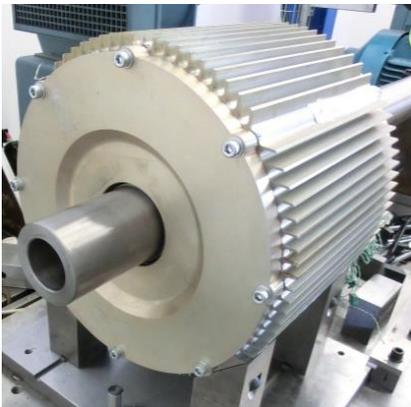


a) Full assembly mounted on plinth



b) Stator lamination pack and winding

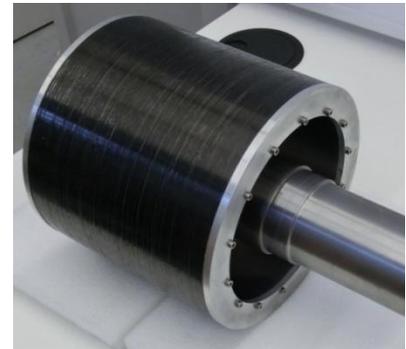
Figure 12 Axial-flux prototype



a) Full machine mounted on plinth

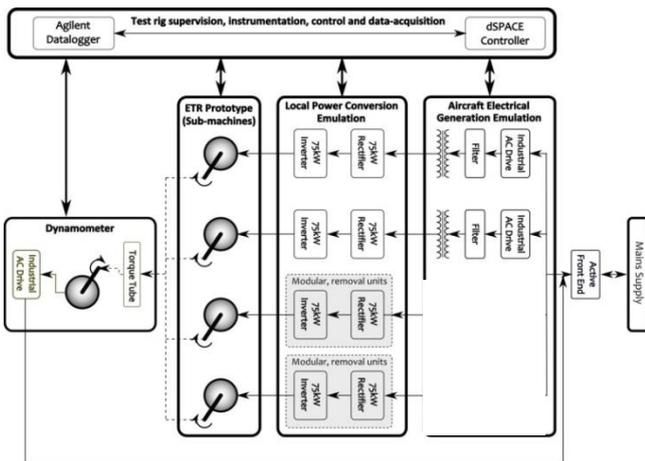


b) Wound stator assembly



c) Rotor assembly

Figure 13 Radial-flux prototype



a) Test rig schematic

4 quadrant dynamometer		Inverter supplies	
Torque (pk.)	2000 Nm	Channels	4
Speed	4500 rpm	Cont. ratings	250 A <sub>rms</sub>
Cont. power	225 kW		130 kVA
Peak power	340 kW	Peak rating	350 A <sub>rms</sub>
Electrical supply system		PWM frequency	2-16 kHz
Voltage	48-380 V <sub>dc</sub>		
Current	1000 A <sub>dc</sub>		
Cont. power	350 kW		

b) System specifications

Figure 14 Test rig schematic and specification

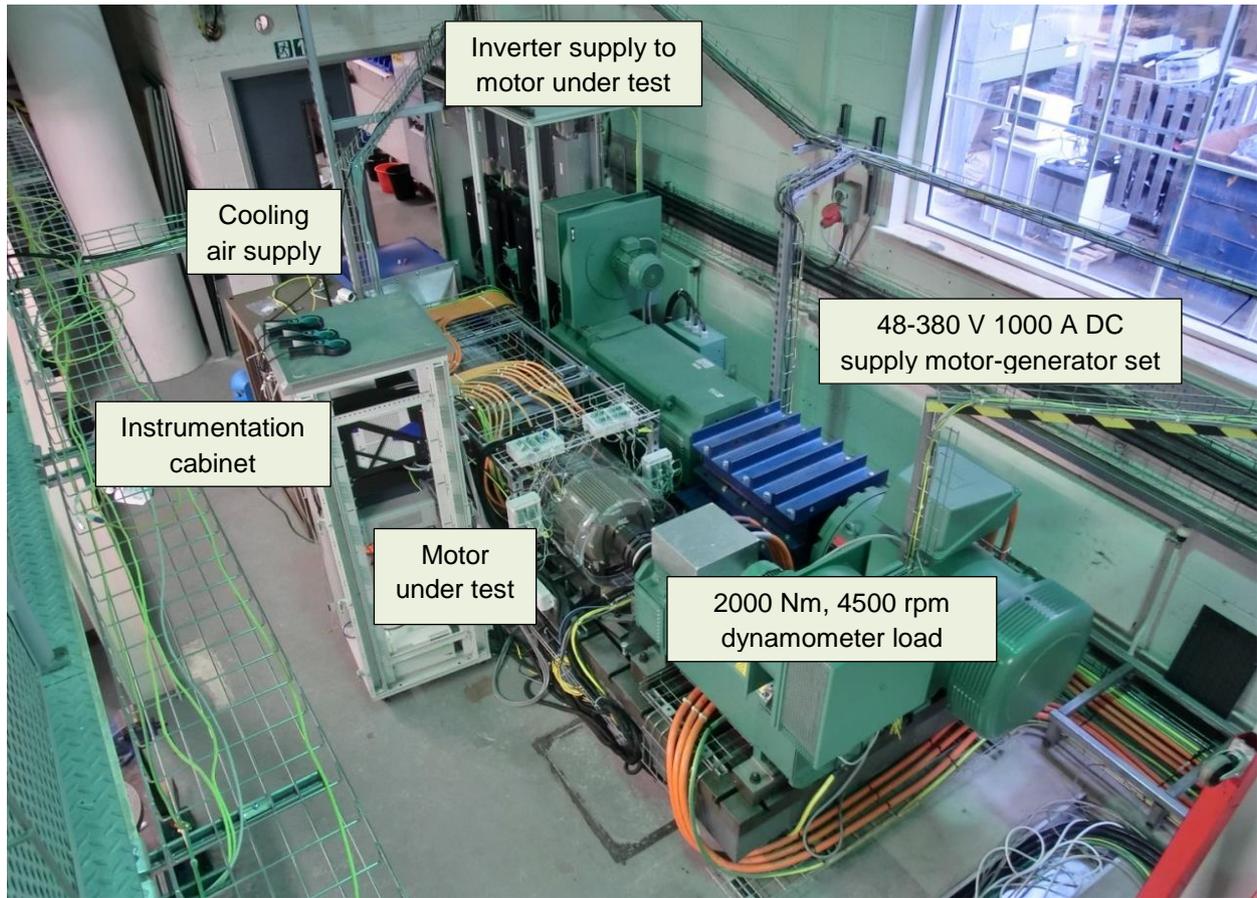
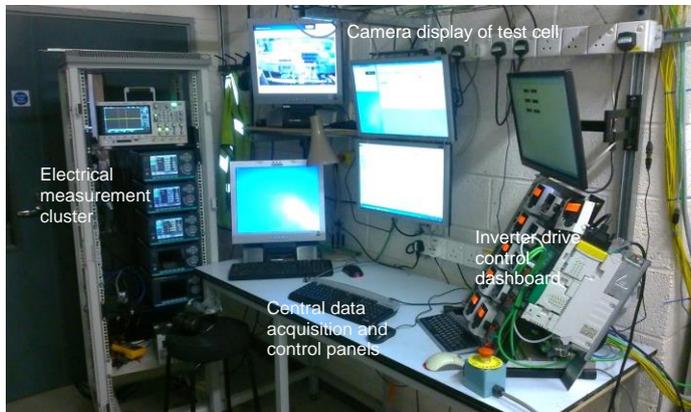


Figure 15 Photograph of integrated test installation in dedicated laboratory

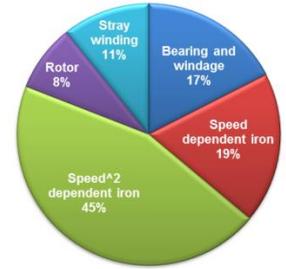
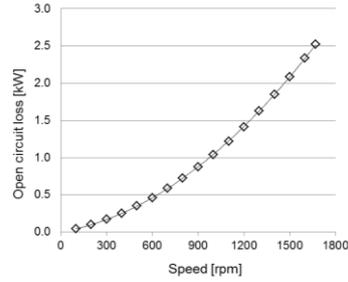
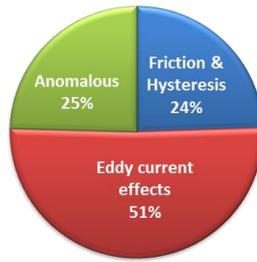
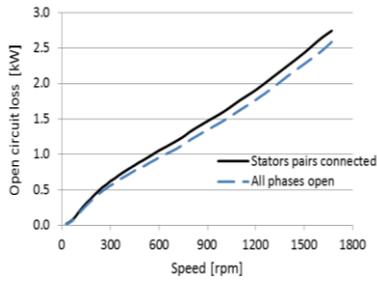


a) Control room dashboard

Equipment	Channels	Function	Accuracy
HBM T40B 3000 Nm torque transducer	1	Shaft torque and speed	0.05 %
LEM LF505 500 A current transducers	12	Current measurement	0.6 %
HBM Genesis 7TA data acquisition system	24	Isolated voltage channels	0.05 %
		3-phase power	0.2 %
Agilent 34980A data acquisition unit	80	Temperature from thermocouples (K)	<1°C

b) Accuracy of installed instrumentation

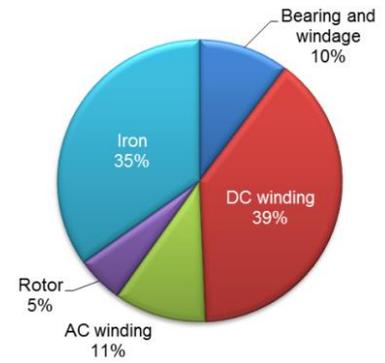
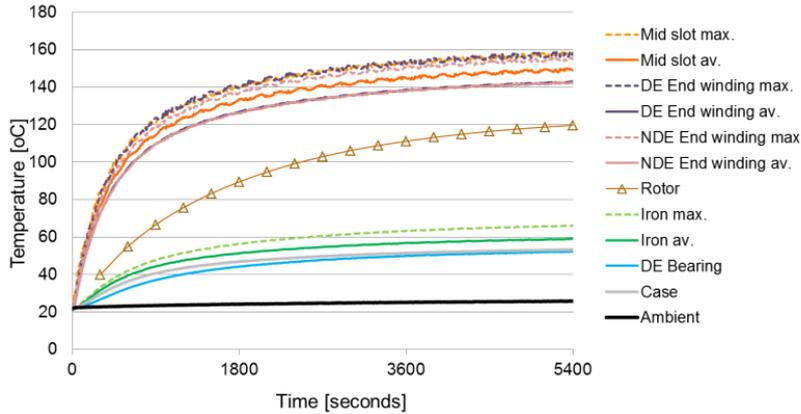
Figure 16 Control and instrumentation of test facility



a) Axial-flux prototype

b) Radial-flux prototype

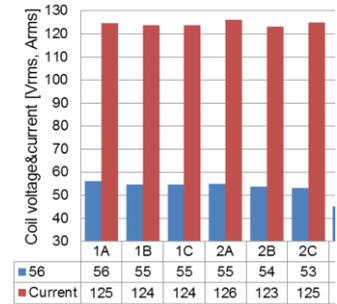
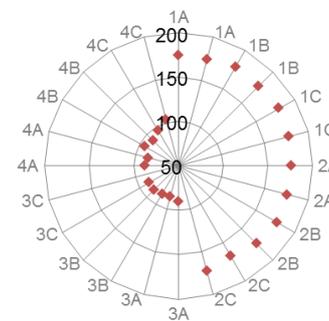
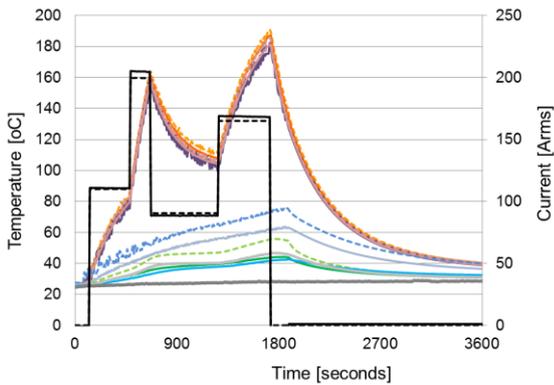
Figure 17 Open circuit loss characteristics and breakdown



a) Recorded temperatures

b) Loss breakdown

Figure 18 Example continuous sustained output measurement on radial-flux prototype

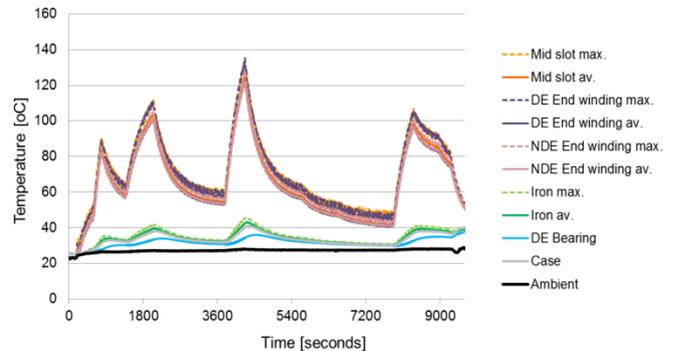
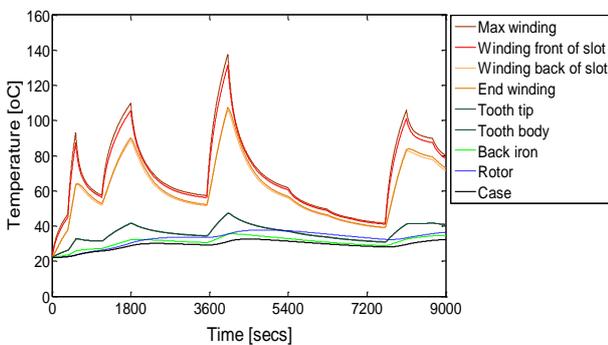


a) Plot of slot temperatures

b) Balance of phase currents and voltages

Figure 19 Mission cycle test

Figure 20 Analysis of sustained faulted operation



a) Model

b) Test

Figure 21 Example comparison of calibrated electrical machine model with test measurements