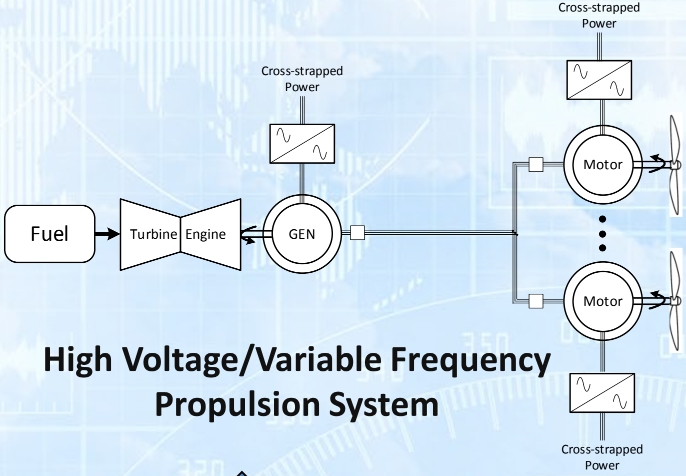
High Voltage Hybrid Electric Propulsion (HVHEP) Activity

Strathclyde

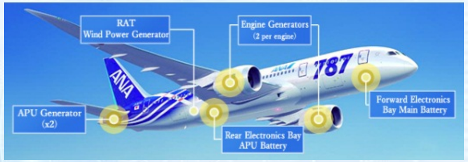
August 2017
Raymond Beach
NASA Glenn Research Center

Convergent Technology

High Voltage
Self Healing Insulation

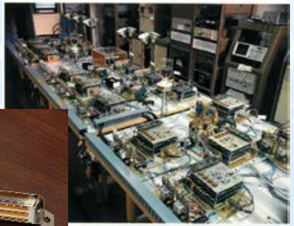


High Voltage/Variable Frequency Propulsion System

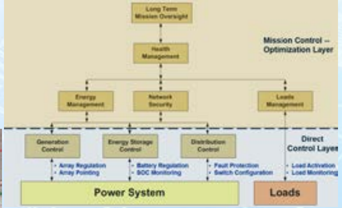


787 Variable Frequency
Power System


Cable


LeRC Testbed

SSF 20kHz Power System



Smart RPC


AES

Modular Power Systems


Ion Engine PPU
Fault Clearance


Wind Turbine
Doubly Fed Machine

CAS HVHEP Progress

- HVHEP Activity in fourth quarter/year 2 of $2\frac{1}{2}$ year effort
- Successfully exited 6 of 10 gated/milestone events

Event-driven activity	Event-driven activity
Initial operation of low power testbed	Setting less protection system with zero energy fault clearance
Stable control of variable frequency power system with DFIM	Manufacturing approach for MFIS
Multi-Functional Insulation Material (MFIS) concept	Monitoring concept for detection of insulation breakdown events
Minimum power electronic conversion for high efficiency and low weight	Validate scaling laws for variable frequency ac power system with DFIM
Self-healing insulation material characterization	Scaling laws applied to N+3 for use in system comparative analysis

HVHEP Teaming and Partners

NASA Team Members

- ARC – Distributed propulsion impacts on vehicle flight control
- LaRC - Self healing insulation materials
- GRC
  - Multi-layered functional insulation system
  - DFIM control development and power testbeds

Partners

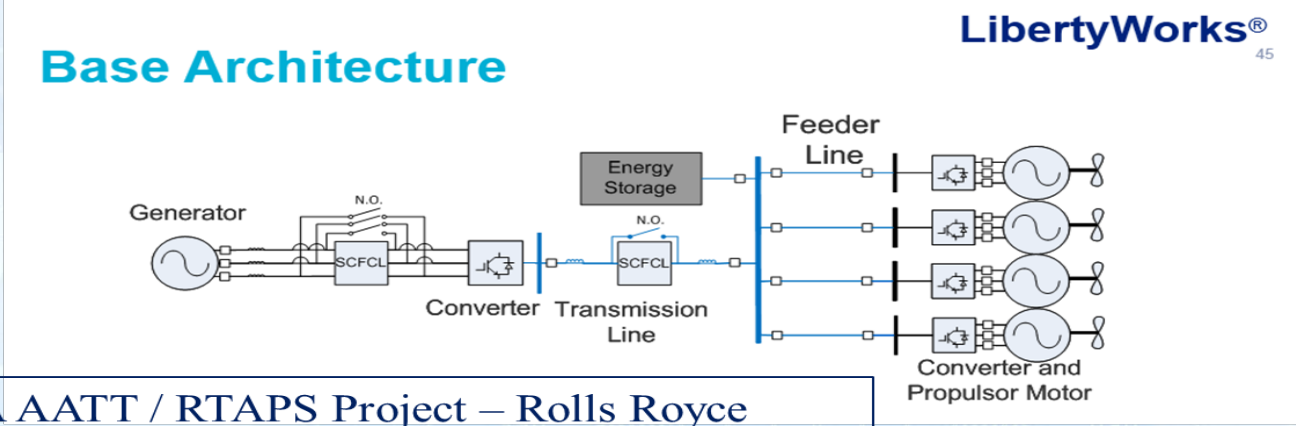
PCKrause and Associates – Models and simulation of DFIM and power testbeds

AFRL/Wright Patterson - INVENT aircraft secondary power model library

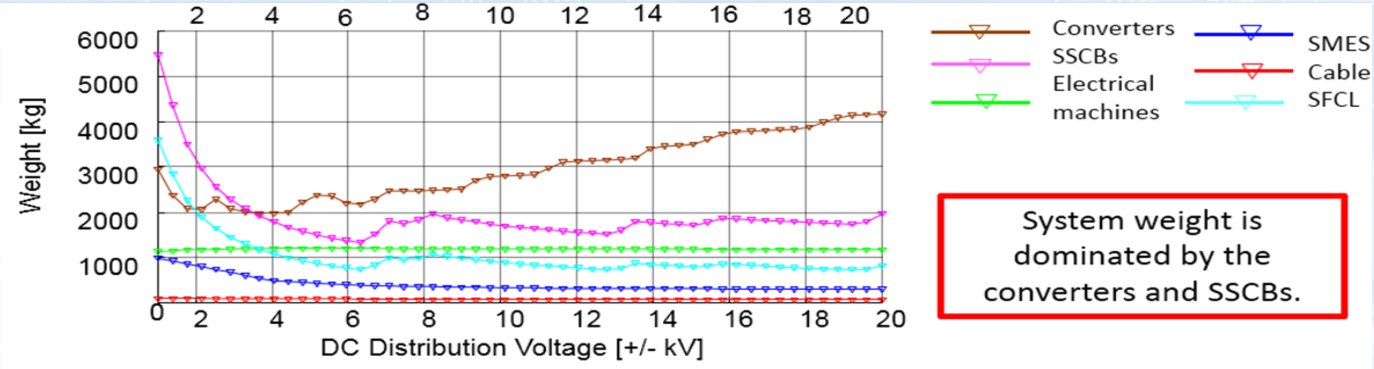
MIT – Dynamic control using DYMONDS software

UT-CEM - High speed brushless DFIM

Hybrid Electric Propulsion Architecture



NASA AATT / RTAPS Project – Rolls Royce

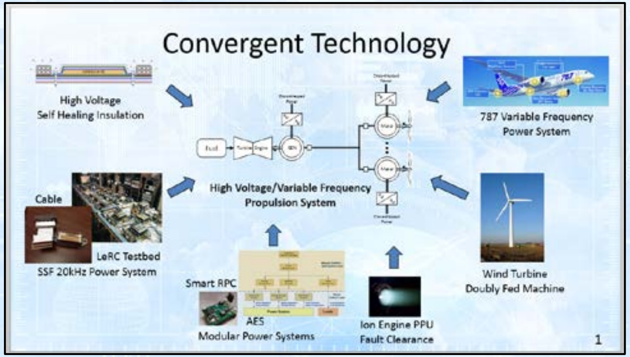


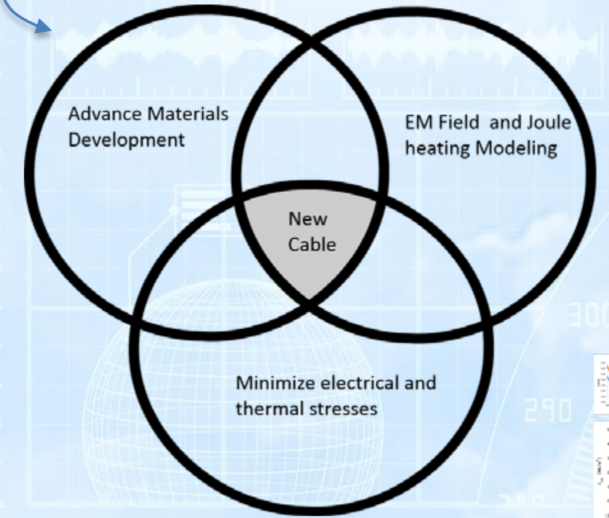
System weight is dominated by the converters and SSCBs.

High Frequency/High Voltage Cable and Wire

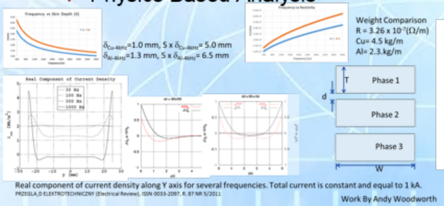
Convergent Technologies

- Multi-functional insulation system with self-healing materials
- Baseline prototype Space Station Freedom 20 kHz flat cable system

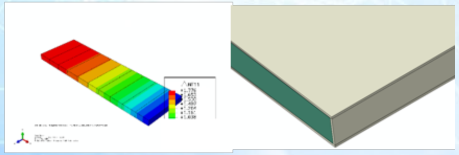




- Physics Based Analysis



- Joule Heating and EM Models



Multilayered Functional Insulation System

Multi-Functional Insulation Material (MFIS) concept

Current Status and Key Findings:

- No testing standards for ***high frequency*** HV power transmission cables
- Cable design requires a ***system engineering*** approach with integrated multidisciplinary Model: EM fields, Mechanical, Temperature, Pressure
- High thermal conductive insulator not needed for rectangular cable configuration but useful for motor windings
- Achieved breakdown voltage of 43.7 kV in multilayered insulator prototype

Future Work:

- Need to design materials with increased performance life to reduce likelihood of disruptive discharge events
- Continue development of advanced lightweight conductors, and EM shielding materials to keep cable weight low
- Collaboration with industry (Gore, Mersen) to address manufacturing

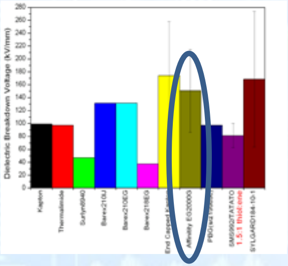
Impact To NASA

- Enable Hybrid Electric Propulsion system
- Development of new materials for AC and DC electrical systems for various industries: Space, Aeronautics, Terrestrial Vehicles, Electronics
- Development of Modeling Tools
- New Cable Architecture
- Partnership with Industry and Universities

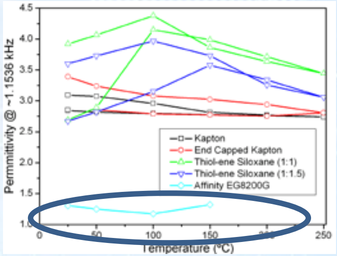
Self-Healing Insulation Materials

Self-healing insulation material characterization

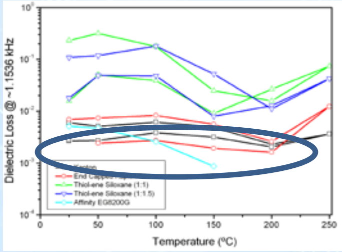
- Current Status



High Dielectric Breakdown Strength

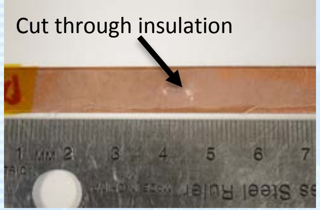


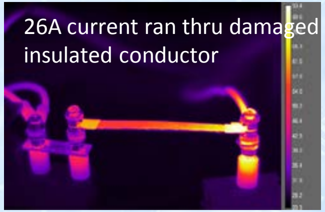
Low Permittivity/Dielectric Constant

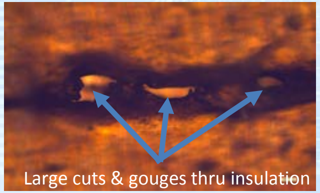


Low Dielectric Loss

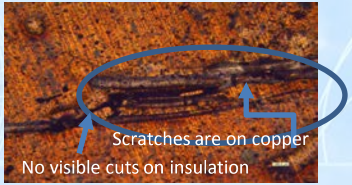
Survey of self-healing materials to evaluate suitability for insulation application







Damage enough to cause shorts

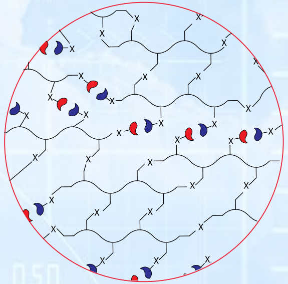


Cuts closed to prevent shorts

Affinity was coated onto copper, cut through to simulate chafing and cuts, then tested by running 26A of current. Insulation was restored to prevent shorting.

- Proposed Future Work
  - Evaluate utility of current self-healing materials in motor winding prototypes subject to use environment conditions
  - Develop self-healing materials for insulation application with service temperatures in the 300°C range

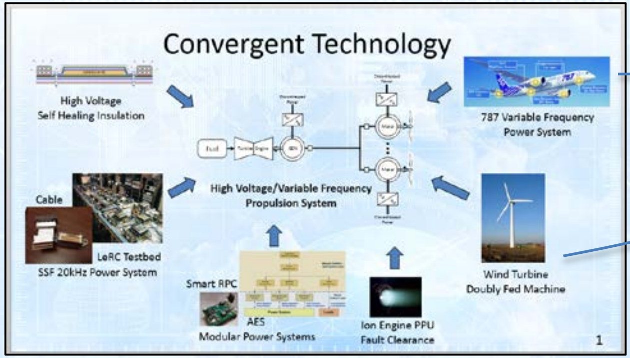
Repair



Inherently Self-Healing Material

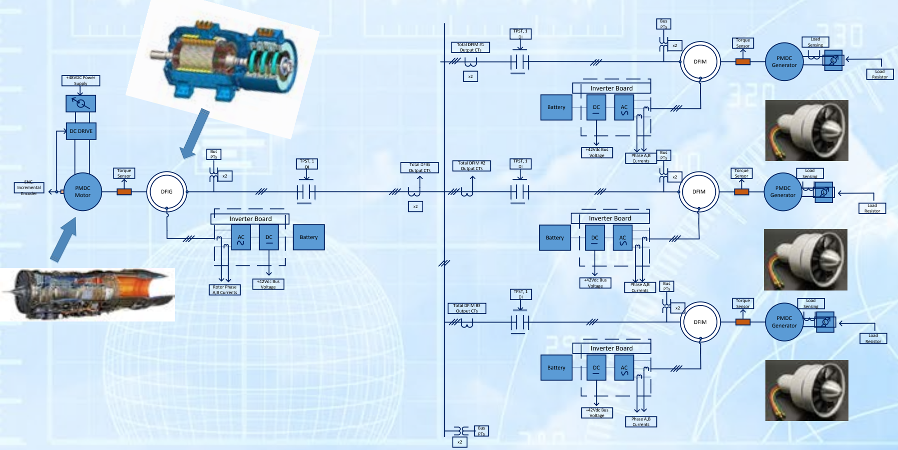
  - Synthesize various polymer compositions to assess thermal, mechanical and electrical self-healing under relevant use environments.

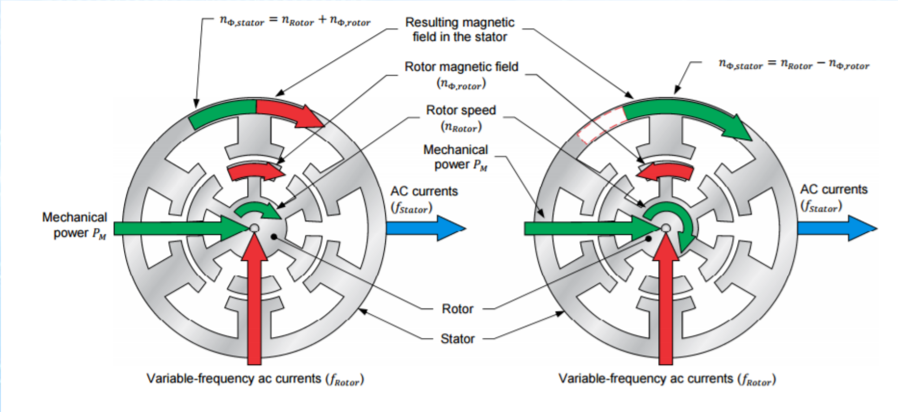
Variable Frequency Power System



Convergent Technologies

- Boeing 787 variable frequency power system (400 to 800 Hz)
- Wind turbine generators with doubly fed electrical machines to enable variable speed operation





CAS HVHEP System Benefits/Challenges

AC Electrical System and DFIM Benefits

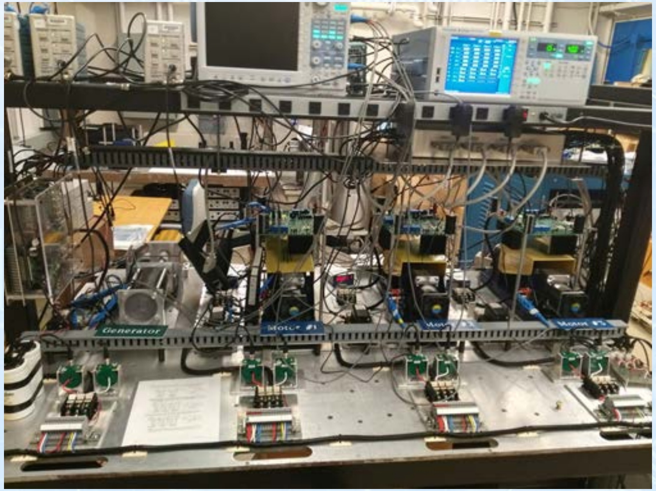
- Direct coupling of generator and propulsors significantly reduces power processing
- Cyclic Energy delivery provides natural commutation of current with each half cycle
- Transformer enables low voltage/high frequency switch mode power electronics
- AC field excitation eliminates remnant field enabling fast deactivation
- Switched doubly fed machine enables recovery from large disturbances (bird strike)
- Small disturbance recovery and variable speed operation of distributed propulsors achieved via ac field excitation and super/sub-synchronous operation of generators and propulsors
  - 60% differential speed for two engine aircraft

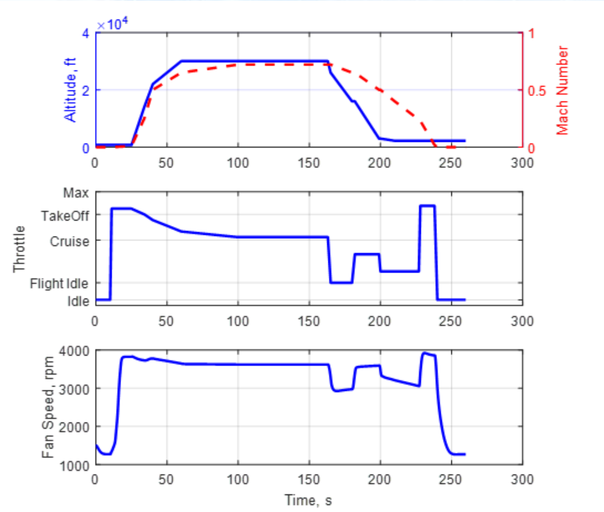
AC Electrical System and DFIM Challenges

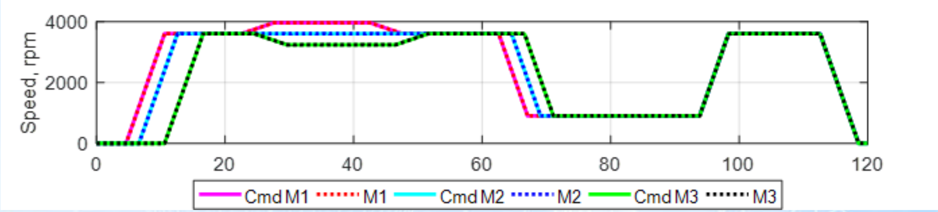
- Develop dynamic propulsion control (turbine, generator, protection, propulsor, fan/propeller, vehicle attitude)
- Develop integrated vehicle and propulsion model/simulation (turbine, generator, protection, propulsor, fan/propeller, vehicle attitude, thermal)
- Develop high speed, high frequency brushless doubly fed electric machine

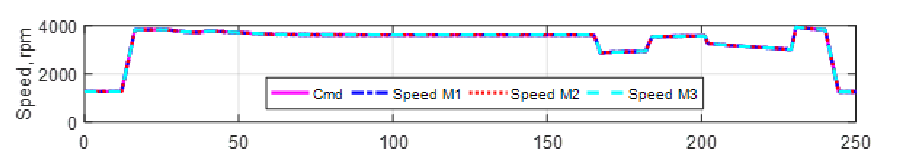
Variable Frequency Power System

Initial Operation of low power testbed	Stable control of variable frequency power system with DFIM	Minimum power electronic conversion for high efficiency and low weight

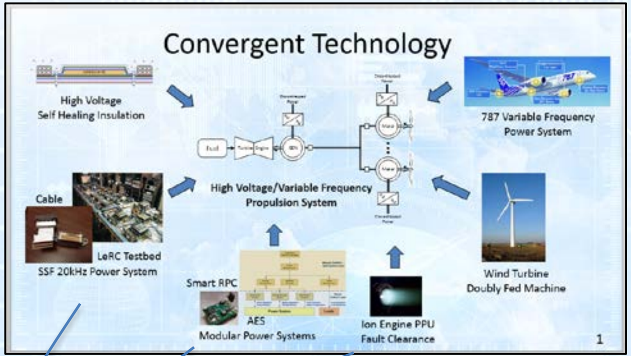


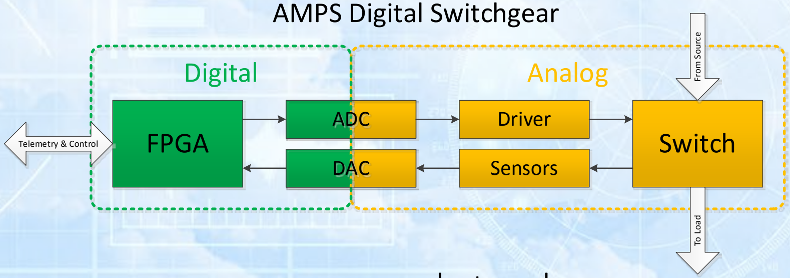


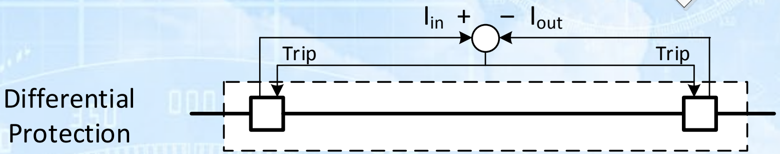




Settingless Protection

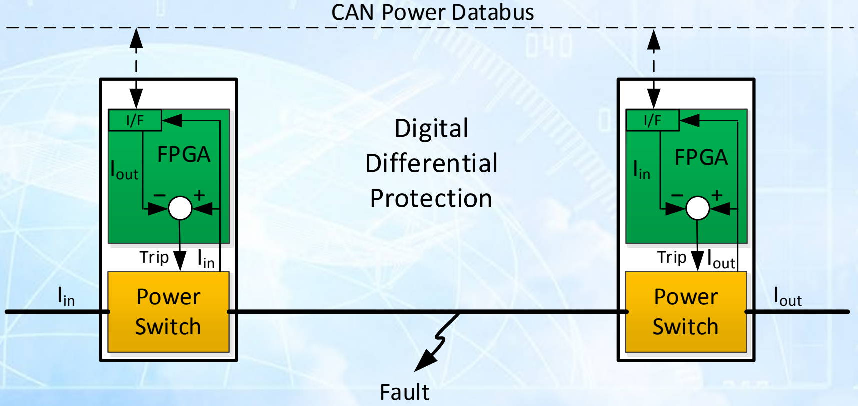






Convergent Technologies

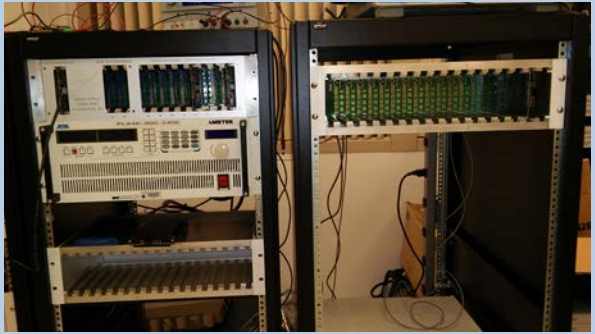
- Advanced Modular Power System digital control technology
- SSF differential protection zones for rapid detection and isolation of faults
- Ion engine zero energy fault clearance technology



HVHEP Protection

Setting less protection system with zero energy fault clearance

- Minimize aircraft collateral damage through fast detection and isolation of electrical faults
- Digital technology provides light weight implementation for distributed protection system, with superior noise filtering and immunity
- Protection system response time includes sensing, transfer of local data, data processing, field deactivation for generators and propulsors, and switchgear operation
- Protection testbed used AMPS digital switchgear in PDU with CAN data bus interconnection
- 3700 ns. response shows feasibility of digital differential zones with zero energy fault clearance and headroom for data checking and redundancy



Objective	ΔTime	Comments (All times from H/W test)
Current sense	500 ns.	Total time to measure current and convert to digital
Data bus	200 ns.	Total time to transmit current between switchgear device
Trip detection	500 ns.	Total time to perform calculation at each switchgear
Field deactivation	500 ns.	Update time for generator and motor regulation
Switchgear isolation	2000 ns.	Hybrid switchgear response time (solid state/mechanical relay)
Total Time	3700 ns.	Total time for all functions for comparison to half cycle @ 2 kHz (250,000 ns.)

Remaining Gates/Milestones

Manufacturing approach for MFIS	Validate scaling laws for variable frequency ac power system with DFIM
Monitoring concept for detection of insulation breakdown events	Scaling laws applied to N+3 for use in system comparative analysis

- Collaboration activities with Gore Industries and Mersen provides wire and cable manufacturing expertise
- LaRC materials testing provides experimental data for detection and healing of breakdown events to enable incorporation into protection system
- GRC 12MW variable frequency power system with DFIM's provides high power test data for scaling law development
- Rolls Royce RTAPS report used for comparative analysis

HVHEP Technical Solutions Beyond Feasibility

- Develop brushless high power, high frequency, high voltage doubly fed electric machine for propulsor application
  - Balcones Technologies/University of Texas-Center for Electro-Mechanics
  - Challenge: High specific power machine with large rotor/stator pole ratio and step up transformer isolated field excitation power inverter
- Develop distributed turbo-electric propulsion control to provide dynamic stability
  - New Electricity Transmission Software Solutions/MIT
  - Challenge: Integrated control of turbine engine, generator, protection system, propulsor, ducted fan/propeller, vehicle attitude
- Develop distributed propulsion model/simulation
  - Paul C Krause and Associates
  - Challenge: Integrated real time simulation of turbine engine, generator, protection system, propulsor, ducted fan/propeller, vehicle attitude, thermal