# *Reinventing Power Programs Through Sustainability Focused Curriculum: An Update*

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**Mission Capable, Persistent and Survivable Naval Platforms**
**Office of Naval Research**
**National Science Foundation**
***21/22 October 2022***

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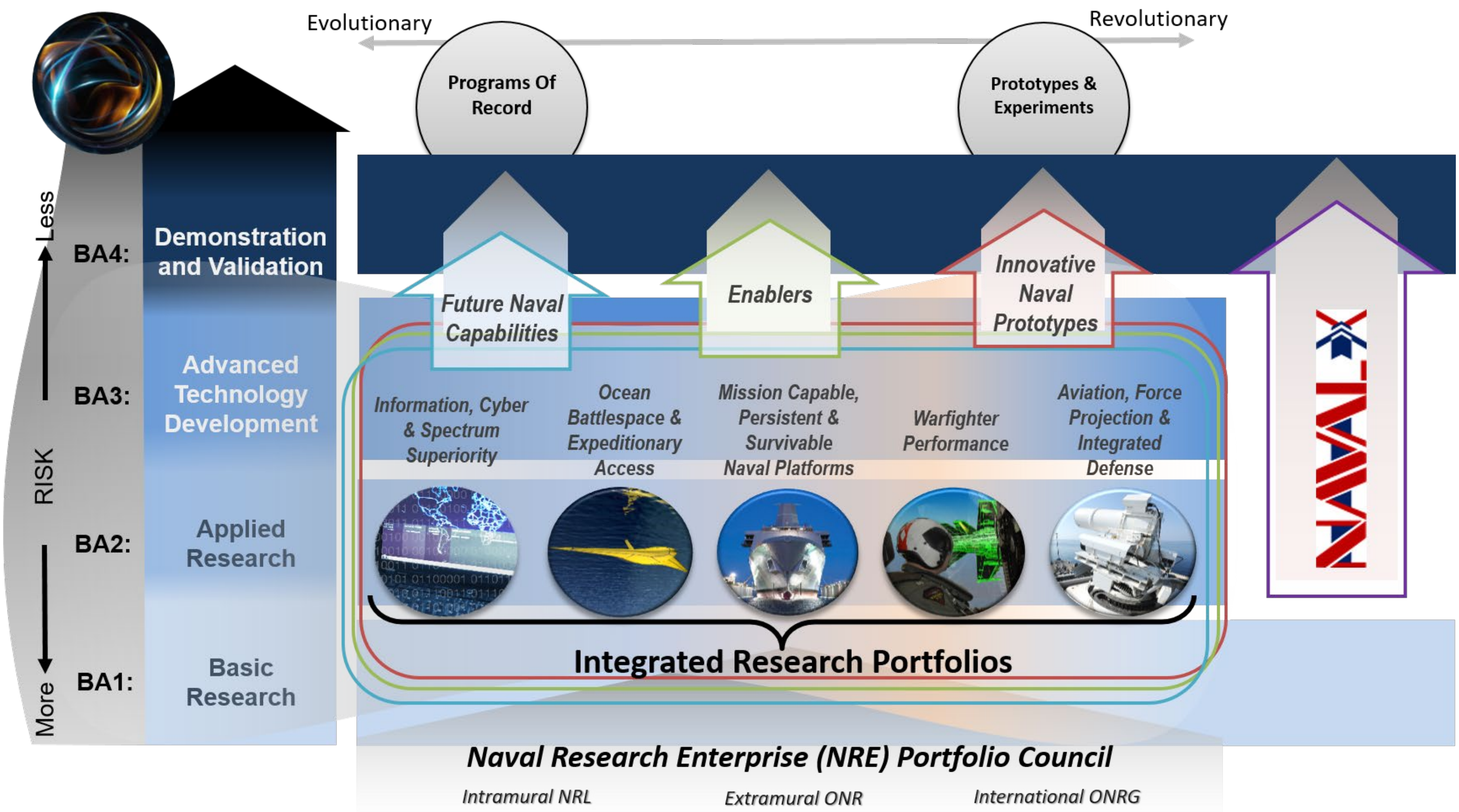
# The Portfolio – ONR Departments

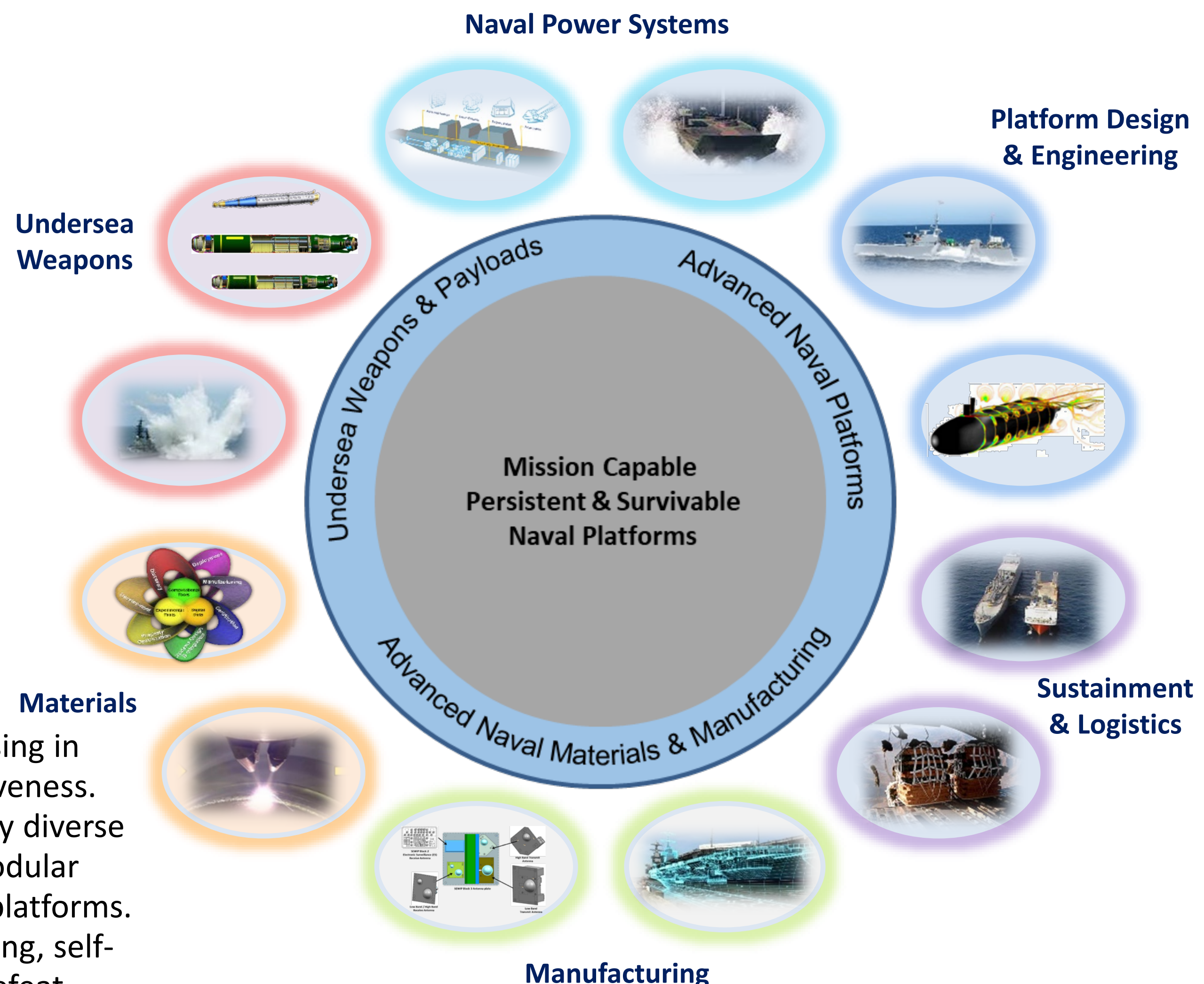


# NAVAL PLATFORMS

## Mission Capable, Persistent, and Survivable

### AT A GLANCE

Research on concepts, systems and component technologies that improve the performance and survivability of Navy and Marine Corps platforms in an increasingly distributed yet interconnected force.




### WHY IS THIS IMPORTANT

- Threats to the fleet/force are increasing in number, range, precision and effectiveness.
- Sustainable operations in increasingly diverse environments require affordable, modular survivable and rapidly upgradeable platforms.
- Maritime superiority requires enduring, self-sustaining platforms able to deter/defeat aggression through overwhelming capability.

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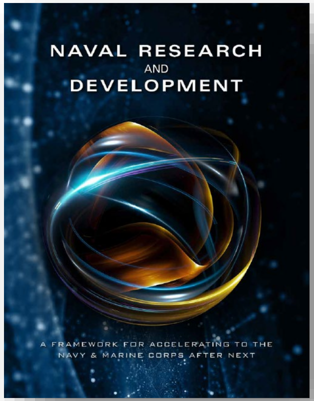
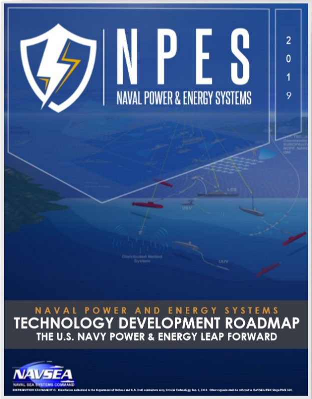
# Strategic P&E Guidance




**From Naval R&D Framework**

**- Operational Endurance Priority:**

- Enable maneuverability, efficiency and resiliency for sustained operations by warfighters, systems and platforms (regardless of the threat or operating environment)
- Improve platform-level energy storage/efficiency for propulsion and weapons systems




**The 2019 Naval Power & Energy Systems Technology Development Roadmap (NPES TDR)**

- Reinforces power and energy as the foundation of the kill chain.
- Promotes energy harvesting and improved efficiency in components, power systems, and energy conversion systems

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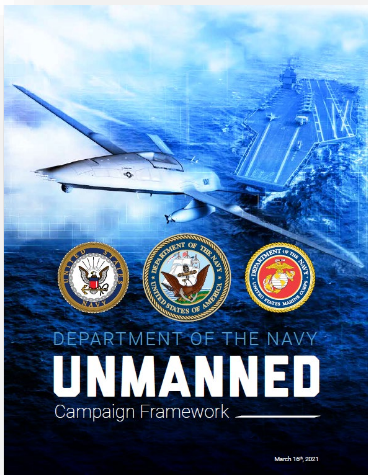
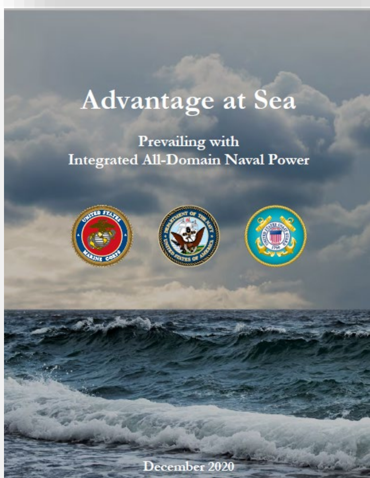
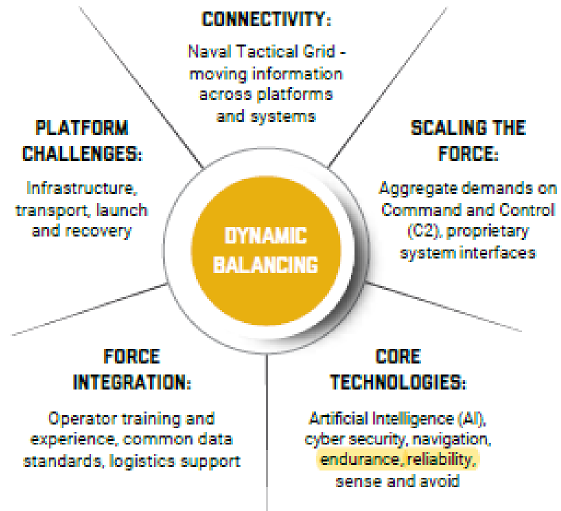
# Strategic P&E Guidance




*"New and converging technologies will have profound impacts on the security environment. Artificial intelligence, autonomy, additive manufacturing, quantum computing, and new communications and energy technologies could each, individually, generate enormous disruptive change."*

# S&T Objectives: Develop Courses and Laboratories for Electric Energy Education

- A better-trained supply of U.S. graduates in STEM to tackle various research challenges in the Navy
- Adding flexibility and safety to ensure that they will be useable in a variety of future Navy courses and learning needs
  - Do so by enabling all universities to provide a first-rate education and educate students in large numbers

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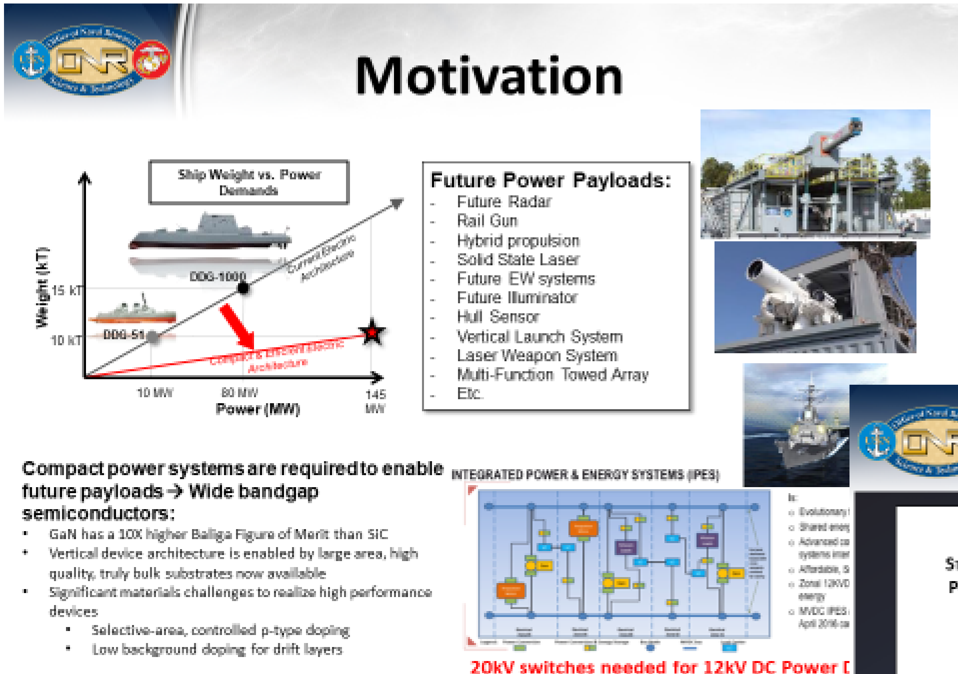
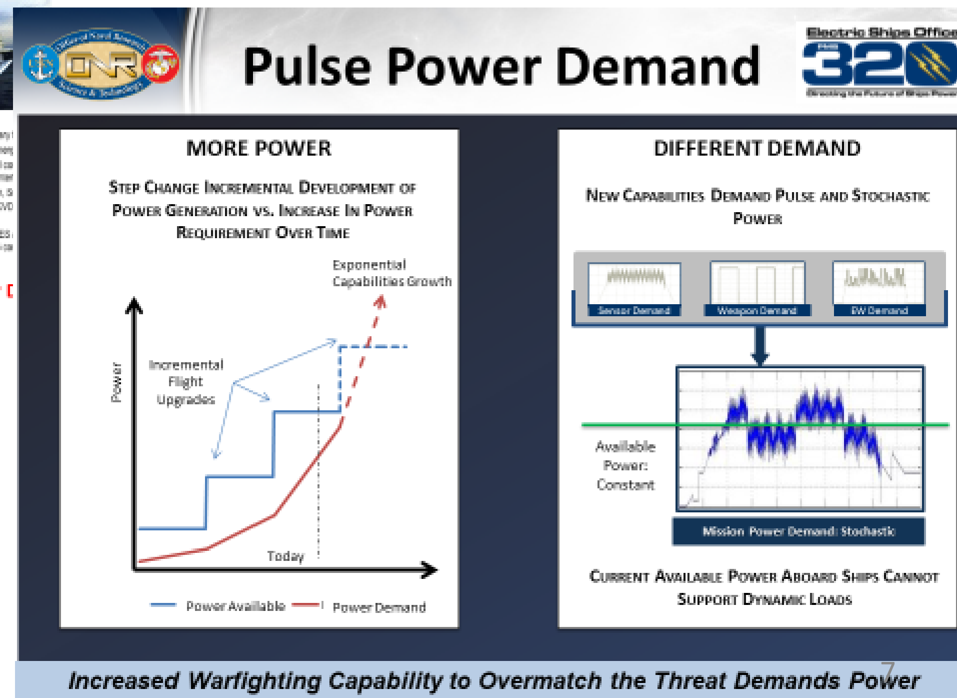
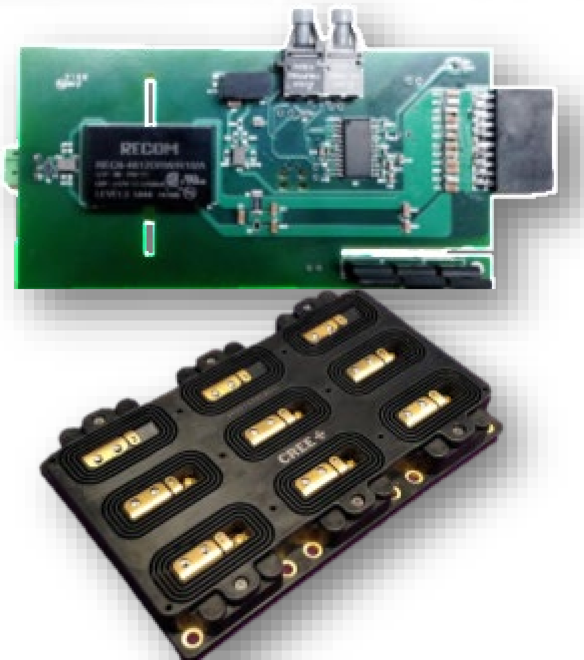
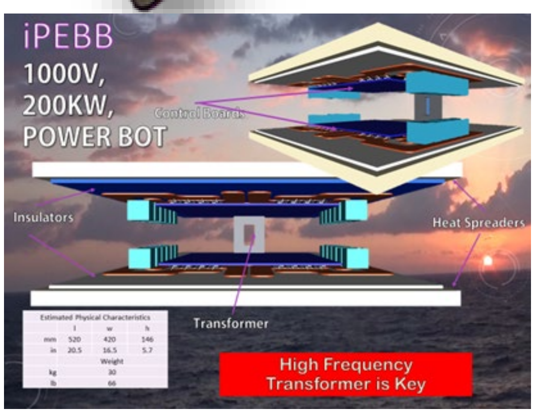
# Motivation: High Power and Pulsed Power Applications



# Technical Advances



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- Silicon Carbide Power Switches
- 100kHz or greater switching
- FPGA
    - Field Programmable Gate Arrays
    - High Speed Control
    - Intelligent Power Modules
- High Frequency Magnetics
- Highly Integrated PEBB (Navy iPEBB) Based Converters
- Enables Power Electronic Power Distribution System Concept

**Curriculum Completed and on CUSP in WBG Theory and Application through an ONR Grant**

# Navy Power Electronic Building Blocks & Power Electronics Power Distribution System



## PEPDS is an Integrated Power and Energy Power Distribution System

**PEPDS**

- Integrated Power, Propulsion, Protection, Filtering, Storage, and Control
- Distribution Converters provide protection, filtering, and (with Energy Magazines) storage
- Distribution Converters create an interface for every load
  - No single interface standard for all loads.
  - AC or DC, Frequency, Voltage, Power, etc. are tailored to meet individual load requirements.
- Common Interface Solutions for All Loads – high commonality
- Integrated Electrical, Thermal, and Mechanical Control

**Challenge**

- Specifying interfaces for every load
- Very little or no reductions in size, weight, and cost will occur, If load components are just moved from the loads to the distribution system.
- Using distributed resources and integrated functionality to eliminate redundant elements.
  - Providing power quality to loads using fewer components.
- Reducing components will require research such as:
  - Advanced power electronic control across many converters,
  - Concepts for distributed storage, and
  - Active filtering across many converters.

**Least Replaceable Unit, Most Common Denominator -- Key To Enabling PEPDS**

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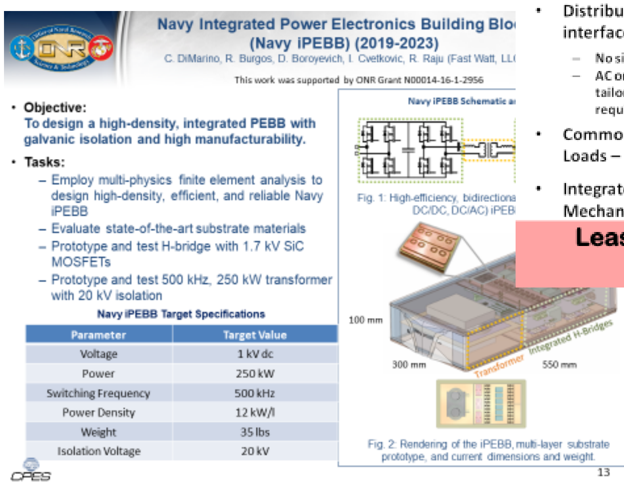


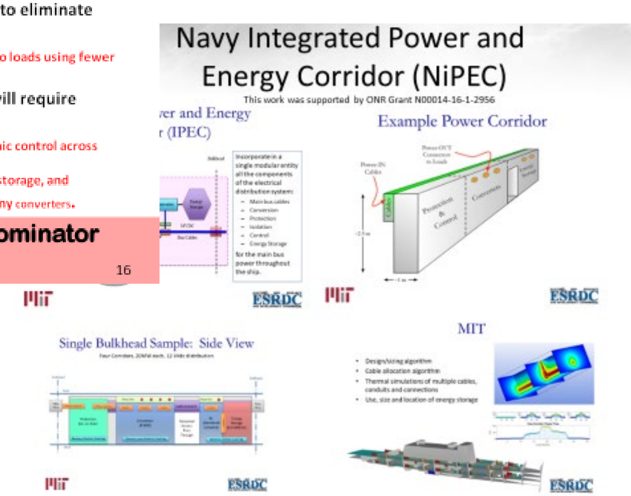


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# Background : Magnetics in Power Conversion

**Magnetics** - key factor determining the size, weight and efficiency of power converters

**Multiple functions -**

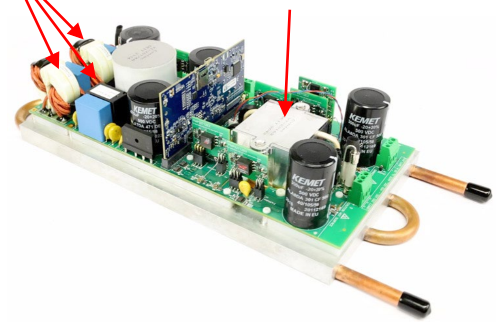
Transformers: voltage and current scaling, sensing
Inductors: energy storage, circuit resonance, filtering, current limiting

**Varied requirements -**

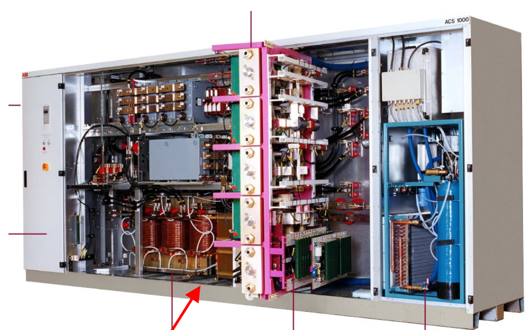
high permeability for line-frequency transformers,
distributed gaps or low permeability for inductors,
high impedance and damping at noise frequencies for CM chokes,
+ low magnetostriction/audible noise, low loss, high saturation flux, etc.

Common/ differential mode filters

Transformer

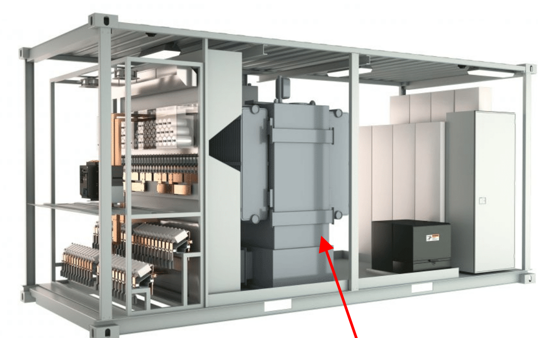


On-board EV charger
(TI reference design, ti.com)



Output filter

Medium Voltage Motor Drive
(ABB ACS1000, abb.com)



Step-up transformer

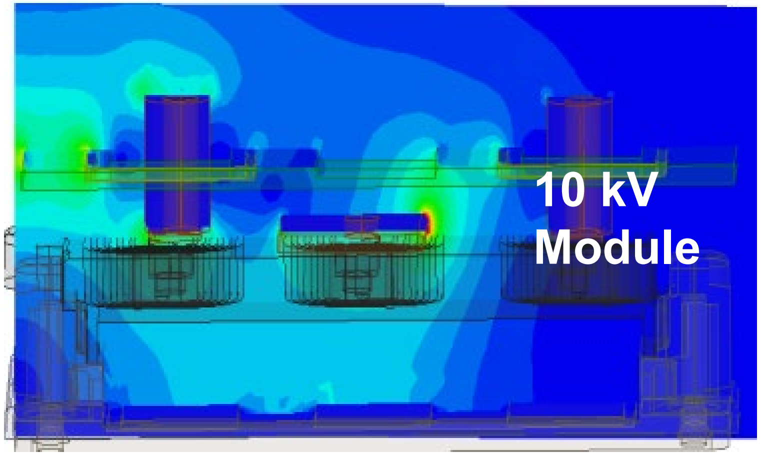
Utility Solar Inverter
(GE Power Conversion, ge.com)



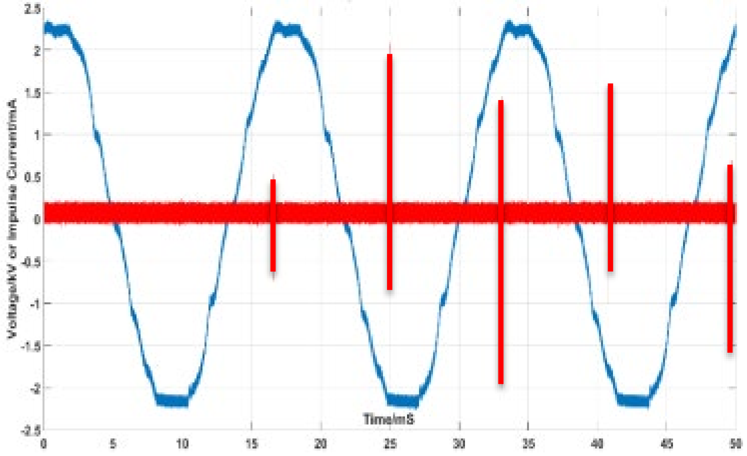
Research Being Conducted Under Grant N00014-21-1-2498

# Key Challenges

- Heightened EMI emissions due to high switching frequency, fast dv/dt, and large parasitic capacitances to ground
  - Mitigation: use impedance-based EMI channeling technique
- Design of high-voltage insulation strategy capable of withstanding high electric fields under fast PWM conditions
  - Mitigation: proper selection of materials, partial discharge (PD) measurements, finite element analysis (FEA)




PD Measurement




**Curriculum Development completed in Sustainable Education in EMI, Common Mode Differential Mode theoretically speaking and in practice, through an ONR Grant, N000141812601, Dr. Andy Lemmon, University of Alabama, and a second in Creepage and Clearance standards development, ONR Grants N000141812547, Dr. Rob Cuzner, University of Wisconsin, Milwaukee; N000141812623, Dr. Lukas Graber, Georgia Tech, and N000141612956, Dr. Michael Steurer, Florida State University. In the near future, sustainable education in machine and drive insulation**

# ONR Grants

1. Center for Reforming Undergraduate Education in Electrical Engineering Energy Systems – A Critical Infrastructure for National Security Jun1, 2006 – Sept 30, 2012, $1,292,441 + $38,062
2. Center for Developing and Disseminating a Graduate/Undergraduate Curriculum 6/1/2011- 02/29/2016, $828,051 + $56,362
3. Increasing Electric Power and Energy Engineering Pipeline Nationwide 3/15/2014- 4/30/2016, $106,000
4. Offering of Web-Enabled, Instructor-Taught Online Courses based on ONR-Funded Graduate Power Curriculum 6/2015 – 05/31/2020, $590,000
5. National Dissemination of the CUSP™ Electric Power Curriculum 8/10/2018- 5/31/2021, UMN Share from TTU $21,392
6. Developing WBG-Based, Extremely Low- Cost Laboratories for Power Electronics, Motor Drives, and Power System Protection and Relays for National Dissemination 01/01/2019 – 12/31/2023, $701,747
7. A Low-Cost Scalable Tabletop Emulator for Shipboard Power System 07/01/2022- 12/31/2026, $788,192

# The Most Important Resource: People

## Objective / Goal

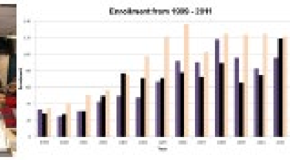
- Revive and Enhance Education - Prepare next generation of Navy electrical & power engineers
- Meet increasing demands in power-related fields in the Navy and elsewhere
- Educate naval officers to maintain, operate, & sustain naval power systems

## Summary of Effort

- Develop 19 courses in Electric Power & Energy Systems
- Disseminate widely by offering course materials free online to all U.S. universities for classroom and distance learning

## Major Participants

- Ned Mohan – University of Minnesota
- Consortium of Universities for Sustainable Power (CUSP) – 235 universities participating as of October 2022 (ref:http://cusp.umn.edu/cusp-members.php)



## Recent Accomplishments

- 19 courses completed
- Adopted by USNA and Naval Postgraduate School for core and distance learning curriculum
- Over 450 faculty members are using the learning curriculum

## Key Milestones / Projected Transition

- **Near:** Publication of all 19 courses complete; Additional courses Master's Program (TTU) commenced in FY19
- **Mid/Far:** Educate/Train Navy and Industry Power Engineering Workforce with emerging technologies


Questions?