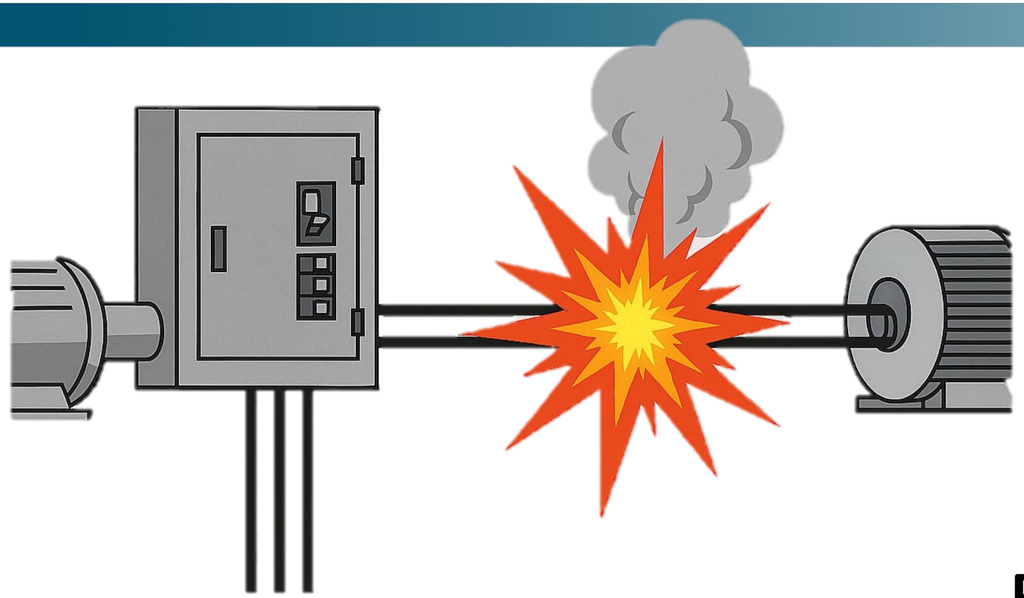


Multiphysics-Driven Arc-Fault Detection for Shipboard Electrical Systems via Sensor Fusion and Machine Learning

(Task Order 2026-361)

Philip Pong
philip.pong@njit.edu
Associate Professor
Department of Electrical and Computer Engineering
New Jersey Institute of Technology

NSRP National Shipbuilding Research Program™ Taking Shipbuilding and Repair to the Next Level
INGALLS SHIPBUILDING A Division of HII
GD Bath Iron Works
NAVSEA WARFARE CENTERS Philadelphia
NJIT New Jersey Institute of Technology
ABB

Outline:

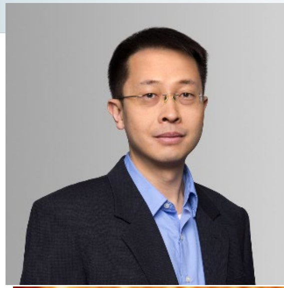
1. Introduction to Team Members
2. Facilities at NJIT
3. Project Overview
4. Next Step

Introduction to Team Members

Team Members

Name	Position	Affiliation	Email
Philip Pong	Associate Professor	New Jersey Institute of Technology	philip.pong@njit.edu
Tanima Bal	PhD student	New Jersey Institute of Technology	tb445@njit.edu
Jason Farmer	Project Lead	Ingalls	jason.farmer@hii-ingalls.com
Brandon Whaley	Engineer	Naval Surface Warfare Center (NSWC) Philadelphia	brandon.f.whaley.civ@us.navy.mil
Jacob Matthews	Engineer	Naval Surface Warfare Center (NSWC) Philadelphia	jacob.e.matthews3.civ@us.navy.mil
Kyle Robinson-Jordan	Engineer Officer	Naval Sea Systems Command	kyle.m.robinson-jordan.civ@us.navy.mil
Christopher Nemarich	Engineering Manager	Naval Sea Systems Command	christopher.p.nemarich.civ@us.navy.mil
Rickey DeLoge	Electrical Engineering Supervisor	General Dynamics Bath Iron Works (GDBIW)	rickey.deloge@gdbiw.com
William Bessette	Electrical Engineering, Design Services	General Dynamics Bath Iron Works (GDBIW)	William.Bessette@gdbiw.com
Odirlei Moser	Product Marketing Specialist	ABB	odirlei.moser@us.abb.com
Walt Skalniak	Territory Manager	Ashby	wskalniak@ashbyco.com
Lydia Szydlo	NSRP Panel Coordinator, Sr. Program Administrator	NSRP/Advanced Technology International	lydia.szydlo@ati.org
Ryan Schneider	Program Manager	NSRP/Advanced Technology International	ryan.schneider@ATI.ORG

Research Background and Expertise: Philip Pong (PI)

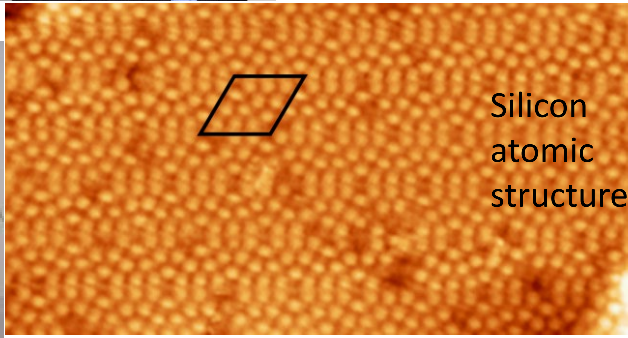


Background:
- Electrical and electronic engineering (BEng, The University of Hong Kong)
- Instrumentation – scanning tunneling microscope (PhD, University of Cambridge)
- Ultrasensitive Sensor device fabrication (Postdoc, National Institute of Standards and Technology, USA)
- Sensor device, sensing system, applications in smart grid and smart city, power industry projects (The University of Hong Kong)

Research interest: sensor fusion, fault detection, condition monitoring

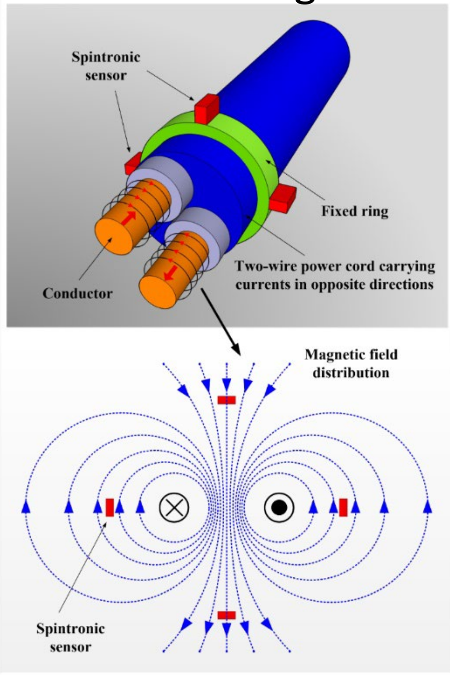
Power & Energy Initiatives:
- Power Systems Engineering Center (NJIT), Center Director
- MS Power and Energy Systems, Program Advisor
- Grad Cert Power Systems Engineering, Program Advisor
- Grad Cert Wind Power Systems Planning, Operation & Maintenance, Program Advisor
- Grad Cert Wind Power Management, Program Advisor

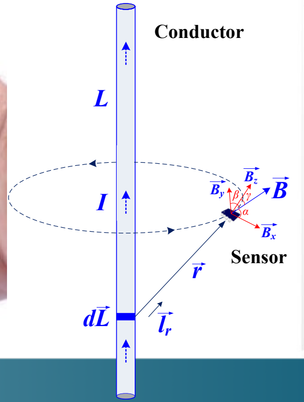
High precision instrument

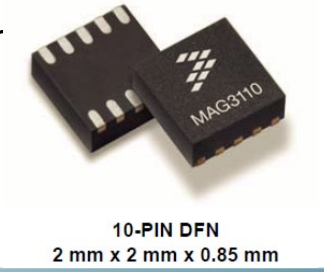


Sensor fabrication

Power grid







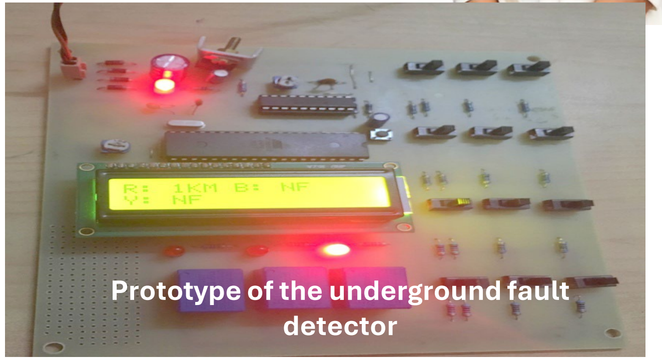
Electromagnetic sensors

Embedded system

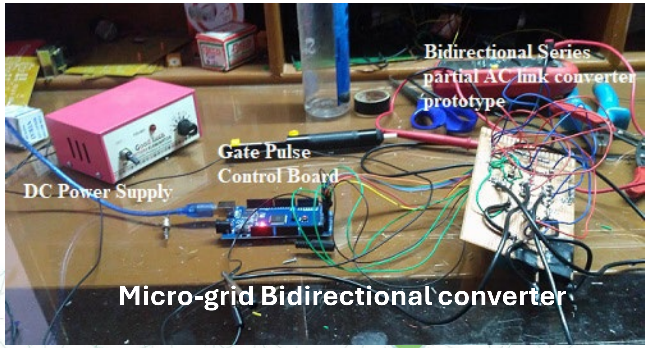
Research Background and expertise: Tanima Bal (PhD student)

❖ Background

- Ph.D. Student, Electrical Engineering – New Jersey Institute of Technology
- M.Tech., Electrical & Electronics Engineering (Power Electronics & Drives), National Institute of Technology India.
- Developed prototype for underground fault detection & localization.
- Designed control strategies for microgrid bidirectional converters.
- Applied real-time, data-driven optimization for net-zero energy buildings.
- Focused on improving system reliability via controller configurations.



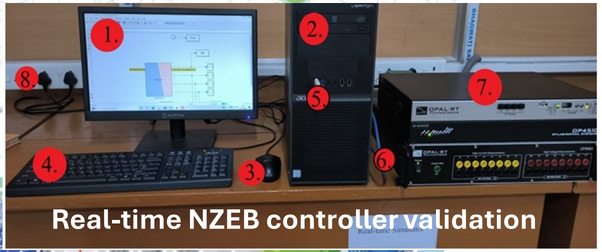
Prototype of the underground fault detector



Micro-grid Bidirectional converter

❖ Research Interest

- **Smart sensor technologies** for monitoring, control, and implementation in modern power grids.
- **Physics-based fault detection** using real-time simulation and finite element method.
- **Machine learning**–based approaches for improving resilience and reliability of modern power systems.



Real-time NZEB controller validation

Facilities at NJIT

New Jersey Institute of Technology (NJIT)

- Located in Newark, NJ – ~20 minutes from Newark Liberty International Airport by car, ~20 minutes from New York City by train
- Proximity enables joint research, student internship programs, and facility access
- ~11,900 students, including 4,200+ graduate students
- Offers BS, MS, and PhD programs across engineering, computing, and science
- Newark College of Engineering (NCE) – including:
    - Electrical and Computer Engineering
    - Mechanical and Industrial Engineering
    - Chemical and Materials Engineering
    - Construction Engineering Technology
- College of Science and Liberal Arts (CSLA)
    - Physics
    - Biological Sciences
    - Chemistry and Environmental Science
    - Mathematical Sciences
- Ying Wu College of Computing – among the largest CS programs in the U.S.

Modeling and Data Analytics Server

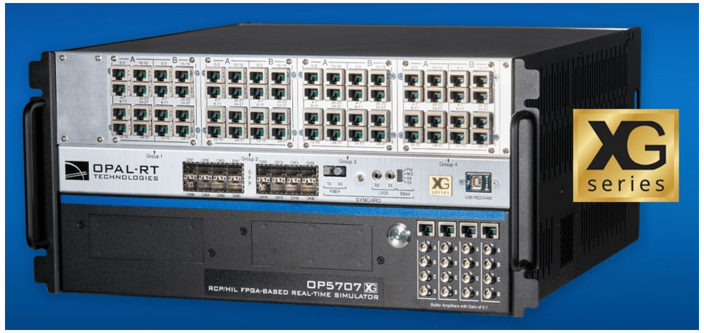
remote access

NREL
Transforming ENERGY

ethernet

OPAL-RT High-End Performance Real-Time Simulator

Hardware
OP5707XG real-time simulator
Intel Xeon 8 cores, 3.8 GHz
Xilinx Virtex 7 485T
Real-time simulation capability
Full scale transmission grid



SIEMENS eMobility DC Fast-Charger

ethernet

optical fiber

optical fiber

OPAL-RT Microgrid PHIL Test Bench

Hardware
OP4610XG real-time simulator
5kW 3-phase 4-quadrant PHIL amplifier
6kW 500V DC power supply
Hardware-in-the-loop simulation example
66kV AC-grid
145kW 3-phase distribution load
480V 1MWh battery energy storage system
480V 12kVA photovoltaic generation system
575V 10kVA wind turbine generation system
600V 70kVA diesel generation system

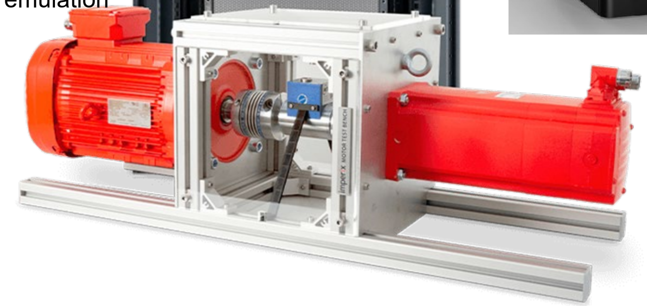
ethernet

Imperix Rapid Control Prototyping for Power Electronics Applications

Hardware
4 kW squirrel cage induction machine
4 kW permanent magnet synchronous machine
800V/38A SiC half-bridge modules
Bidirectional torque sensor
2x PT1000 temperature sensors
Resolver (position sensor)
Real-time simulation capability
Control hardware-in-the-loop (C-HIL)
Grid-following and grid-forming control schemes
Wind turbine emulation

Vizimax PMU

Hardware
10x digital inputs
6x high-current digital outputs
Measurements
Synchrophasor up to 240 frames per second
Sampled values reporting with IEC 61850-9-2LE and IEC 61869-9



NJIT New Jersey Institute of Technology

NHR 9410 Regenerative Grid Simulator 12kW (3 phases)

NHR 9430 AC Regenerative Load 12kW (3 phases)

NHR 4760 DC Electronic Loads 600V, 6kW

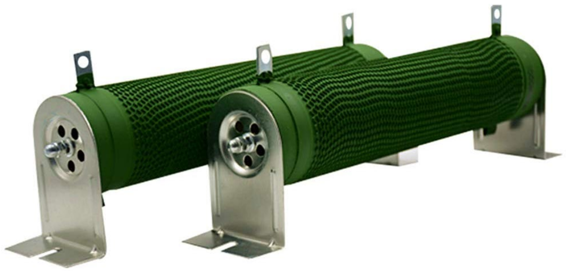
ITECH Bidirectional DC Power Supply 300V/120A/12kW

Fronius Symo Advanced 208-240V 3-Phase Inverter 10kW

Keithley High-Precision Sourcemeter

Digital Oscilloscopes

Digital Multimeters



NJIT
New Jersey Institute of Technology

Digital Function Generator

Digital DC Power Supply

High-Power Resistive Load

Lucas-Nuelle: ESG1
Smart Grid Trainer

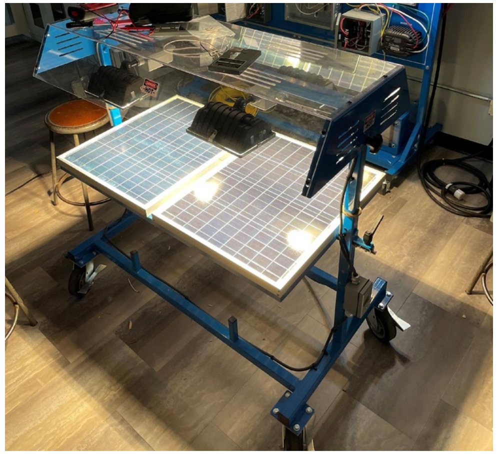
Lucas-Nuelle: EUC
Energy Management

Lucas-Nuelle: EPH
Professional Photovoltaics
Trainer

Lucas-Nuelle: EUG1
Manually Operated
Synchronous Circuits

Amatrol Photovoltaic
Installation Learning System
950-SPF1

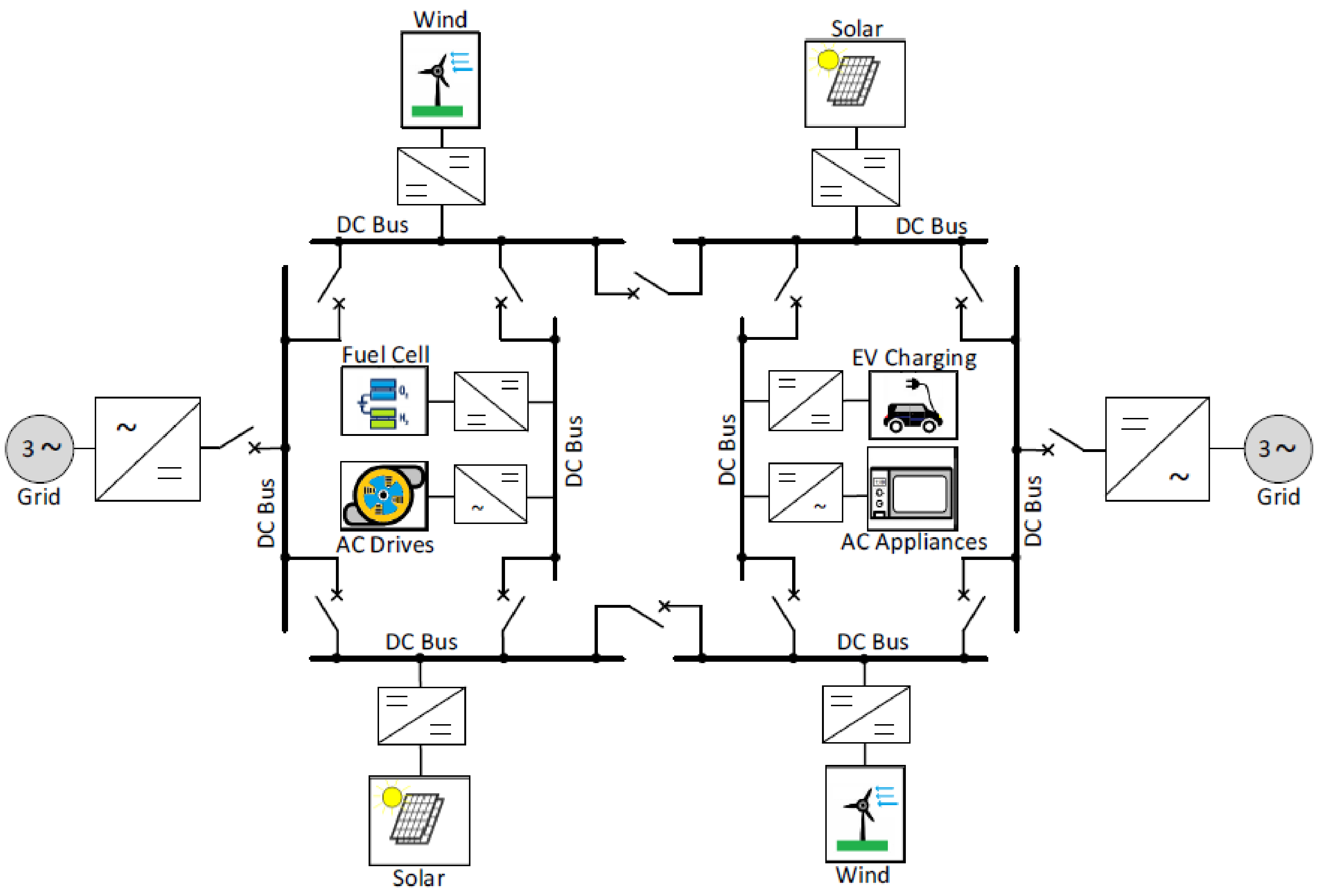
Amatrol Photovoltaic
Troubleshooting Learning
System 950-SPT1

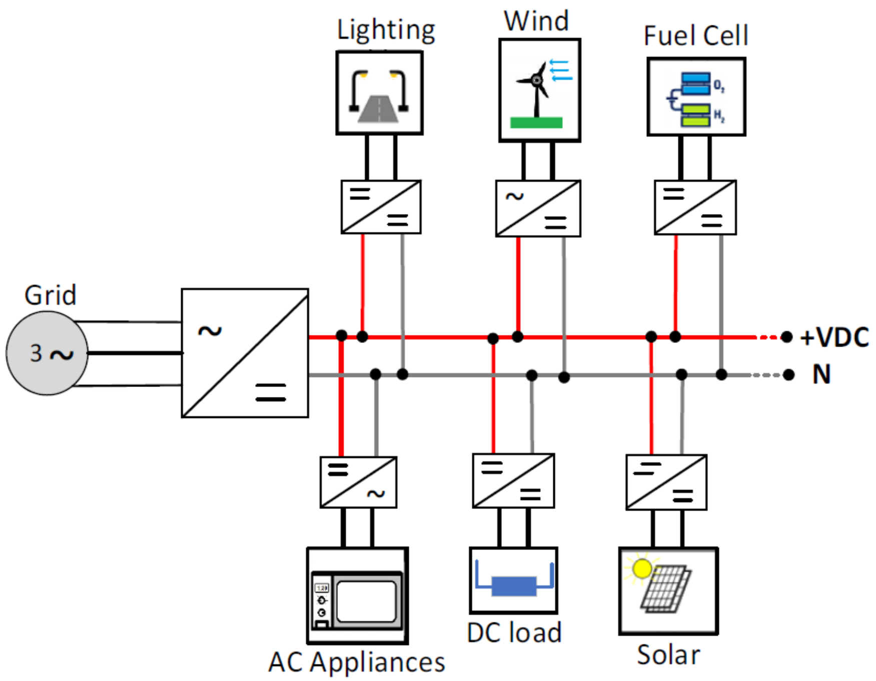


NJIT
New Jersey Institute
of Technology

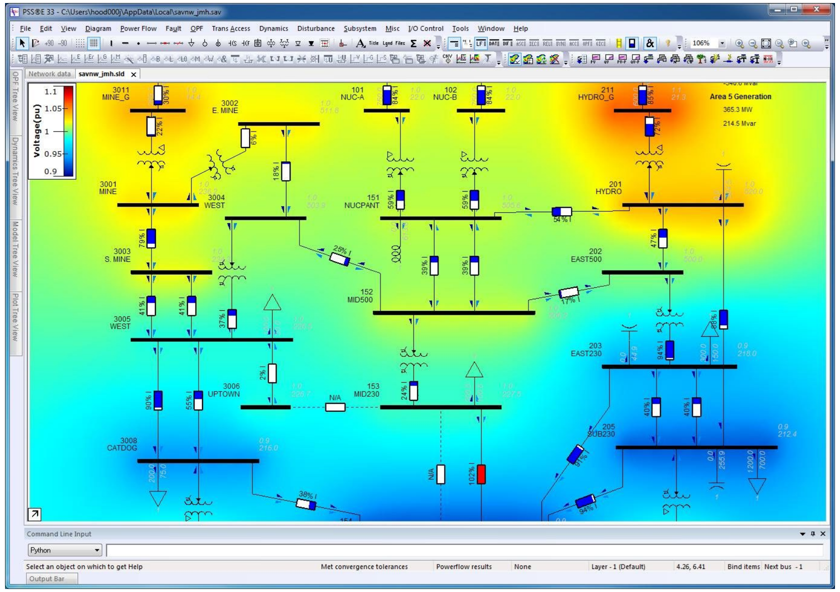
200-kW Reconfigurable Microgrid Testbed

We can experimentally explore and test with various microgrid topology



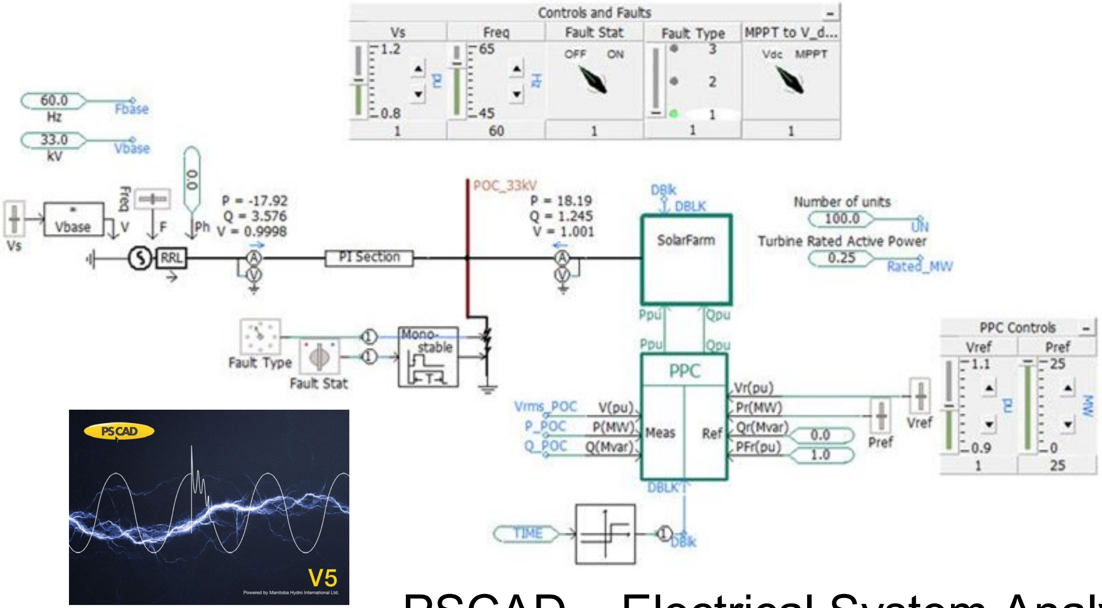


New Jersey Institute of Technology



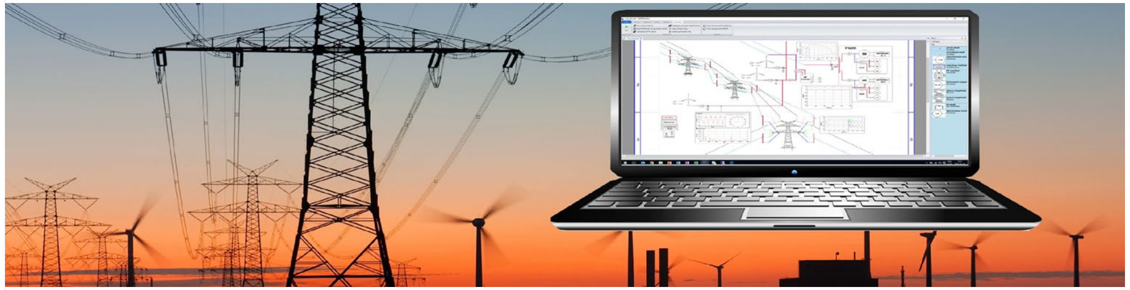
PSS®E

PSSE – Transmission Planning and Analysis

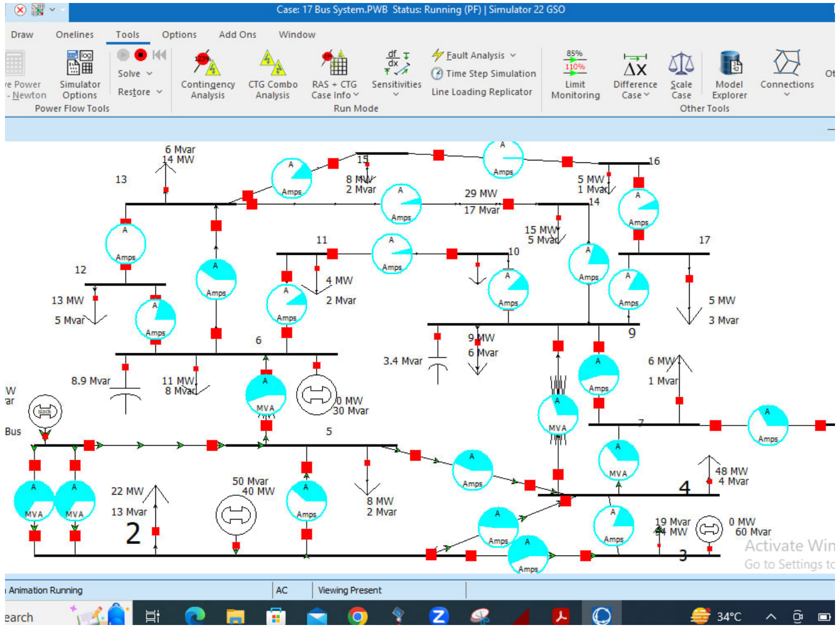


PSCAD – Electrical System Analysis

EMTP-RV
SIMULATION SOFTWARE



Load-Flow, Stability, and EMT simulations



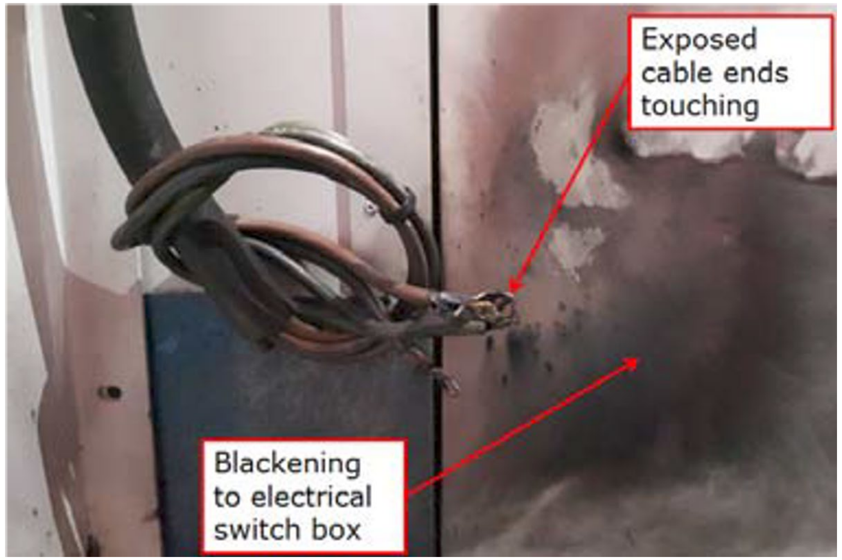
PowerWorld Simulator – Interactive Power System Analysis and Visualization

NJIT
New Jersey Institute of Technology

Project Overview

1. Introduction - Importance of Arc-Fault Detection in Naval Ships

- **Safety of Personnel**
- **Equipment Protection**
- **Operational Reliability**
- **Fire Prevention**
- **Compliance with Safety Standards**



The cabin's internal main electrical power cable arced, tripping the vessel's power circuit breaker.
[Image from the Internet]

Internal core temperature may reach 20,000 °C, posing a serious threat to personnel and the switchgear assembly
[Image from the ABB Review]

2. Challenges with Current Arc-Fault Detection Systems

- **High False Alarm Rates**
- **Obsolescence**
- **Compatibility with Modern Equipment**

Rule-Based Approach with Fixed Threshold

Rule a.1

For any single $i \in \{1,3\}$ and for $\forall X_i \subseteq X$

IF $PI\left(\rho_{X_i}(k)\right) > PI^{max}\left(\rho_{X_i}(k)\right)$ for $1 \le k \le nk_i$

THEN Schedule appropriate control for $X_i(\rho)$

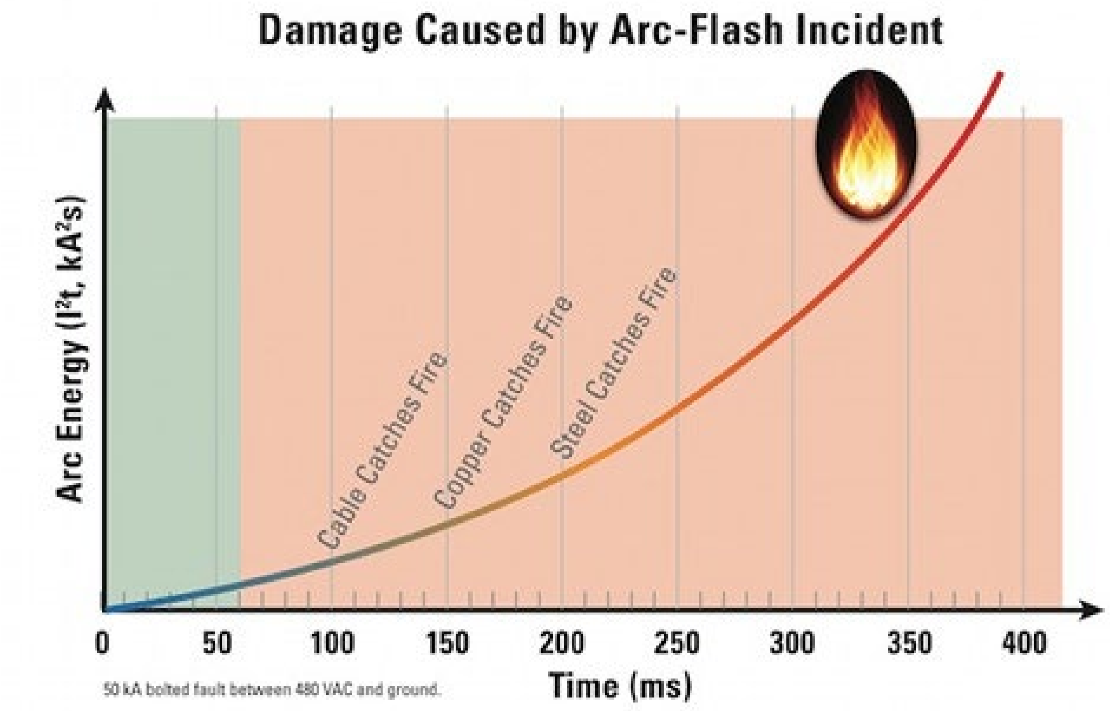
Parameter ρ_{Xi} associated with state X_i is the dominant violator contributing to the arc fault.

Communication Capability of Modern Equipment [Image from the Internet]

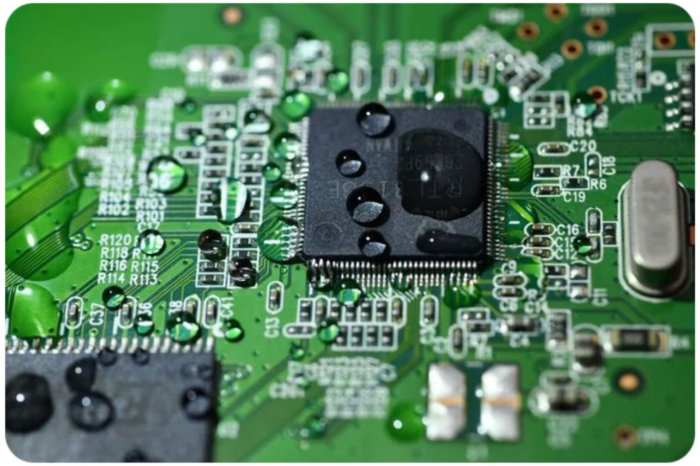
End-of-Life Products [Image from the Internet]

3. Objectives of the Proposal

- **To reduce False Alarm Rate to less than 1%**
- **To enhance Detection Speed to less than 2.5 milliseconds**
- **To adapt to harsh and variable conditions of Shipboard Environments**
- **To comply with stringent naval safety standards and regulations.**



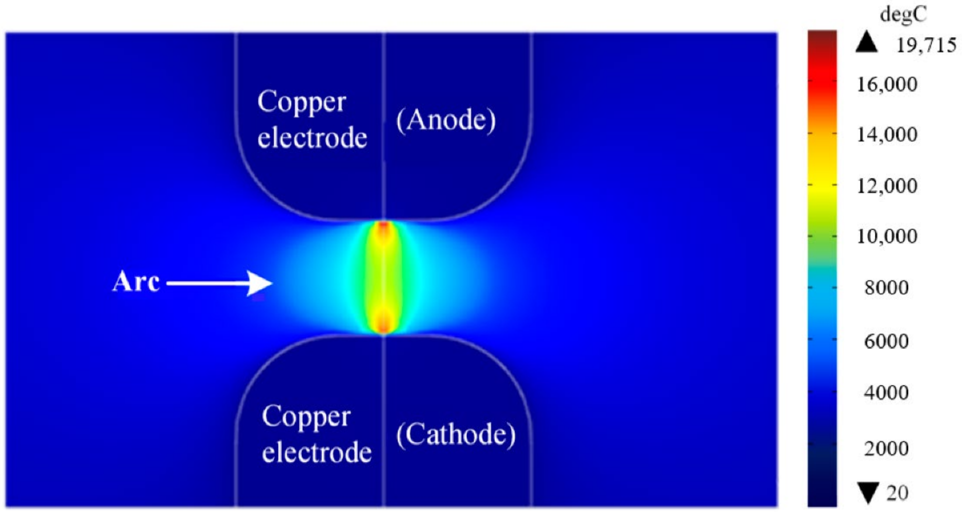
White, James, 2010. Exploding the Myths about Arc Flash, Plant Engineering, April 8, 2010



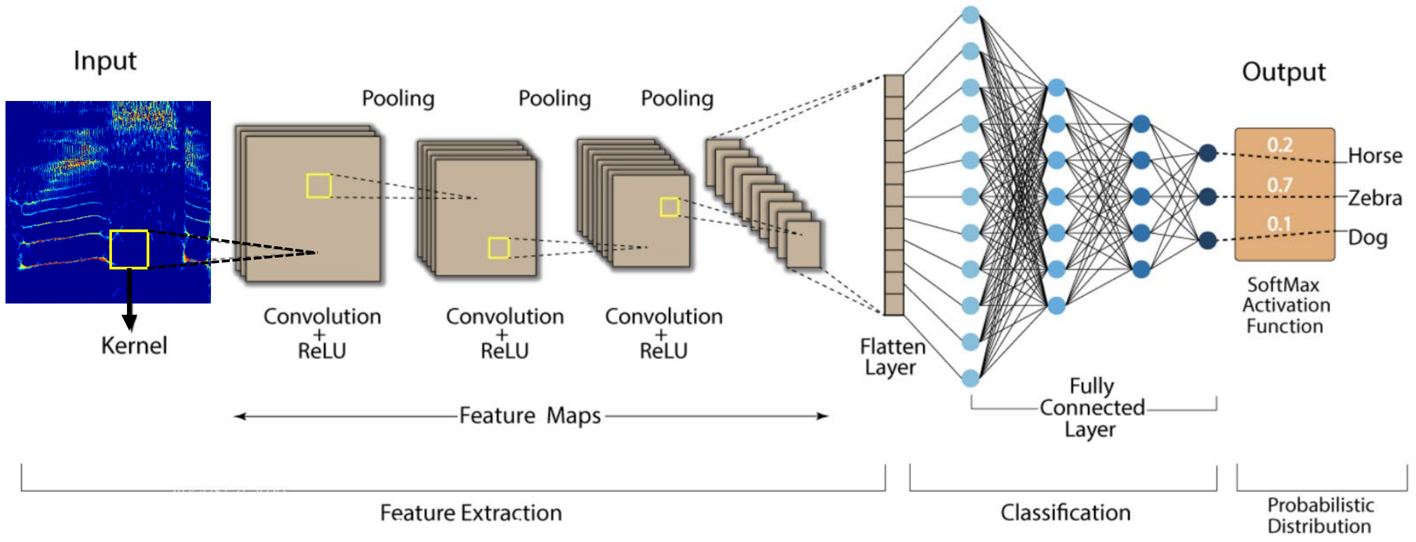
Marine PCB applications face the unique challenges of saltwater environments, temperature extremes, and constant vibration exposure.

4. Proposed Solution

- **Accuracy:** multiphysics approach by sensor fusion: light, current, and acoustic sensors
- **Speed, Compatibility and Environmental Hardening :** adopt ABB REX640 protective relay for high-speed reliable fault detection with up-to-code communication.
- **Reliability:** taking machine learning and statistical approaches to develop algorithms to reduce false alarm due to thresholding issue and improve detection reliability.
- **Compliance**: Lab and On-Site Testings with Shipyard and Navy partners



Convolution Neural Network (CNN)



Acoustic sensor

Current sensor

Optical sensor

5. Technology Description:

ABB REX640 Arc Fault Detection Device:

•**Advanced Sensor Fusion**: Combines light (loop and lens) and current sensors for precise arc fault detection.

•**Sensor Integration**: Flexible input for signals from other sensors and programmable algorithms for sensor fusion.

•**Supervised Sensors**: self-testing feature

•**High-Speed Detection**: less than 2.5 milliseconds.

•**Flexible Configuration**: Modular design

•**Integrated Communication**: Supports various communication protocols (e.g. DNP3) for seamless integration with shipboard systems.

•**Compatibility and Compliance**:

- •IEC 61850: Communication networks and systems for power utility automation.
- •IEC 60255: Measuring relays and protection equipment.
- •IEC 61000: Electromagnetic compatibility (EMC) standards.
- •IEC 60947: Low-voltage switchgear and controlgear.
- •IEC 60068: Environmental testing

•**Marine Certifications**: Certified by DNV GL and ABS for harsh shipboard environments

CERTIFIED BY DNV·GL

ABS

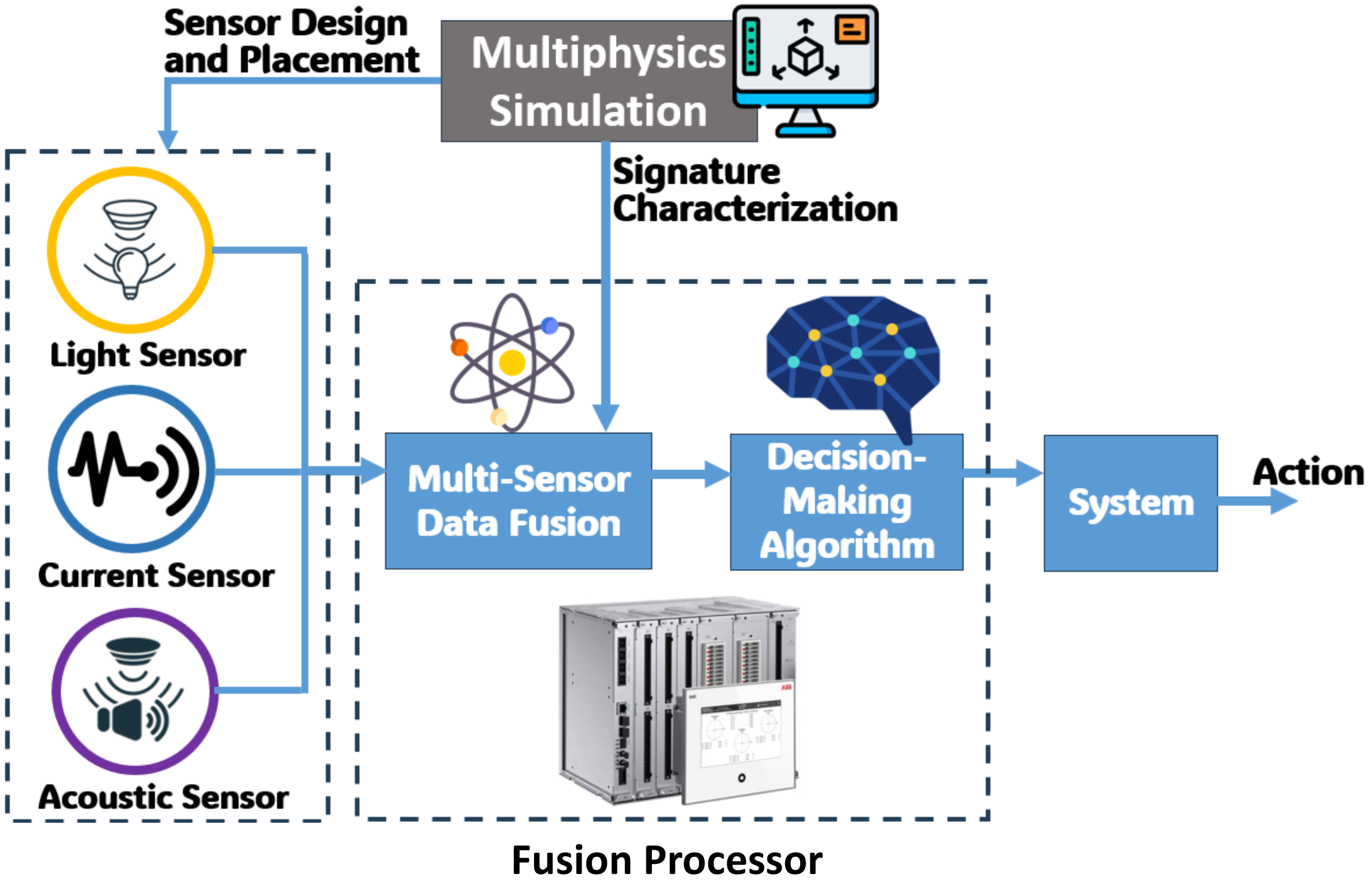
6. Multiphysics Approach with Sensor Fusion and Machine Learning

Why Multiphysics?

- Arc fault is not just an electrical phenomenon — it involves tightly coupled electrical, optical, and acoustic effects.

Mechanism

- Each type of sensor has its strengths and weaknesses. By combining data from all three, the system can correlate different types of signals and cross-verify the presence of an arc fault.
- Fusion processor: synchronize, pre-process and combine sensor data. Machine learning takes the combined feature set and learn complex, non-linear relationships that are not obvious from any single sensor



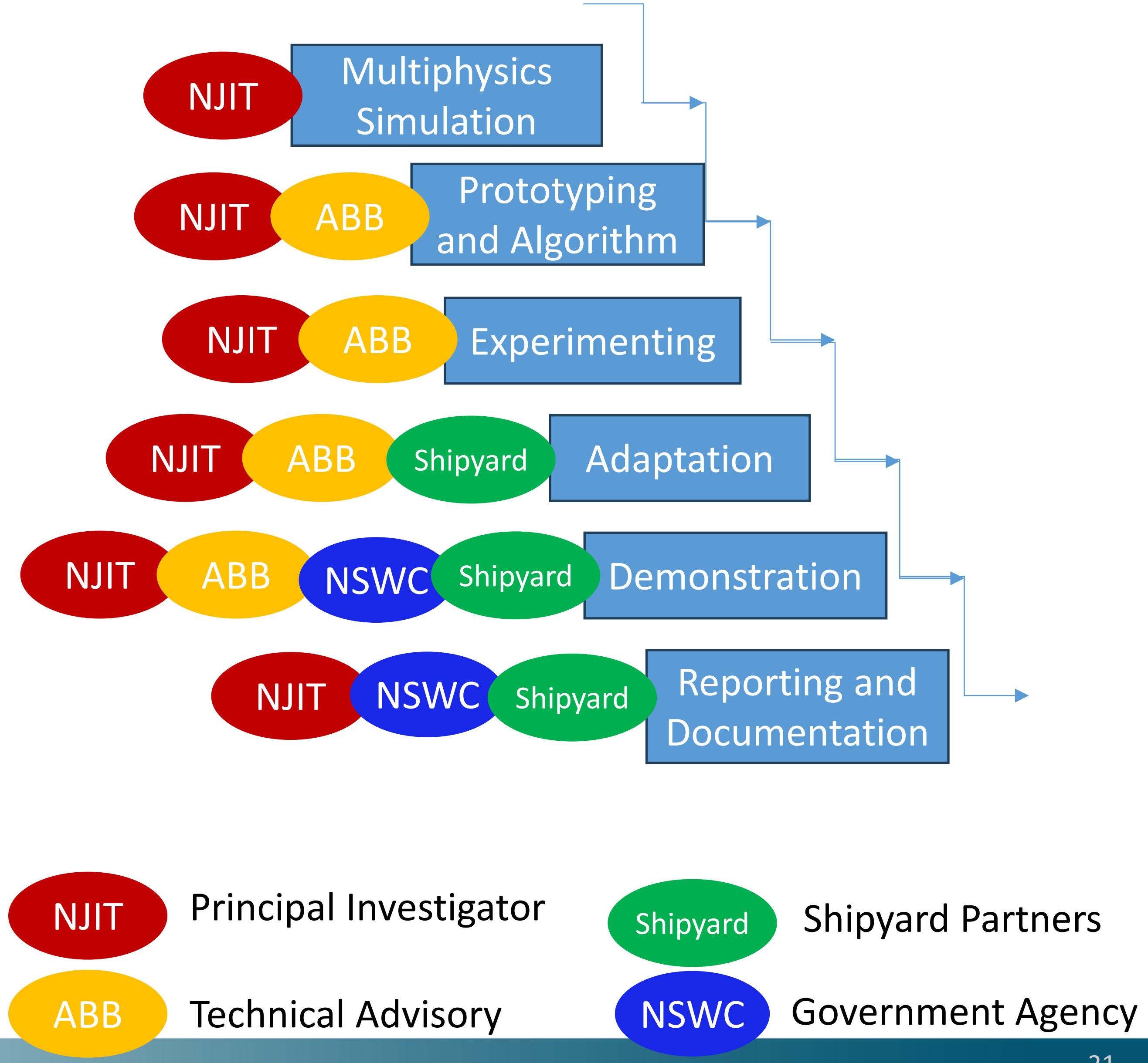
Benefits of Sensor Fusion

- **Enhanced Accuracy:** Reduces false positive / false negative
- **Robust Detection**: Improves reliability in detecting arc faults under various conditions.
- **Adaptability**: Can incorporate additional sensor inputs (e.g. magnetic sensors).
- **Data Analytics:** Customize data analytic algorithms

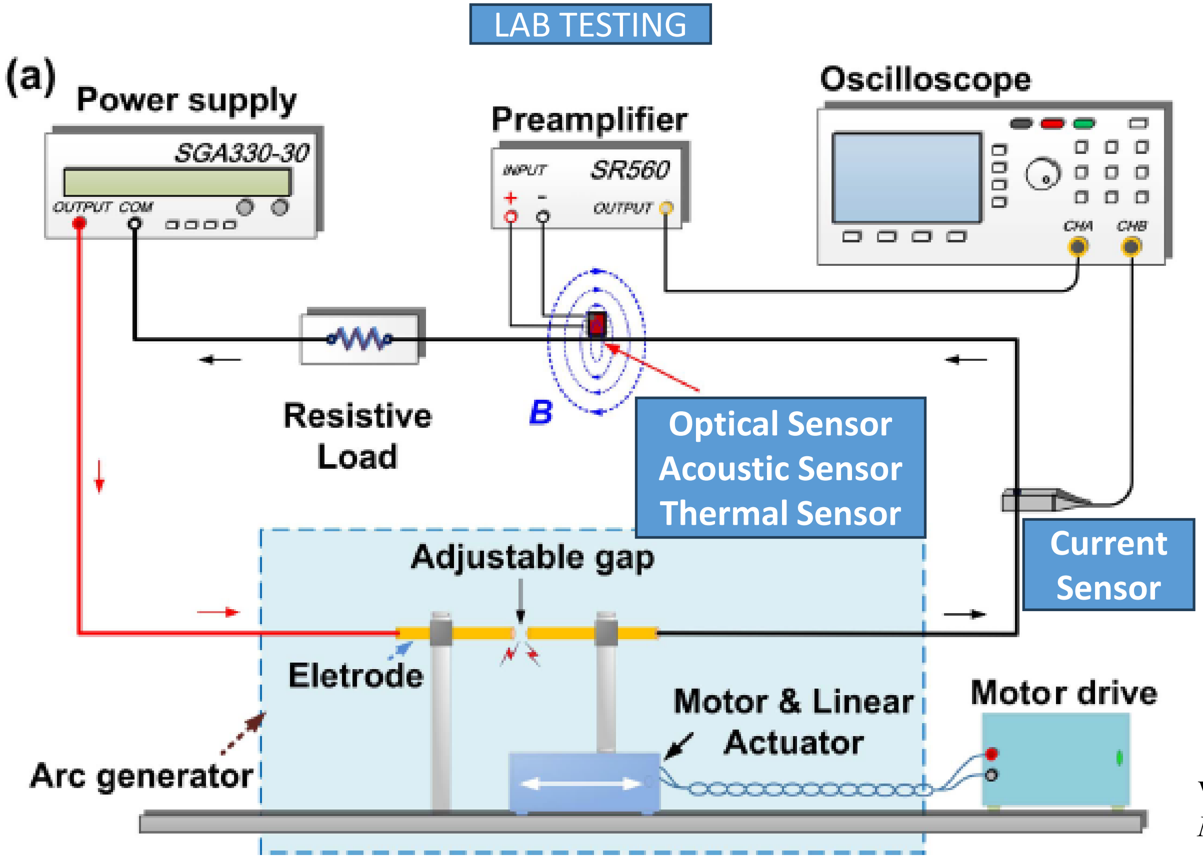
7. Methodology and Collaboration

Tasks

1. **Multiphysics Simulation:** Model realistic fault events and predict and understand what each type of sensor will detect
2. **Prototyping and Algorithm:** Implement ABB REX640 and incorporate the additional acoustic sensor. Develop customized sensor fusion and data analytic algorithms.
3. **Experimenting:** Conduct rigorous tests in controlled conditions at NJIT lab.
4. **Adaptation:** Customize the system for shipboard environmental conditions (e.g. conformal coated PCBs).
5. **Demonstration:** Perform tests in representative shipboard conditions.
6. **Reporting and Documentation:** Preparing documents regarding installation and integration, technical requirements and specification, and validation and testing



8. Envisioned Lab-Based Testing Setup at NJIT



W. Miao, X. Liu, K. H. Lam, Philip W. T. Pong, "*Arc-Faults Detection in PV Systems by Measuring Pink Noise with Magnetic Sensors*", IEEE Transactions on Magnetics, vol. 55, 4002506 (2019)

- **Sensor Technologies for Arc Fault Detection in Naval Ship Power Systems: Applications, Challenges, and Future Prospects – A Review**
  - "Arc Fault Challenges and Detection Technologies in Various Naval Ship System Configurations: A Review", Machine Failure Prediction Technology (MFPT) Annual Conference, Virginia Beach, Virginia, 20-22 May 2025
  - Review article (to be submitted)

Next Step

9. Deliverables

Deliverable	Team Member(s)	Due Date	Due Date in Calendar
Kick-Off Meeting	All	Within 10 days of award	7 April 2026
Project Plan & Schedule	Philip Pong, New Jersey Institute of Technology	Within 30 days of award	27 April 2026
			Bimonthly Meeting on 15 June 2026
			NSRP Electrical Technologies Panel Meeting 5-6 May 2026
Project Status Report 1: Prototype Requirements and Architecture	Philip Pong, New Jersey Institute of Technology	90 Days	27 June 2026
			Bimonthly Meeting on 17 August 2026
Project Status Report 2	Philip Pong, New Jersey Institute of Technology	180 Days	27 Sep 2026
			Bimonthly Meeting on 19 October 2026 **Bimonthly Meeting on 21 December 2026**
Project Status Report 3	Philip Pong, New Jersey Institute of Technology	270 Days	27 Dec 2026
			Bimonthly Meeting on 15 February 2027
Prototype Demonstration / Webinar Summary	Philip Pong, New Jersey Institute of Technology	Month 11	27 Feb 2027
			***15 March 2027 (Closing Meeting)**
Final Report with Recommendations	Philip Pong, New Jersey Institute of Technology	End of Month 12	27 Mar 2027

10. Project Timeline and Finance

We are here

Month	1	2	3	4	5	6	7	8	9	10	11	12
1. Multiphysics Simulation	■	■	■									
2. Prototyping and Algorithm			■	■	■	■						
3. Experimenting					■	■	■	■				
4. Compliance and Adaptation for Shipboard							■	■	■			
5. Demonstration									■	■	■	
6. Reporting and Documentation										■	■	■

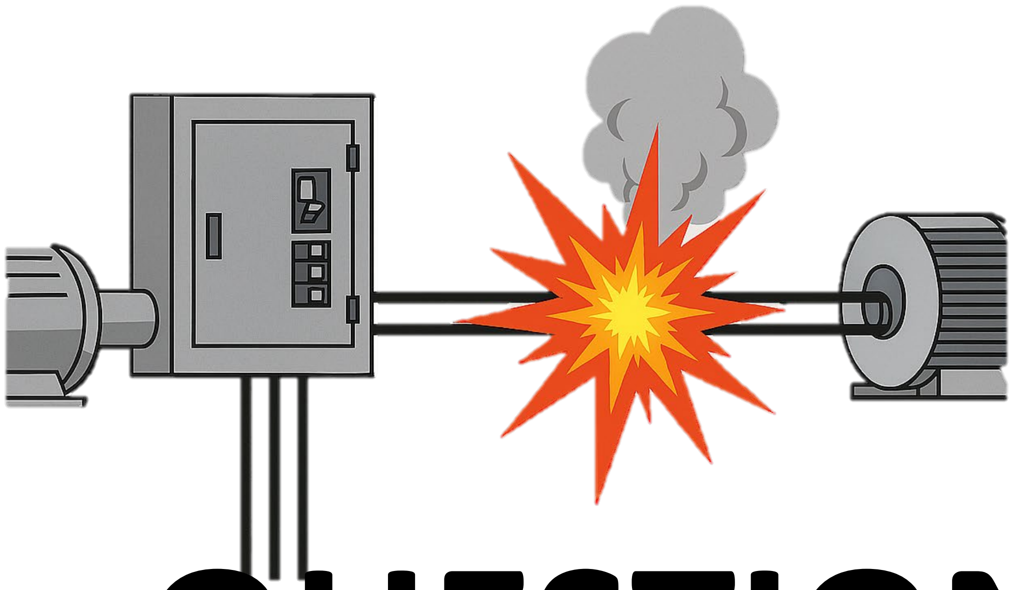
- **Program Funds: $199,700**
- **Project Duration: 27 March 2026 – 27 March 2027**

11. Conclusion

- **Summary of Proposal**:
  - Multiphysics Simulation for Sensor System Design
  - Advanced Sensor Fusion and Machine Learning for Arc Fault Detection
  - Leverage ABB-supported REX640 with up-to-code communication capabilities, proven adaptability to harsh marine environments, and compliance with marine standards

- **Key Benefits**:
  - Faster and More Reliable Detection
  - Updated and Supported Technology
  - Compatibility with Modern Shipboard Equipment
  - Enhanced Safety
  - Cost Savings
  - Operational Efficiency

- **Teamwork:** We are collaborating with the Government – Naval Surface Warfare Center (NSWC) Philadelphia Division, the Shipyards – Huntington Ingalls Industries (HII) and General Dynamics Bath Iron Works (GDBIW), and the Industry – ABB.



Multiphysics-Driven Arc-Fault Detection for Shipboard Electrical Systems via Sensor Fusion and Machine Learning

QUESTIONS/FEEDBACK?

Philip Pong

philip.pong@njit.edu

Associate Professor

Department of Electrical and Computer Engineering

New Jersey Institute of Technology

INGALLS SHIPBUILDING A Division of HII

GD Bath Iron Works

NAVSEA WARFARE CENTERS Philadelphia

NJIT New Jersey Institute of Technology

ABB