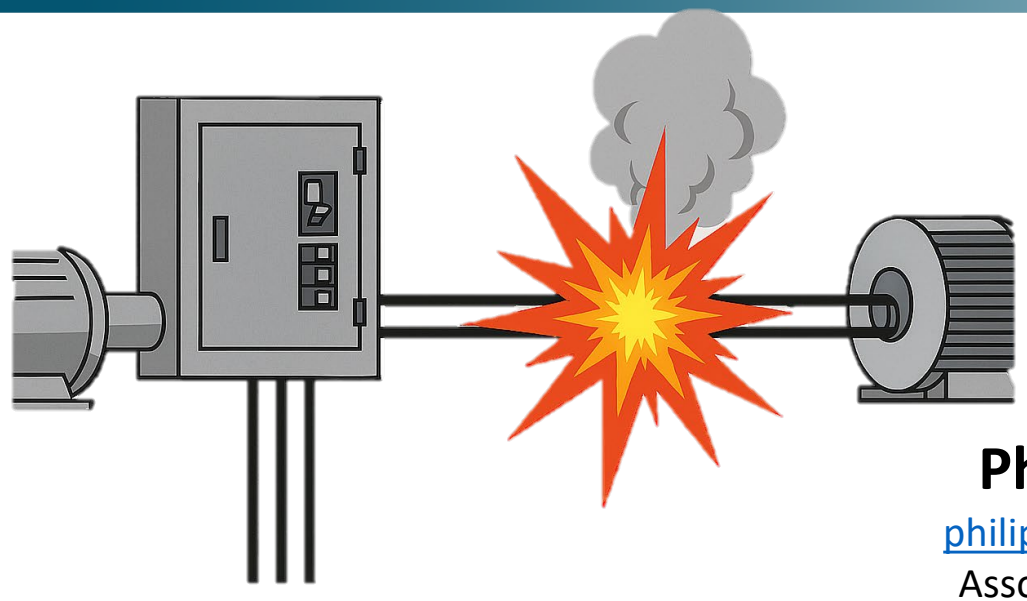

Multiphysics-Driven Arc-Fault Detection for Shipboard Electrical Systems via Sensor Fusion and Machine Learning

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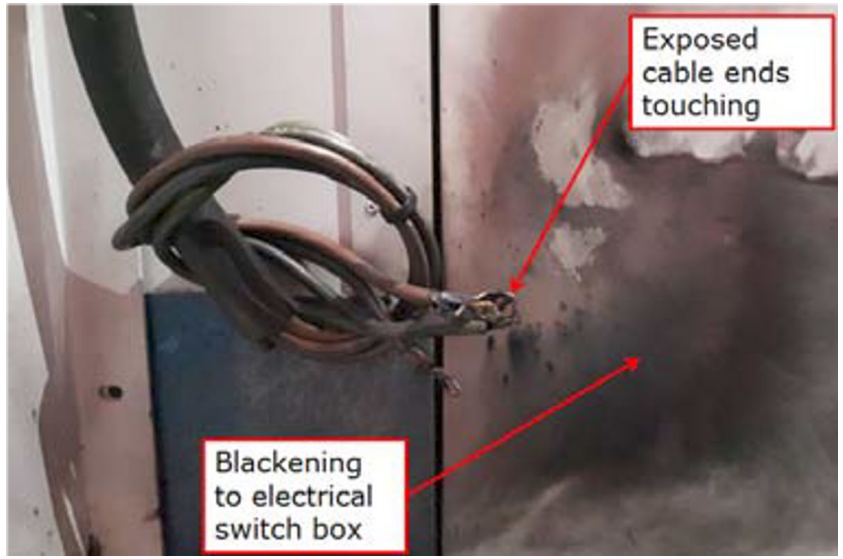
1. Introduction - Importance of Arc-Fault Detection in Naval Ships

- **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 $X_i(\rho)$

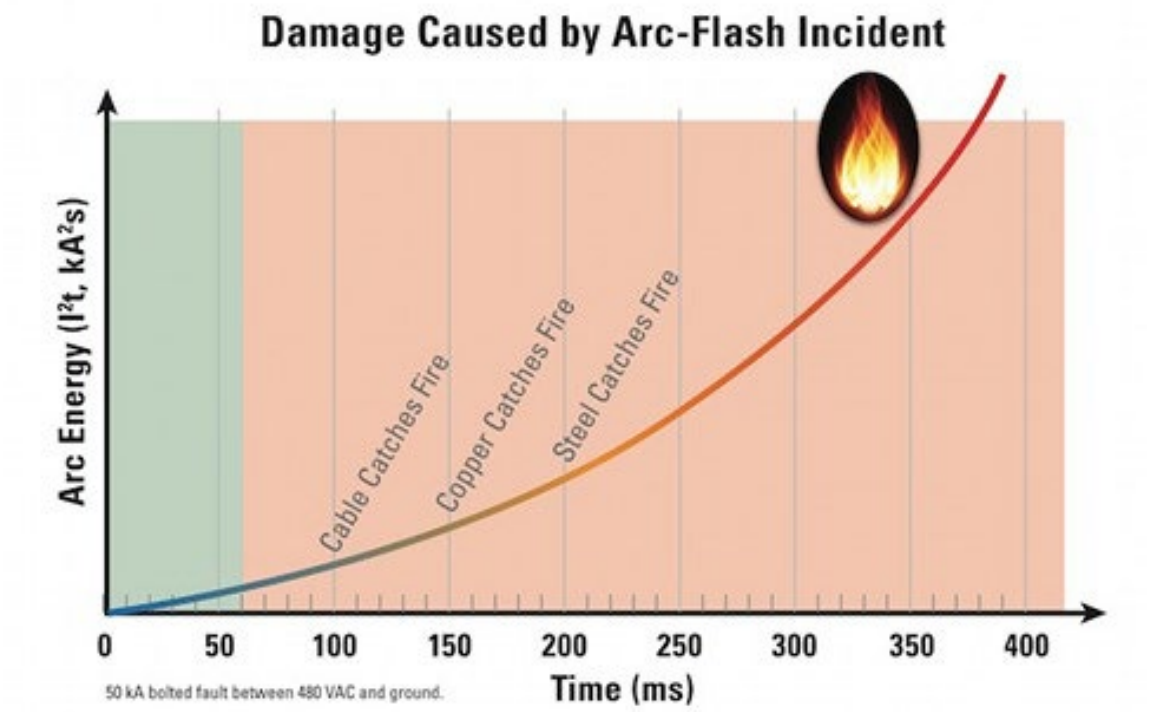
Parameter ρ_{Xi} associated with state X_i is the dominant violator contributing to the arc fault.

Communication Capability of Modern Equipment [Image from the Internet]

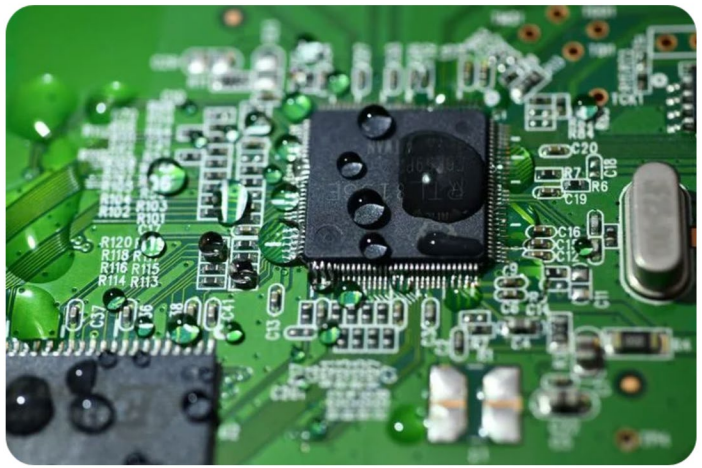
End-of-Life Products [Image from the Internet]

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

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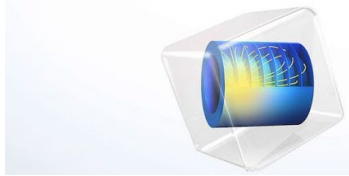
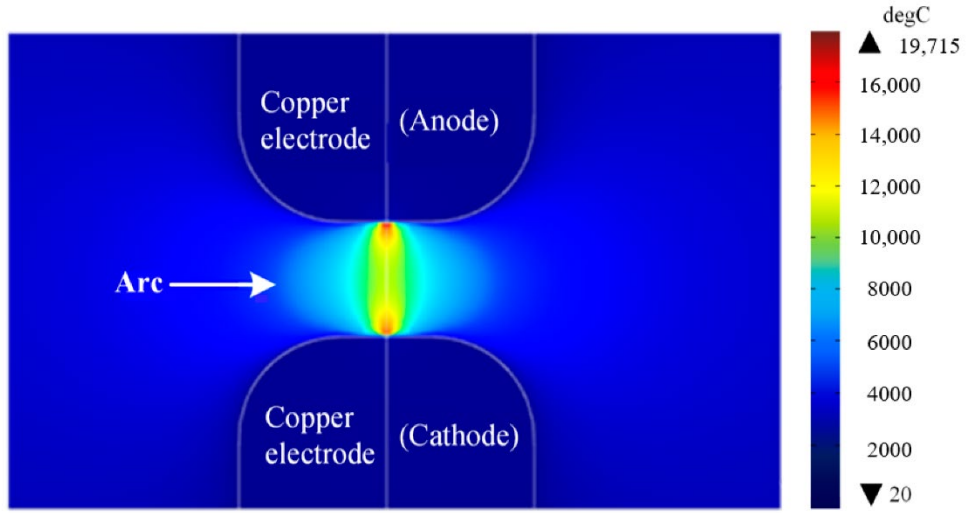
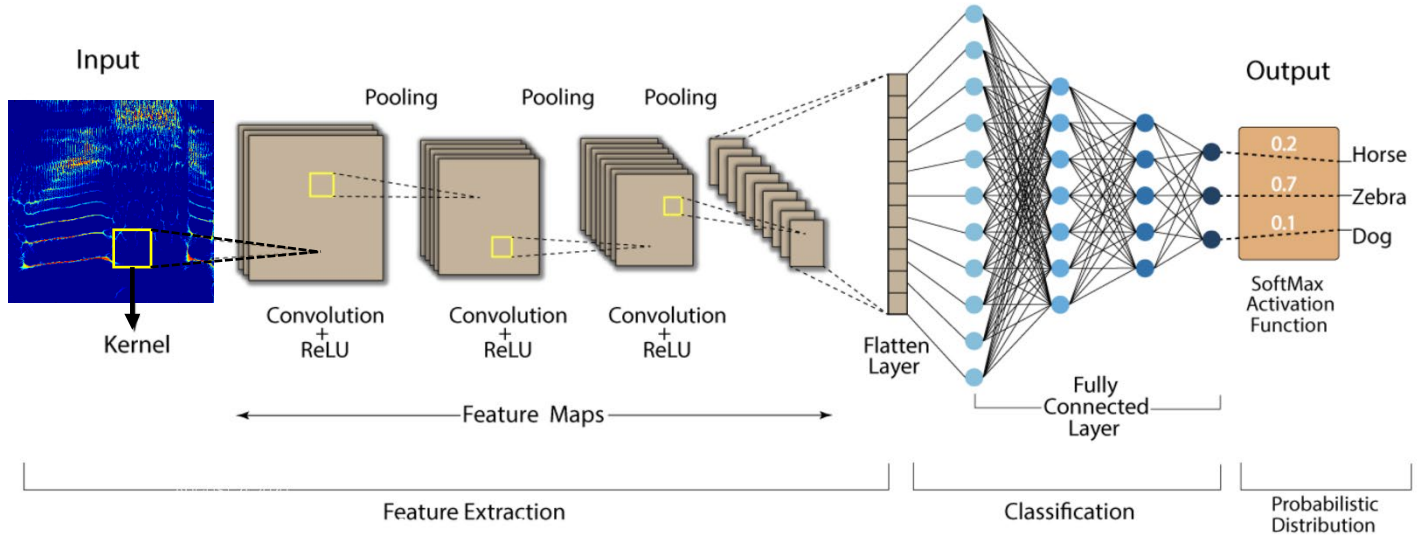




Convolution Neural Network (CNN)



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

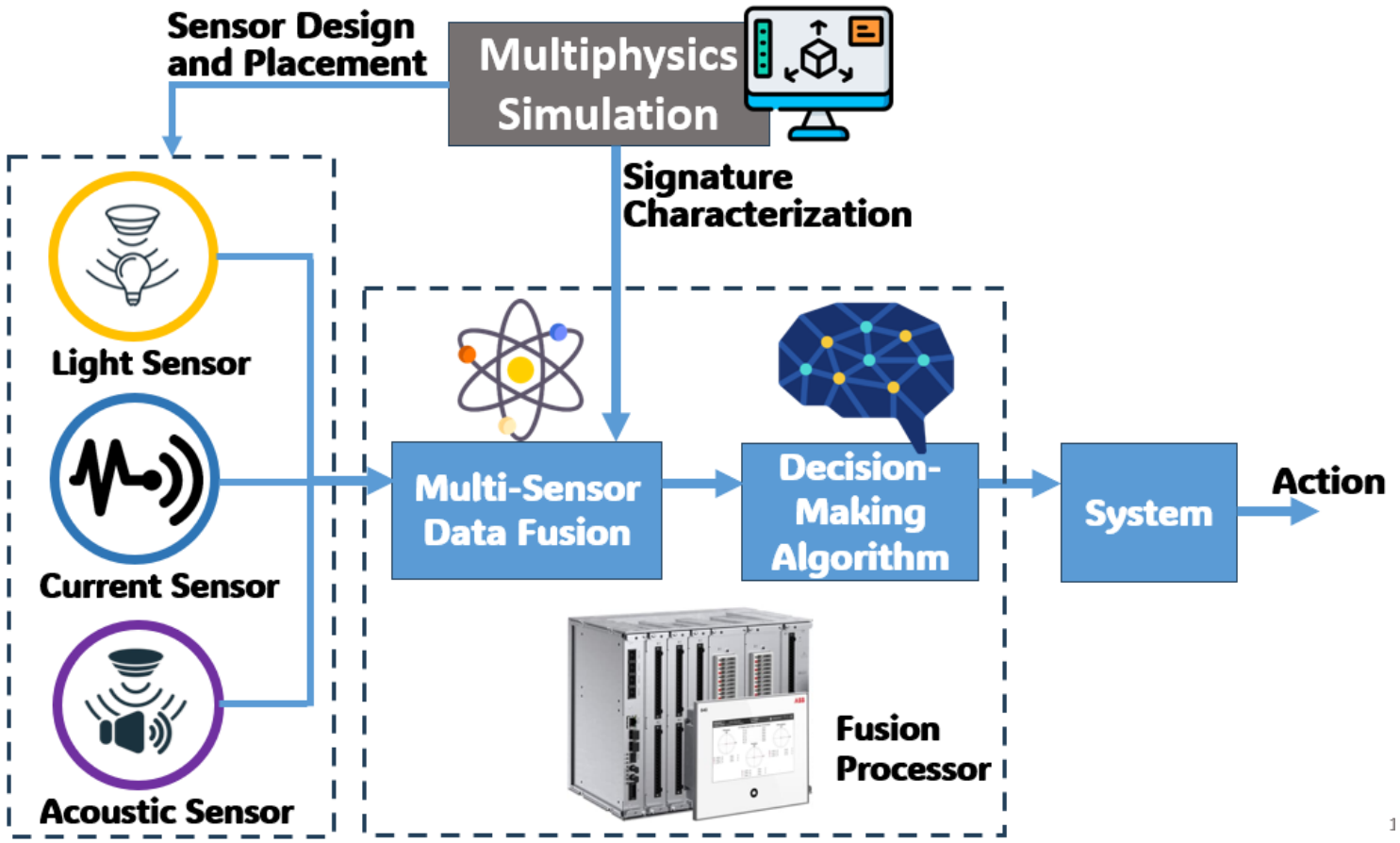
6. Multiphysics Approach with Sensor Fusion and Machine Learning

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

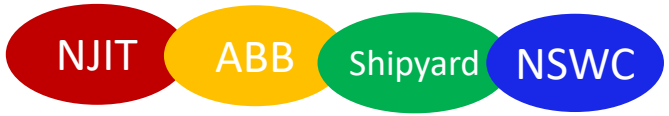
Tasks

Task 1 – Requirements Definition, System Architecture, and Multiphysics Modeling

Task 2 – Prototype Development (Sensors, Algorithms, and Data Acquisition)

Task 3 – Integration with Protective Relay and Laboratory Testing

Task 4 – Analysis, Refinement, and Final Documentation



Principal Investigator

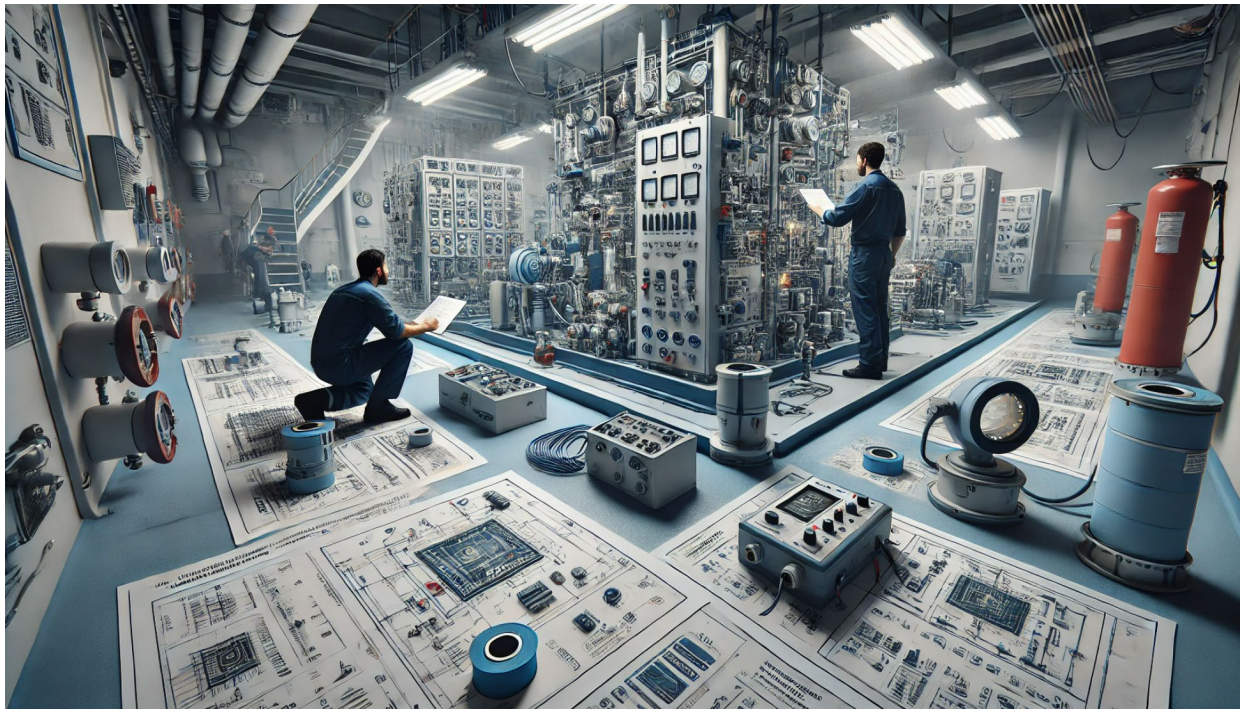
Technical Advisory

Shipyard Partners

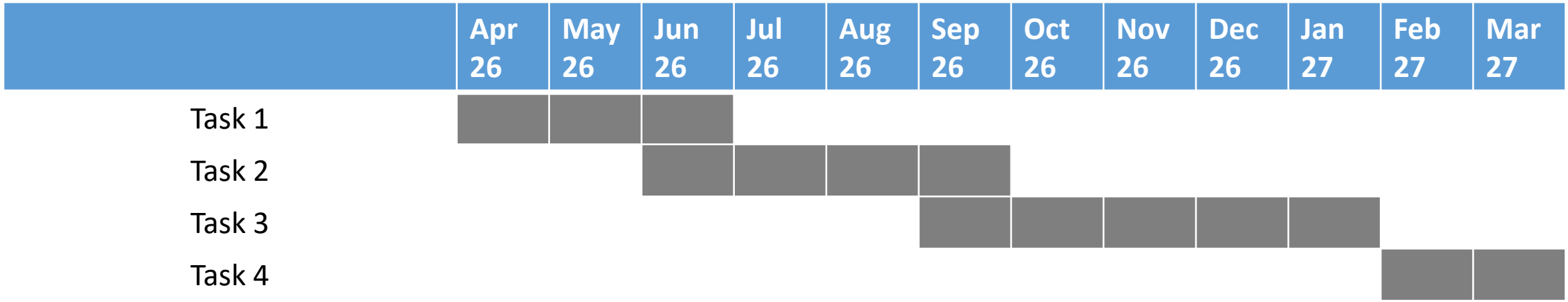
Government Agency

8. Deliverables

1. Kick-Off Meeting
2. Project Plan & Schedule
3. Project Status Report 1: Prototype Requirements and Architecture (3 months)
4. Project Status Report 2 (6 months)
5. Project Status Report 3 (9 months)
6. Prototype Demonstration / Webinar Summary
7. Final Report with Recommendations



9. Project Timeline and Finance



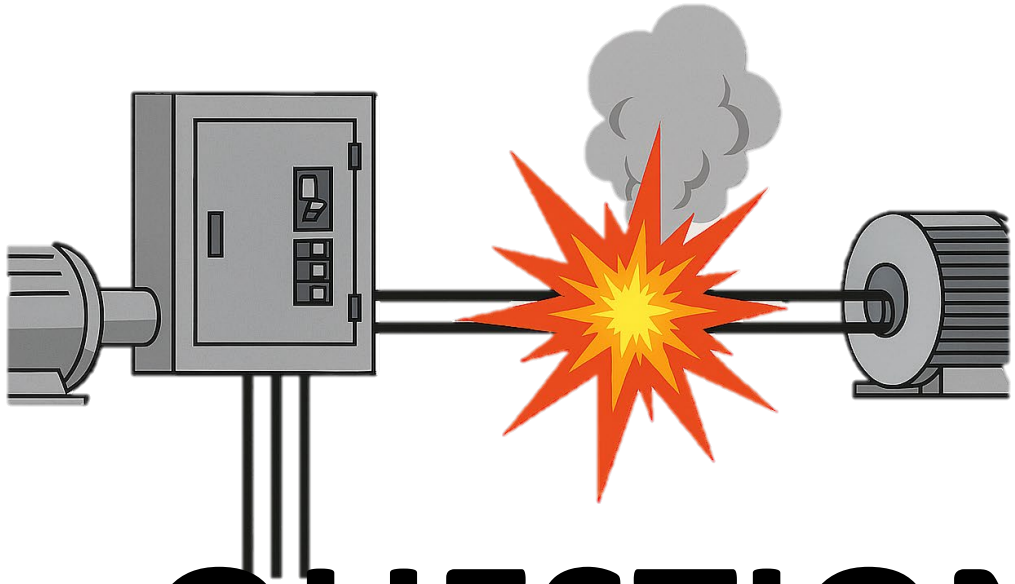
- **Program Funds: $200,000**
- **Cost Share: NIL**

10. Conclusion

- **Summary of Proposal**:
  - Multiphysics Simulation for Sensor System Design
  - Advanced Sensor Fusion and Machine Learning for Arc Fault Detection
  - Leverage ABB-supported REX640 (or equivalent) 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

- **Future Steps**:
  - 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.



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QUESTIONS/FEEDBACK?

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