U.S. DEPARTMENT OF ENERGY | OFFICE OF Cybersecurity, Energy Security, and Emergency Response

Cyber-Physical Resilience for Wind Power Generation GE Research

Fernando D'Amato

Cybersecurity for Energy Delivery Systems (CEDS) Peer Review

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Project Overview

Objective

Develop commercially viable cyber protection technology for wind power generation systems that is effective against attacks at the control domain in the physical layer.

Schedule

Project dates: Start: 10/01/18 -- **End**: 3/31/22*

Milestones

• Baseline Detection technology	12/19
• Advanced Det. & Localization	6/20
• Product requirements and strategy	9/20
• Prototype build	9/20
• Prototype validation	12/20
• Advanced accommodation	2/21
• Field test	3/22
• Red team assessment	3/22

Total Value of Award:	**$3.6M (fed)+$1.2 (GE) = $4.8M**
Funds Expended to Date:	**$2.9M / $4.8M = 61%**
Performer:	**GE Research**
Partners:	**GE Renewable Energy** **Idaho National Lab**

* No-cost extension pending approval

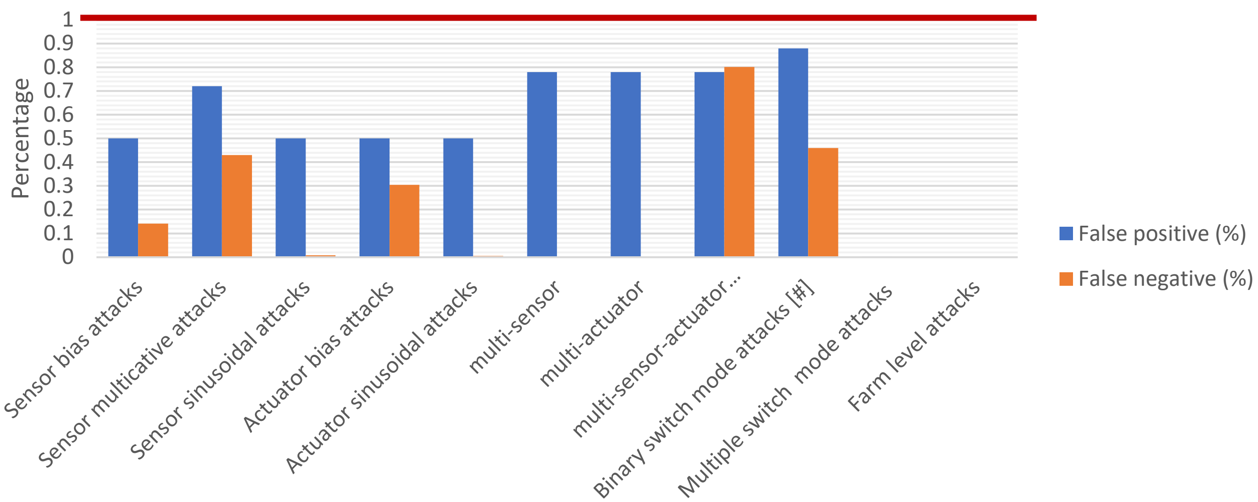
Advancing the State of the Art (SOA)

1-Current State of the Art

- Solutions address vulnerabilities at enterprise and operations layers of Energy Delivery Systems

2-Feasibility of approach

- Rigorous assessment completed for attack detection and neutralization using high fidelity models of wind turbines and actual control code



- >7,500 attack cases simulated
- >500 normal scenarios simulated
- Detection performance surpassed program target of 1% FP & FN

3-How GE approach is better than SOA

- Increased resilience and defense against sophisticated cyber threats
- Handles zero-day vulnerabilities (assumed attacker accessed the controller)
- Introduces defense at all layers of the control system architecture: layers 0 (device), 1 (controller), 2 (supervisory)
- Increased understanding of risks

- Uses intimate knowledge of asset (design models, control code) to achieve unprecedented performance

Advancing the State of the Art (SOA)

4-Benefit to the end user

- Additional line of defense: complementary cybersecurity offering to the existing IT/OT solutions
- Highly accurate detection and localization for all critical attacks
- Fast and safe neutralization of 171 types of attacks

5-How our approach will advance the cybersecurity of Energy Delivery Systems

- Systematic approach developed for GE wind turbines but applicable to any utility scale wind turbines (may require re-tooling for non-GE assets)
- Can easily expand to new attacks types to address customer specific needs

6-Potential for sector adoption

- Engaged in technology discussions with 3 future potential customers with encouragement, but with caution due to the fact that wind power industry is a cost sensitive segment
- Strategy to introduce first generation of technology for detection and localization only, integrated in customers SCADA and SIEM systems; future versions to include neutralization

Progress to Date

Major Accomplishments

1. Designed most critical cyber-attacks for wind power generation
2. Developed novel attack detection & accommodation for wind turbine and demonstrated performance exceeding program goals
3. Developed multiple attack neutralization strategies:
    1. Reconfigurable virtual sensing
    2. Model based backup controller with and without curtailment
    3. Preventive shutdown
4. Defined product requirements and commercialization strategy
5. Discussed technology with 3 potential customers in the wind power utility sector and defined its potential integration in SCADA network
6. Designed and built cyber-security prototype for lab and field test
7. Designed and implemented Software in the Loop (SIL) and Hardware in the Loop (HIL) simulation platforms
8. Submitted 4 patent disclosures for attack detection, localization and neutralization
9. Reserved schedule for field test for phase 2 of the program

Challenges to Success

Challenge 1: Stringent performance in highly stochastic environment

Mitigation steps

- Massive design of experiments including datapoints of 30M floats at 500 normal operating conditions and > 140,000 attack cases
- Extensive feature engineering to provide discriminating data to ML algorithms

Challenge 2: Economic viability of cyber-security HW at each turbine

Mitigation steps

- Move the cybersecurity solution from turbine level to the farm level using EDGE devices
- Addressed high communication rates requirements targeting turbine fleet with high bandwidth SCADA
- Combine business case of cyber security with anomaly detection for O&M benefits

Challenge *3: Technology sustainability, support of diverse fleet*

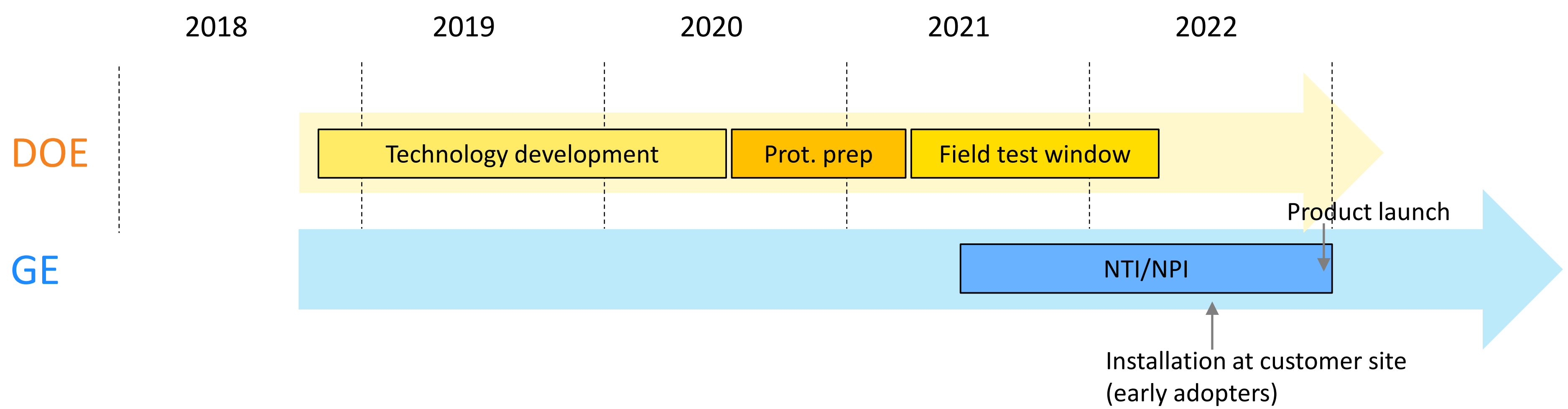
Mitigation steps

- Automated tools preparation for dataset generation
- Transfer Learning of decision models for expansion to other wind turbine fleets

Collaboration/Sector Adoption

Plans to transfer technology/knowledge to end user

- Prototype preparation and validation for field test 3/21
- Field test the technology at GE test facility (Lubbock, TX) 4/21– 3/22
- Launch New Product Introduction program for productization, 6/21
- Field test customer site (early adopter in wind utility TBD) 6/22
- Product launch 12/22



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Next Steps for this Project

Approach to the end of project

Phase 1 (ending March 2021)

1. Field test plan 11/20
2. Complete detection with watermarking 12/20
3. Develop transfer learning tools for adapting solutions to site-specific characteristics 12/20
4. Prototype laboratory testing 12/20
5. Adapt technology to site turbine 2/21
6. Develop neutralization using advanced learning 3/21
7. Final report Phase 1 3/21

Phase 2 (ending March 2022)

1. Prototype field test
2. Possible technology adjustment
3. Field testing Red team
4. Final report phase 2

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Datasets

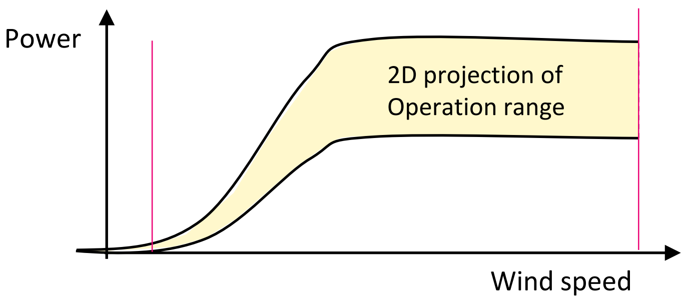
Normal

Normal Dataset Design of Experiments

- *Sample full range of operation: wind speed, turbulence, shear, yaw, curtailment, …*

Highly stochastic environment need extensive dataset coverage

- *Over 500 data points*
- *Each including about 1M floats*



Attack

Critical Attack Design → Elementary Attack Library → Smallest Relevant Elementary attacks → Attack Design of Experiments

Critical Attack Design

- *Control and operability experts working as cyber-attacker*
- *Rank attacks by RPN*
- *Select the most critical*

Elementary Attack Library

- *Decompose critical attacks into elementary components*
- *Collect building blocks for critical attacks by type & location*

Smallest Relevant Elementary attacks

- *Define attack impact in terms of effects on power, loads, fatigue life, …*
- *Iterate on attack size reached a "relevance threshold" wrt normal operation*

Attack Design of Experiments

- *Define attack cases in the range of operating conditions (wind speed, air density, yaw, …)*
- *Define DoE on which to measure performance*

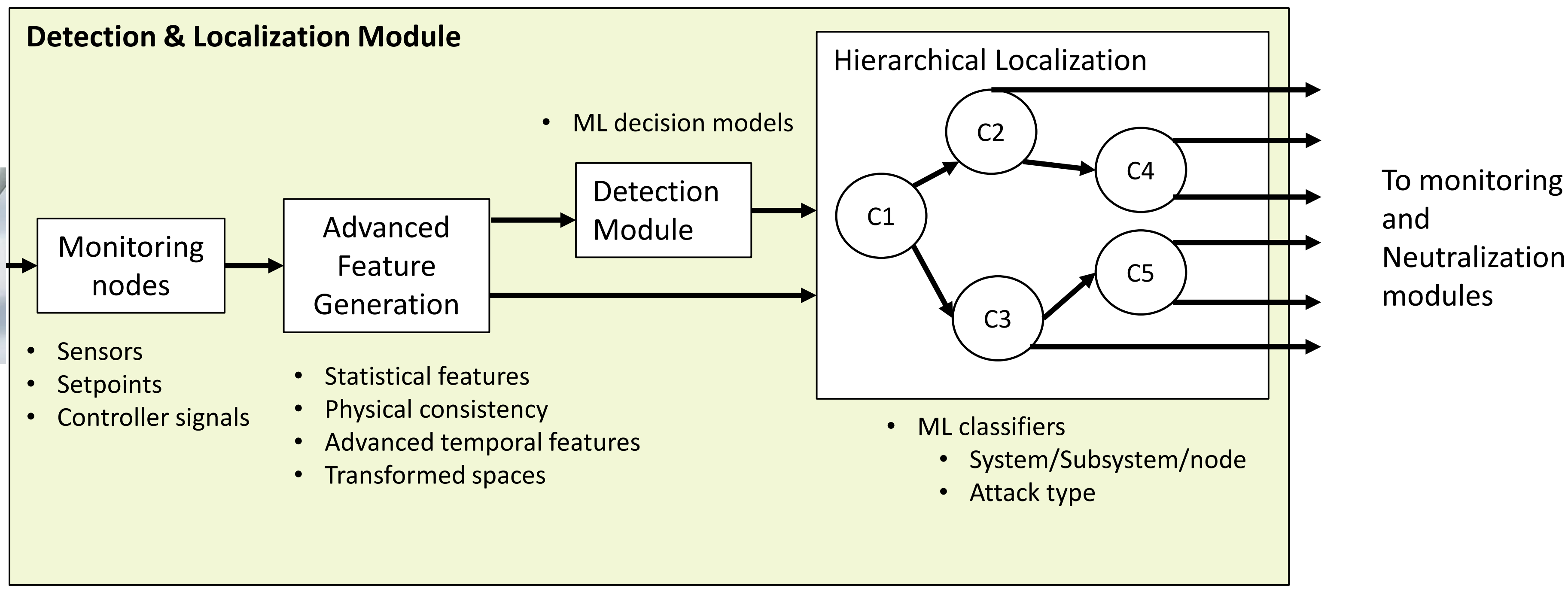
- Over 170 attack types
- Over 7500 attack cases

Detection and Localization architecture

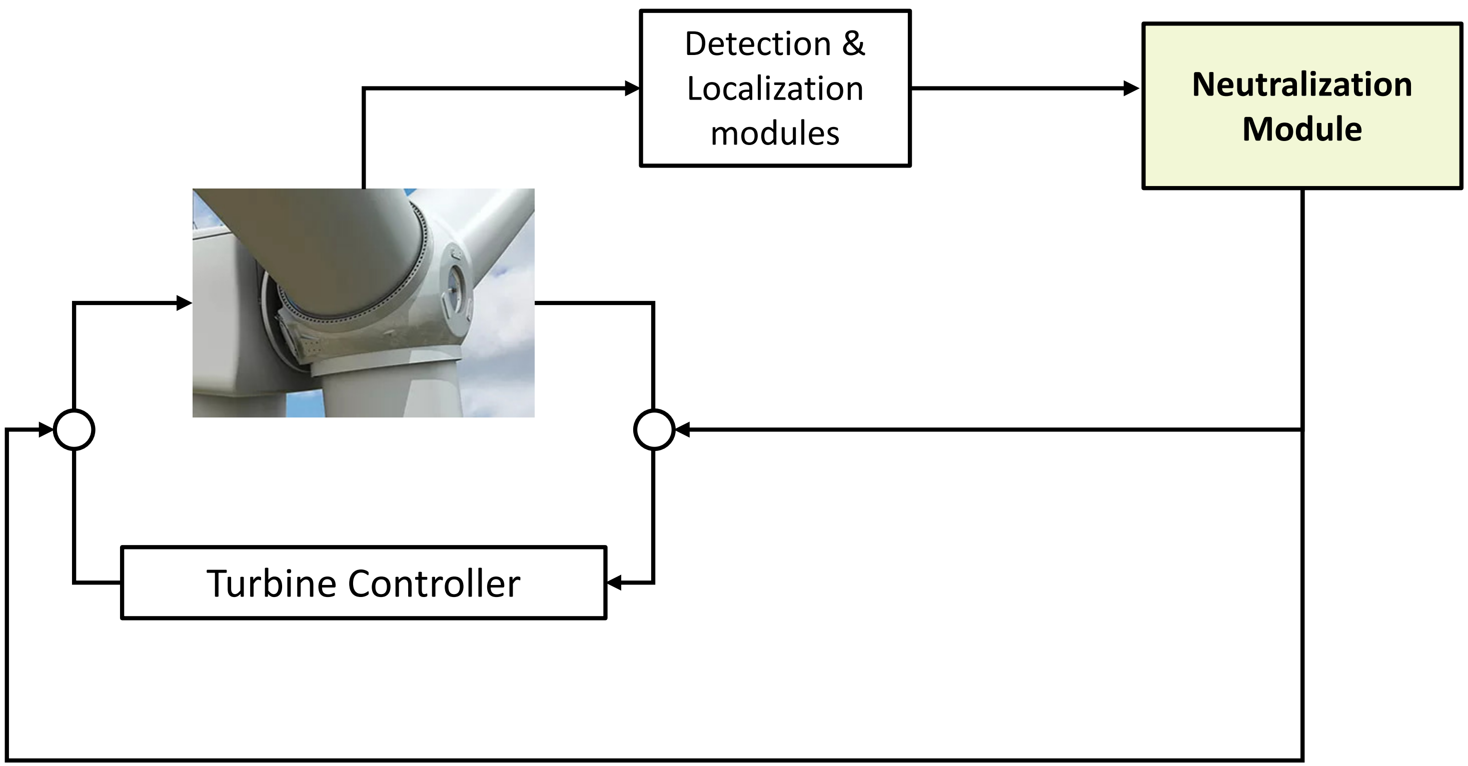
Minimal number of nodes to achieve target performance

Domain-specific knowledge

Machine learning technology to fine tune performance and adapt solutions



Neutralization architecture

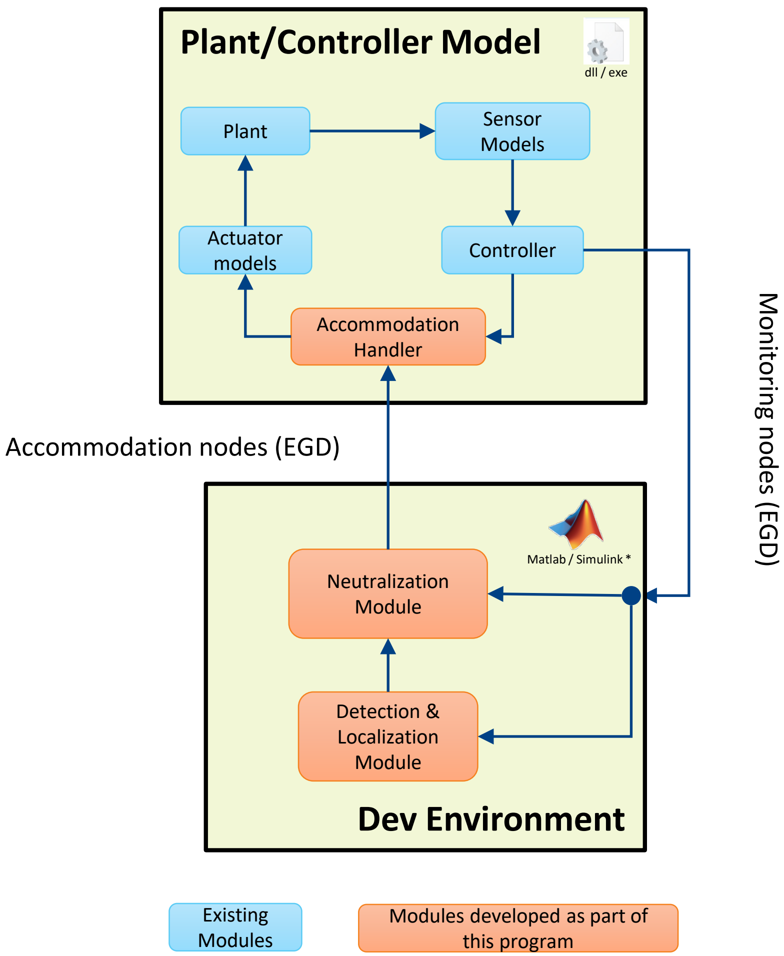


Neutralization

- *Applies optimal strategy to minimize attack impact, based on the real time assessment from the Detection and Localization*
- *Includes Virtual Sensing and Backup controller to counteract cyber attacks*

Development/Testing Environments

Software in the loop (SIL) development



* MATLAB/Simulink are registered trademark of The MathWorks, Inc.

Processor in the loop (PIL) testing