CPS: Small: Collaborative Research: CYbersecure Distribution systems with power Electronically interfaced Renewables (CYDER)

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1. Problem Statement

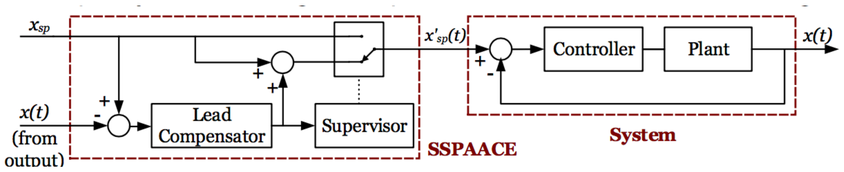
- The overarching research goal of this proposal is to design a new comprehensive methodology for cybersecurity monitoring and mitigation in systems with a multitude of dynamical devices that are prone to cyberattacks
- To demonstrate the performance of our proposed algorithms, we study their application for an electric power distribution system as a critical cyberinfrastructure, which includes substations, feeder devices, and smart meters.
- If this project is successful, it will result in a new vision for the next generation of cyber-enabled distribution systems. It will also address the increasing need for technologies to secure the power grid due to the growing sophistication of computer hacking and helps U.S. utilities, which already spend between $1M to $10M annually on cybersecurity, to meet the North American Electric Reliability Corporation (NERC) requirements.
- The intellectual merit of this exploratory research project lies in the design of algorithms and theories to detect cyberattacks and mitigate their impact at the distribution system level.

2. Objectives

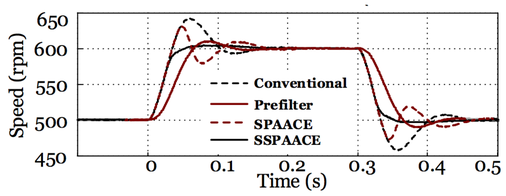
- Detection of cyberthreats on the distribution system;
- Mitigation of and response to cyberintrusions especially with power electronically interfaced renewables via multiagent-based algorithms; and
- Preparing the next generation of cyber-aware engineers.
- Our objectives contribute mainly to the Science of CPS, with our validation efforts, including testbeds, contribute also to Technology for CPS.

3. Resilient Controls and Methods

- A cyberattack can put a distribution system under stress due to changes in its topology or forced disconnection of DER units. This in turn may deteriorate the performance of the controllers and lead to deviation of the system variables, e.g., frequency, voltage, and power, from their reference set points.
- We propose an auxiliary control method, to be augmented to MAS, called SSPACE (smooth set point automatic adjustment with correction enabled) as shown in the diagram below:



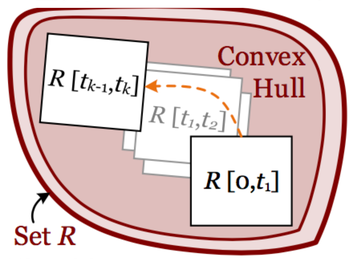
- SSPACE temporarily changes the system set point in anticipation of a tracking error. Figure below shows the results:



- An important concern in applying the proposed control and UFLS algorithms is to ensure all possible dynamic trajectories are feasible, i.e., dynamics stay within their limits.
- We propose to use a powerful numerical technique called reachability analysis, a branch of optimal control theory, to study how states transition between the initial and final conditions as a result of unknown but bounded disturbances resulting from IMD adjustments and/or probabilistic component failures.

$$\mathcal{R}([0,t_f]) \supseteq \mathcal{R}^e([0,t_f]) \triangleq \{(t,x(t),y(t)) \mid (x(0),y(0)) \in \mathcal{R}(0), u(t) \in \mathcal{U}, d(t) \in \mathcal{D}\}$$

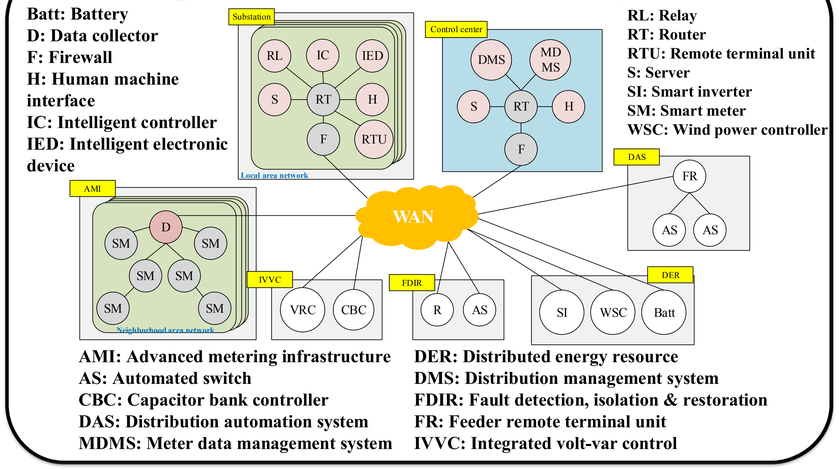
$$\mathcal{Z} = \{z \in \mathbb{R}^{n_x+n_y} | z = c + \sum_{i=1}^{p} \beta_i g^{(i)}, \quad -1 \le \beta_i \le 1\}$$



4. Coordinated Cyber Attacks

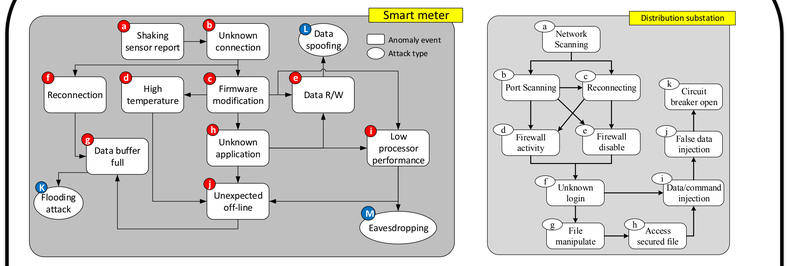
- Unlike the single/random/multiple cyber attacks, coordinated cyber attacks target multiple utility facilities simultaneously, making a serious impact on a distribution system.

Proposed Cyber Model of Distribution System



- Mitigation method: Integrated underfrequency load shedding strategy (UFLS) and advanced multi-agent controllers to provide the fast response required of DER units.

TFPG Model for AMI and Substations



Machine Learning Based Detection Algorithm

- **Classification Problem:**

$$\begin{cases} class1, & if\ g_1(x) > 0\ and\ g_2(x) \\ class2, & if\ g_1(x) < 0\ and\ g_2(x) > \end{cases}$$

- **Decision Function:**

$$\begin{cases} class1, & if\ g_1(x) > 0 \\ class2, & if\ g_2(x) > 0 \end{cases}$$