

# An Energy Management System Approach for Power System Cyber-Physical Resilience

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**Abstract**—Power systems are large scale cyber-physical critical infrastructure that form the basis of modern society. The reliability and resilience of the grid is dependent on the correct functioning of related subsystems, including computing, communications, and control. The integration is widespread and has a profound impact on the operation, reliability, and efficiency of the grid. Technologies comprising these infrastructure can expose new sources of threats. Mapping these threats to their grid resilience impacts to stop them early requires a timely and detailed view of the entire cyber-physical system. Grid resilience must therefore be seen and addressed as a cyber-physical systems problem. This short position paper presents several key preliminaries, supported with evidence from experience, to enable cyber-physical situational awareness and intrusion response through a cyber-physical energy management system.

## I. INTRODUCTION

Power system infrastructures have long been rigorously studied and analyzed. Historically, however, their cyber systems, the interplay between cyber and physical, and the potential impacts of loss of trustworthiness at any point, have not been given the same level of attention. The current need is that cyber-physical power systems must be able to “ride through” extreme events, including human-perpetrated events, while maintaining their critical societal functions. Part of the challenge is these events fall outside the scope of normal daily operations, so they require a new approach with new models and tools to address.

Cyber-physical Resilient Energy Systems (CYPRES) [1] is funded by the U.S. Department of Energy’s Cybersecurity for Energy Delivery Systems (CEDs) to achieve its name. CYPRES aims to transform the energy sector’s resilience capabilities in cyber-physical power systems by designing a new approach to energy management. A primary function is to *help electric utility industry stakeholders more effectively prevent and detect cyber-attacks that threaten their operational environment, and recommend controls, by coupling cyber-physical models and cyber-physical data.*

CYPRES, as a new type of energy management system (EMS), would provide cyber-physical grid analyses for stakeholders over the entire life cycle of an event. The new EMS must include the modeling and data analytic capabilities to prepare for, endure, and respond to events (threats), as well closing the loop to learn from these events (threats) and plan the system better. This resilience life cycle approach is critical to grid cyber-physical security. In fact, the importance of security for critical infrastructure is completely rooted in

operational resilience. This perspective is a key strategy: it is *the* way to create solutions that will be tractable: by prioritizing security based on resilience.

The CYPRES techniques are being developed and validated with respect to the following threat model: *Advanced cyber adversaries are targeting physical power system impact through multi-stage attacks.* Such threats require cohesive use of cyber and physical data and models together to defend. The elements of CYPRES help form the answer for how to achieve this defense in the most effective coordinated manner.

## II. CYBER-PHYSICAL RESILIENCE FRAMEWORK

CYPRES has been developing modeling and analytic techniques and tools that comprise a proposed next generation energy management system. The framework is cyber-physical and inherently considers security and risk throughout the data flow pipeline (monitoring, to analysis, to control). The feasibility is supported by use of well-known (industry used) data sources, coupled with the analytics that form its functional modules (Fig. 1).

Resilience begins in the planning phase. The goal is always to catch and prevent potential events early, while intentionally planning for the inevitable imperfection of models and for the inevitable imperfection of security defenses.

**Model fusion.** Hence, first is *cyber-physical model fusion*, that combines cyber and physical model information. To provide cyber-physical situational awareness, a map is needed, to help stakeholders understand the system. The map includes the power system topology, the cyber network topology, and the part in between, where they intersect [2], [3]: A *cyber topology* of the control network protects and thus affects grid operational reliability; it encompasses control center and substation networks. A *power topology* is how cyber-physical interactions map to physical impact; topology and state are essential to quantifying impacts. A *threat model* represents the characteristics of cyber-physical threats that are critical to design and test of the defense tools. Part of the challenge is that these requirements are not historically well-known or documented. This cannot be the case going forward, because a stakeholder needs to understand the system to best defend it. This major challenge is also where CYPRES helps: in identifying, mapping, and characterizing the system.

**Fused model mathematical representation.** The model generation step incorporates the topologies and threat information to create a state space representation for subsequent analyses. It is updated when needed based on changes. The state space embeds physical impact/operational reliability metrics specific to the use case and threat model.

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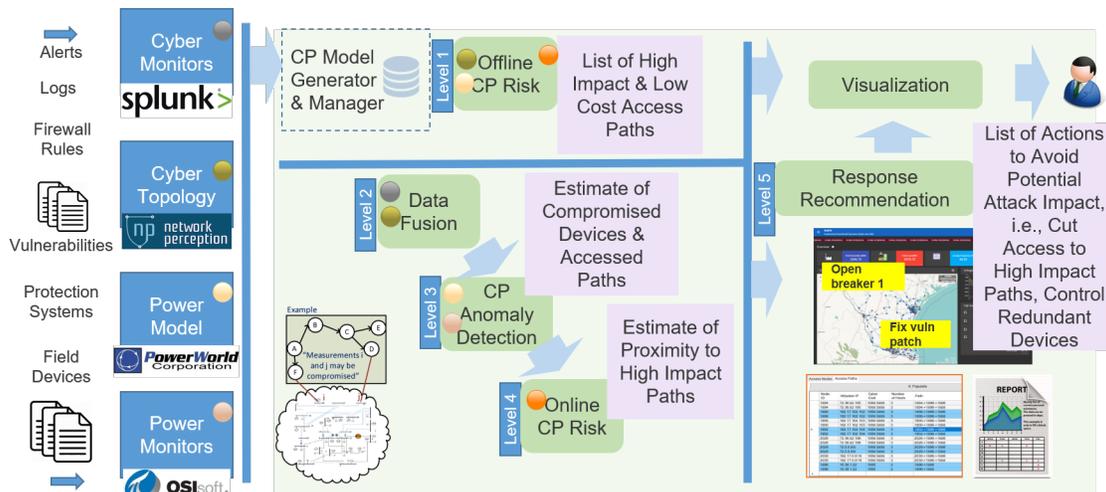


Figure 1. The CYPRES model and example of the cyber-physical energy management system workflow.

**Dataflow integrity and security monitoring.** Detection is an indispensable component of situational awareness. Monitoring for resilience is based on dataflows and their functions. This flow-based approach directly supports the collection and correlation of data from cyber and physical components throughout the networks. This enables use of the generated models with available alerts to estimate the security state of the system.

**Data fusion for ML-enhanced CPS state estimation.** Next is fusion of cyber and physical network data through techniques with feature extraction enabling *effective* machine learning (ML)-based cyber-physical intrusion detection, inferencing, and/or state estimation. Alerts from sensors on the cyber side are correlated with data from the physical side to infer what is going on in the system [4], [5], [6], [7].

**Preventative risk analyses for ahead-of-time mitigations.** Fused models and data enables cyber-physical risk analyses [8], [9], [10], to find potential events and identify components that need more defense. Prevention also involves planning: learning from past events, current state, and fused models enables such studies. Specialized testbeds (such as our Resilient Energy Systems Lab *RESLab* [11], a realistic emulated cyber-physical grid environment) support the realism of such studies without exposing or requiring the real stakeholder network.

**Adaptive risk analyses for online decision support.** No security is perfect. Regardless of how well a system is defended, response strategies are critical. Such a response plan is well-informed by the other components and can be designed to provide recommendations for response and mitigation.

The above components are primary functions of resilience. These would run periodically in the cyber-physical energy management system, updating as system state changes. With well-defined and consistent interfaces, each may be researched and improved independently. Ideally, multiple (or all) functions should be optimized together, e.g., reducing computational burden of modeling, monitoring, and control, and to simplify system defenses (including its design) based on key functions and their interdependencies. The framework also facilitates comparison of two or more cyber-physical systems against a given threat model.

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## REFERENCES

- [1] "Deep Cyber Physical Situational Awareness for Energy Systems: A Secure Foundation for Next-Generation Energy Management," Cyber-Physical Resilient Energy Systems, Sept. 2021. [Online]. Available: <https://cypres.engr.tamu.edu/>
- [2] G. A. Weaver, K. Davis, C. M. Davis, E. J. Rogers, R. B. Bobba, S. Zonouz, R. Berthier, P. W. Sauer, and D. M. Nicol, "Cyber-physical models for power grid security analysis: 8-substation case," in *2016 IEEE International Conference on Smart Grid Communications (Smart-GridComm)*. IEEE, 2016, pp. 140–146.
- [3] P. Wlazlo, K. Price, C. Veloz, A. Sahu, H. Huang, A. Goulart, K. Davis, and S. Zonouz, "A cyber topology model for the texas 2000 synthetic electric power grid," in *2019 Principles, Systems and Applications of IP Telecommunications (IPTComm)*, 2019, pp. 1–8.
- [4] P. Wlazlo, A. Sahu, Z. Mao, H. Huang, A. Goulart, K. Davis, and S. Zonouz, "Man-in-the-middle attacks and defence in a power system cyber-physical testbed," *IET Cyber-Physical Systems: Theory & Applications*, vol. 6, no. 3, 6 2021.
- [5] A. Sahu, Z. Mao, P. Wlazlo, H. Huang, K. Davis, A. Goulart, and S. Zonouz, "Multi-source multi-domain data fusion for cyberattack detection in power systems," *IEEE Access*, vol. 9, pp. 119 118–119 138, 2021.
- [6] A. Kundu, A. Sahu, E. Serpedin, and K. Davis, "A3d: Attention-based auto-encoder anomaly detector for false data injection attacks," *Electric Power Systems Research*, vol. 189, p. 106795, 2020. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0378779620305988>
- [7] O. Boyaci, A. Umunnakwe, A. Sahu, M. R. Narimani, M. Ismail, K. Davis, and E. Serpedin, "Graph neural networks based detection of stealth false data injection attacks in smart grids," *IEEE Systems Journal (accepted)*, 2021.
- [8] S. Zonouz, C. Davis, K. Davis, R. Berthier, R. Bobba, and W. Sanders, "SOCCA: A security-oriented cyber-physical contingency analysis in power infrastructures," *IEEE Transactions on Smart Grid*, vol. 5, no. 1, pp. 3–13, 2014.
- [9] K. R. Davis, C. M. Davis, S. A. Zonouz, R. B. Bobba, R. Berthier, L. Garcia, and P. W. Sauer, "A cyber-physical modeling and assessment framework for power grid infrastructures," *IEEE Transactions on smart grid*, vol. 6, no. 5, pp. 2464–2475, 2015.
- [10] A. Umunnakwe, A. Sahu, and K. Davis, "Multi-component risk assessment using cyber-physical betweenness centrality," in *2021 IEEE Madrid PowerTech*, 2021, pp. 1–6.
- [11] A. Sahu, P. Wlazlo, Z. Mao, H. Huang, A. Goulart, K. Davis, and S. Zonouz, "Design and evaluation of a cyber-physical resilient power system testbed," 11 2020. [Online]. Available: <http://arxiv.org/abs/2011.13552>