Smart Grid Cyber-Resilience

Prof. Dr. Sebastian Lehnhoff

Three Major Trends

...that influence the stability of KRITIS Energy

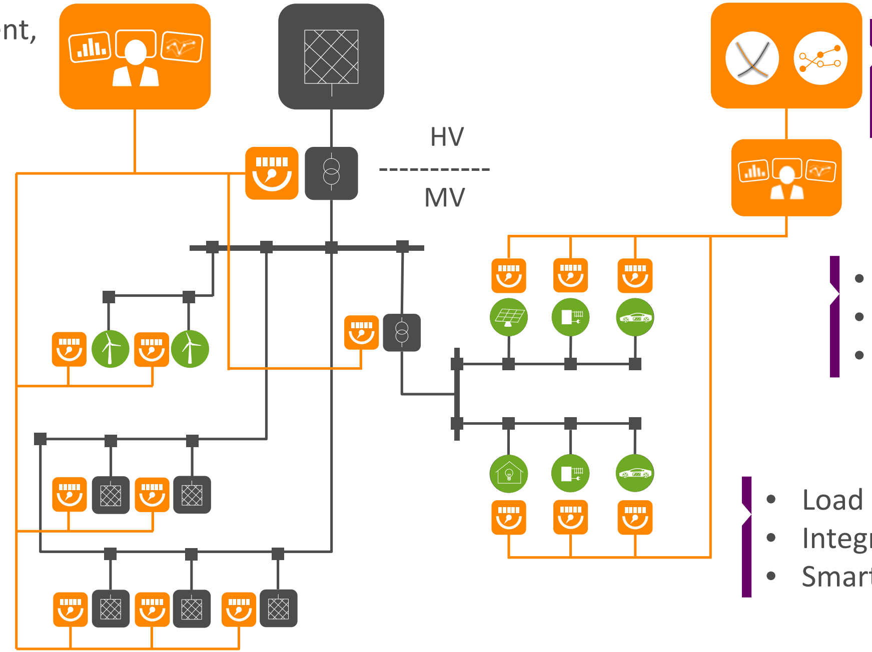
1. **Conversion of the energy system, e.g.**
   - > Many smaller systems, system-critical as a whole
   - > Competition and new business models
   - > Interconnectivity, flexibilization through digitalization
2. **Digitization trends, including**
   - > Internet of Things (IoT): several billion devices on the Internet and connected to our power grid (televisions, baby monitors, alexa, etc.)
   - > Smart Services, Cloud, Outsourcing, Artificial Intelligence, Big Data,...
3. **Susceptibility to new effects, e.g.**
   - > Occurrence of "classic" IT challenges (errors, update management, interactions)
   - > Sophisticated cyber-attacks (partly supported by states)

Energy Systems are Complex Cyber-Physical Systems

Diverse tasks in heterogeneous, distributed (sub)systems under different responsibilities

- Forecast of network conditions,
- Optimized reactive power management,
- Detection of anomalies in power and communication networks.

- Monitoring of the operating states,
- Automation yellow traffic light phase,
- decentralised system services.



- Algorithmic energy trading,
- Market integration of renewable energies.

- Virtual power plants,
- multi-modal optimization,
- Sector coupling.

- Load and flexibility management,
- Integration of end customers,
- Smart metering.

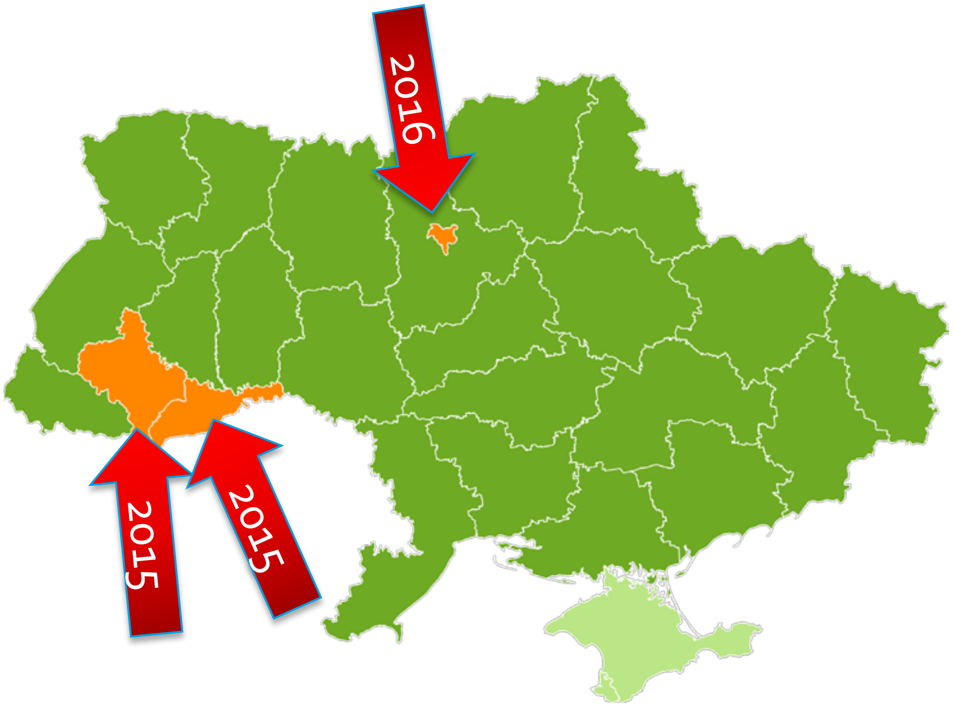
A wide range of entry-points into a safety-critical infrastructure...

"There are two types of companies:
those that have been hacked
and those who don‘t know
that they have been hacked.“

John T. Chambers.

This also applies to „our“ Energy Systems

Cyber-attacks on the power system in the Ukraine, 23.12.2015 (and subsequently in 2016)



- Blackout in Ukraine due to hacker attack
- 3 Power utilities affected
- Operative manipulation of the automation systems and decoupling of several transformer stations from the network
- Several months of preparation

- *Power Systems are high-value targets: how to reliably detect vulnerabilities?*

Vulnerabilities

...to critical dependencies and cyber-attacks

Critical attack vectors in energy systems (non exhaustive)

- Reconnaissance, data theft
- IT/OT-hacking: remote access and control
- Data-spoofing: bad data injection, data manipulation, excitation of dynamic instabilities/sliding modes

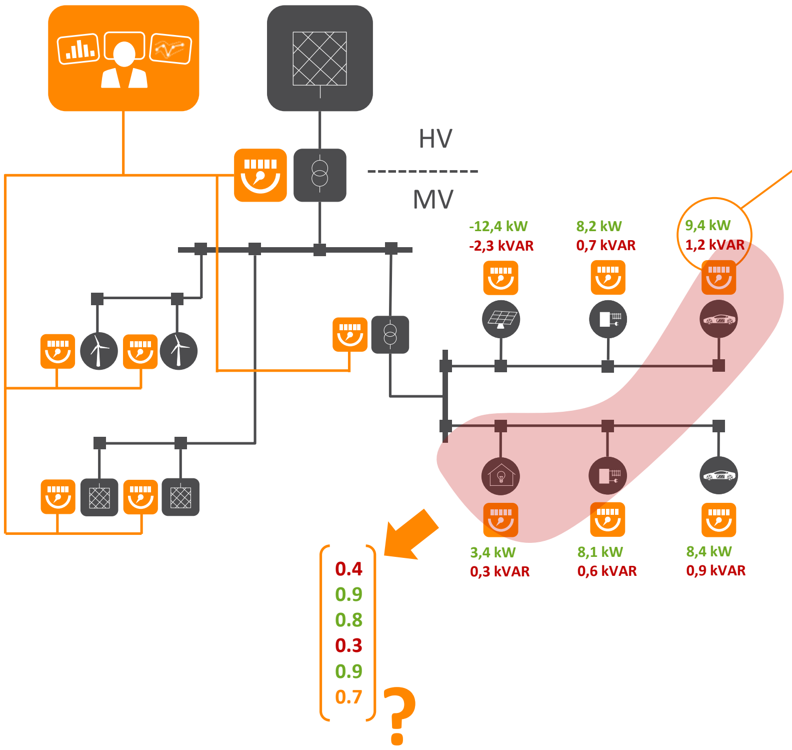
Existing monitoring systems

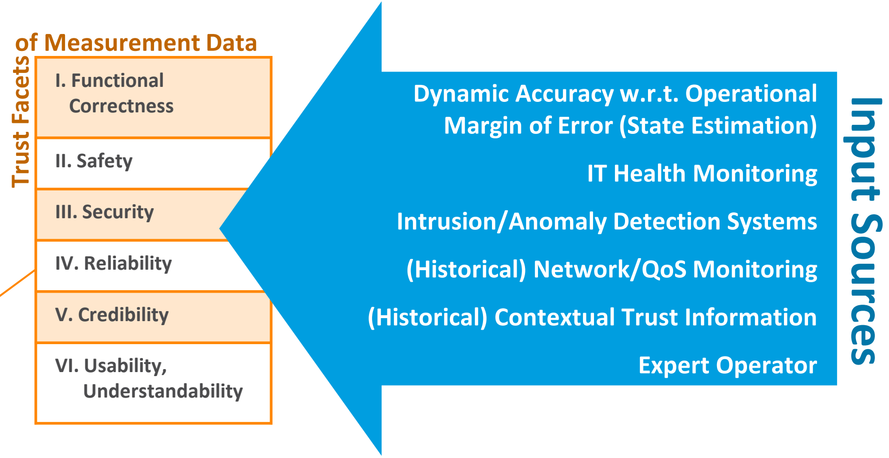
- Intrusion/anomaly detection → abnormal network traffic
- State estimation → measurement outliers (statistical), varying accuracy of measurements

Not sufficient for detecting critical situations in digitalized energy systems!

State Assessment based on Trust Facets

…

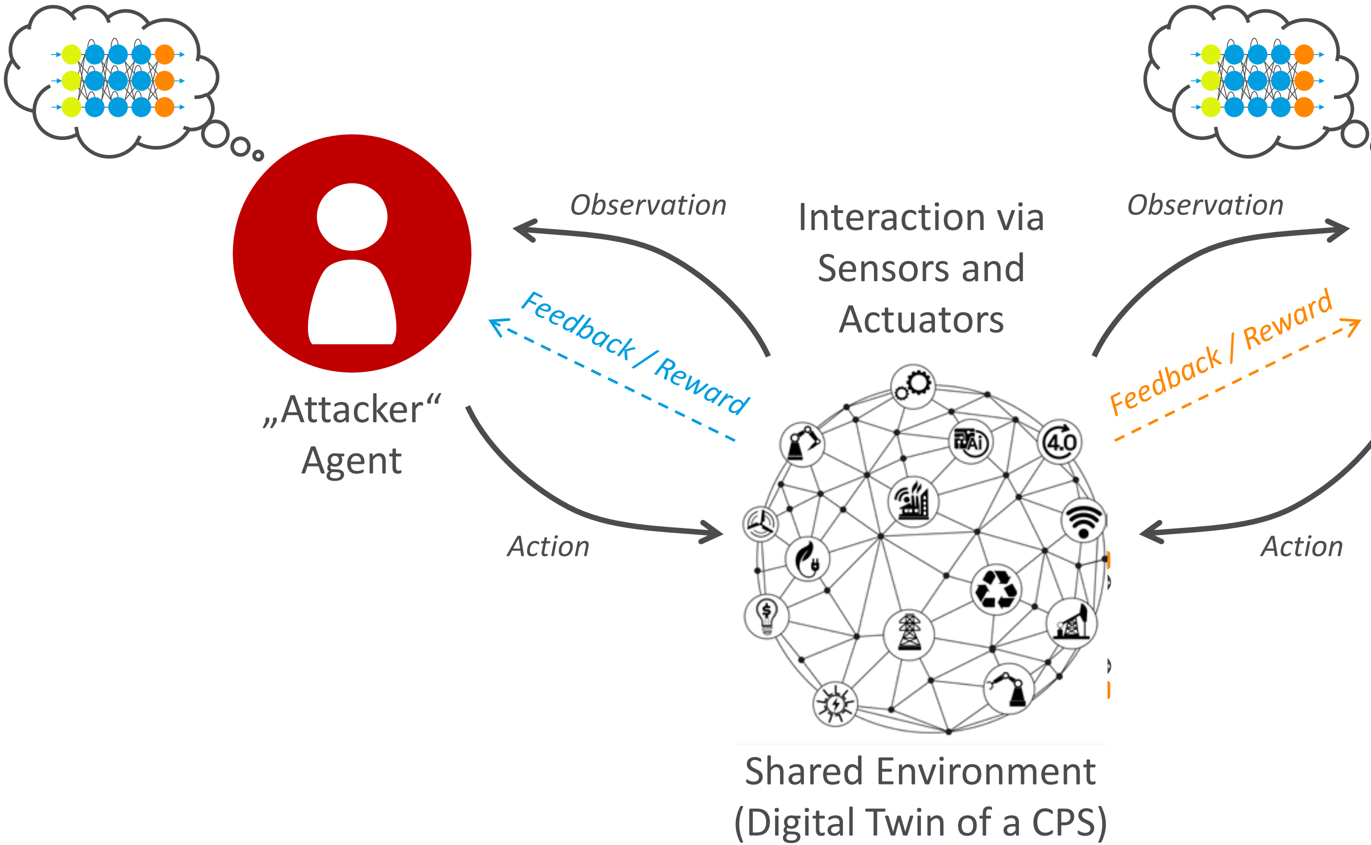




- **All conceivable attack vectors manifest themselves in a combination of (violated) trust facets**
- What to do with this multivariate assessment?
  - E.g. substitute measurements with historical/simulated values?
  - Do nothing?
- *What is the worst that could happen?*

The Concept of Adversarial Resilience Learning

Competing agents learn by interacting on a shared environment



Use Case: Resilient Systems Analysis and Training

Variations of ARL

Analysis – only Attacker

- Test laboratory for resilient systems
- Attacker explores vulnerabilities
- "Conquest" of the system
- Attack vectors/results as a basis for analysis

Training – Attacker and Defender

- AI for automated operation
- Resilience strategies of the overall system
- Attacker trains defender
- Attacks: not only malicious, but also natural environmental factors
  - forecast deviations
  - Damage caused by accidents etc.

What about the obvious ethical dilemma?

- ARL as "assault weapon"?
- License as a solution?
- Making “laws of robotics” inherent by transfer learning?

Demo: Attack on a Power System

Prevention of (sub-)system takeover as a secondary problem

Smart Grid
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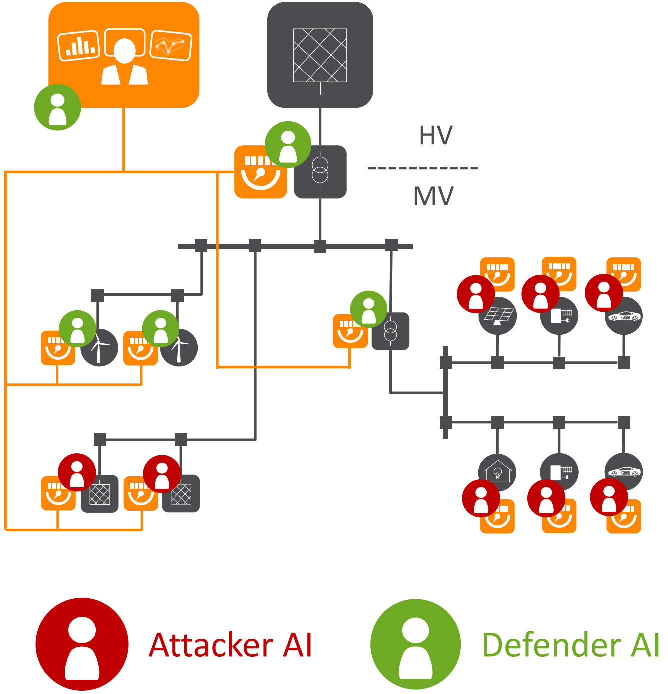

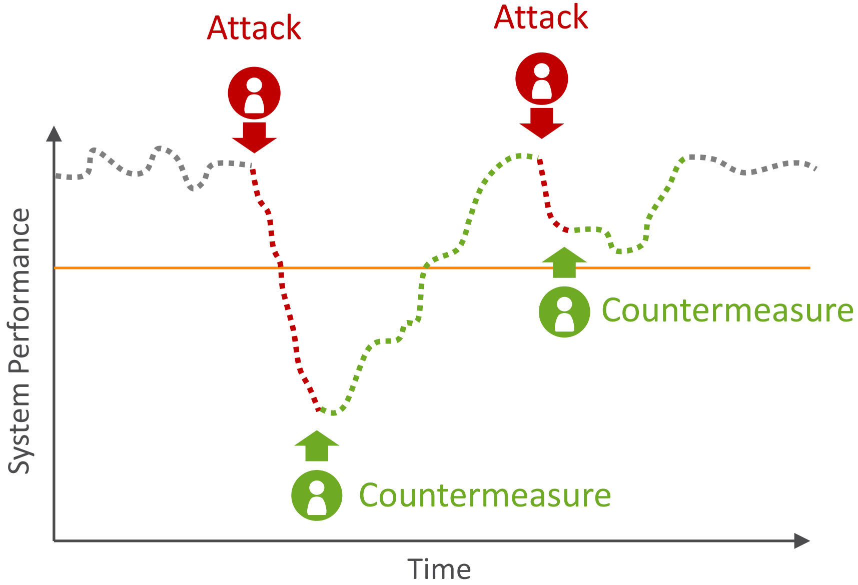

Conclusion and Outlook

Digitalization is indispensable for flexible energy systems (and highly vulnerable at the same time)

Traditional means/methods have been proven to miss:

- Vulnerabilities to interdependent/dynamic failures
- Specialized/targeted attacks

Multivariate impact analysis necessary

- Basis for (automated) decision-making during operation ("always compromised")
- *Risk-based investments in countermeasures?*

ARL as an AI-based game-theoretic approach to vulnerability testing (CPS modelling)

- Equilibria more relevant (and achievable) than "absolute" safety

There is no way back from digitalized energy systems!

- Most promising answer against highly specialized/targeted attacks is *Operational Flexibility (on-line change of system characteristics) for Cyber-Resilience!*

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