

IS MY GRID BOUNCING BACK? A CYBER-PHYSICAL RESILIENCE METRIC FOR SMART GRIDS

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IVO FRIEDBERG

Research Fellow

Center for Digital Safety & Security

AIT Austrian Institute of Technology GmbH

ivo.friedberg.fl@ait.ac.at | www.ait.ac.at



WHAT IS RESILIENCE?

A resilient control system is one that **maintains state awareness and an accepted level of operational normalcy** in response to disturbances, including threats of an **unexpected and malicious nature**.

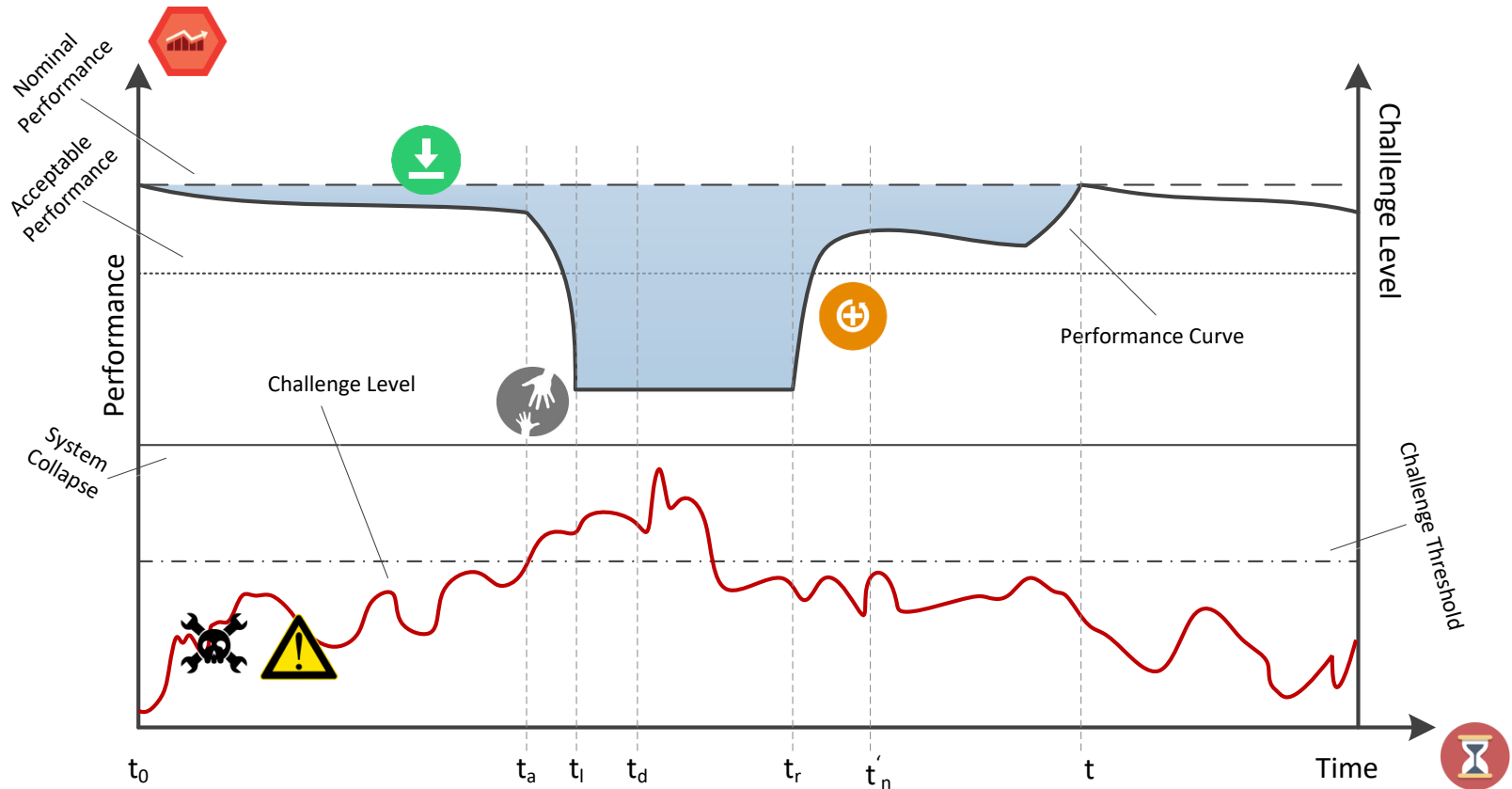
A resilient industrial control system (RICS) is the one that is designed and operated in a way that:

- **most of the undesirable incidents can be mitigated;**
- the **adverse impacts** of undesirable incidents **can be minimized...**
- **it can recover to normal operation in a short time.**

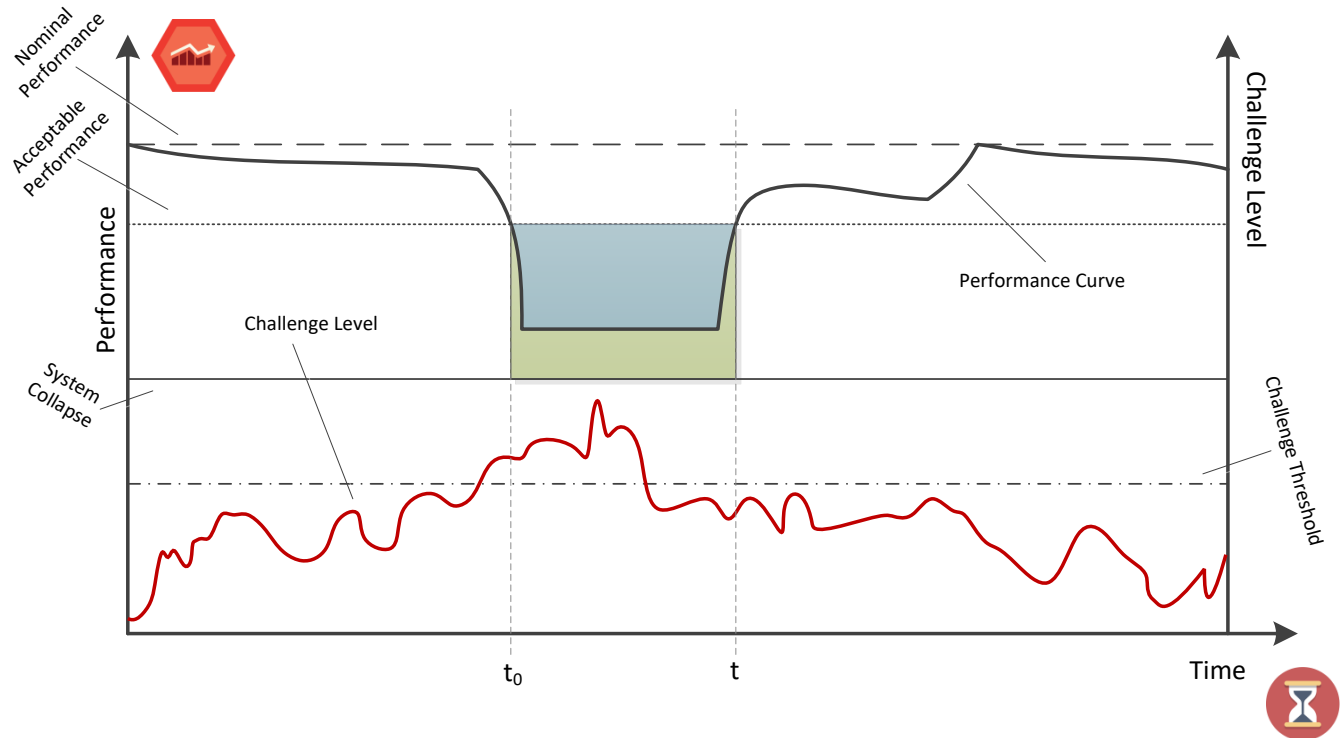
Power system cyber-physical resilience is the system's ability to **maintain continuous electricity flow** to customers given a certain load prioritization scheme. A resilient power system **responds to cyber-physical disturbances in real-time or semi real-time, ...**

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MEASURE RESILIENCE



MEASURE RESILIENCE



$$R_{p_i}: \mathbb{R}^+ \rightarrow [0,1]: t \mapsto 1 - \frac{\int_{t_0}^t p_i(\tau) d\tau - p_i^T \cdot (t - t_0)}{(t - t_0)(p_i^N - p_i^T)}$$

SO WHAT ABOUT $p(\tau)$?

- Evaluate resilience with respect to one performance indicator...

$$R_{p_i}: \mathbb{R}^+ \rightarrow [0,1]: t \mapsto 1 - \frac{\int_{t_0}^t p_i(\tau) d\tau - p_i^T \cdot (t - t_0)}{(t - t_0)(p_i^N - p_i^T)}$$

- ... under consideration of related challenges,

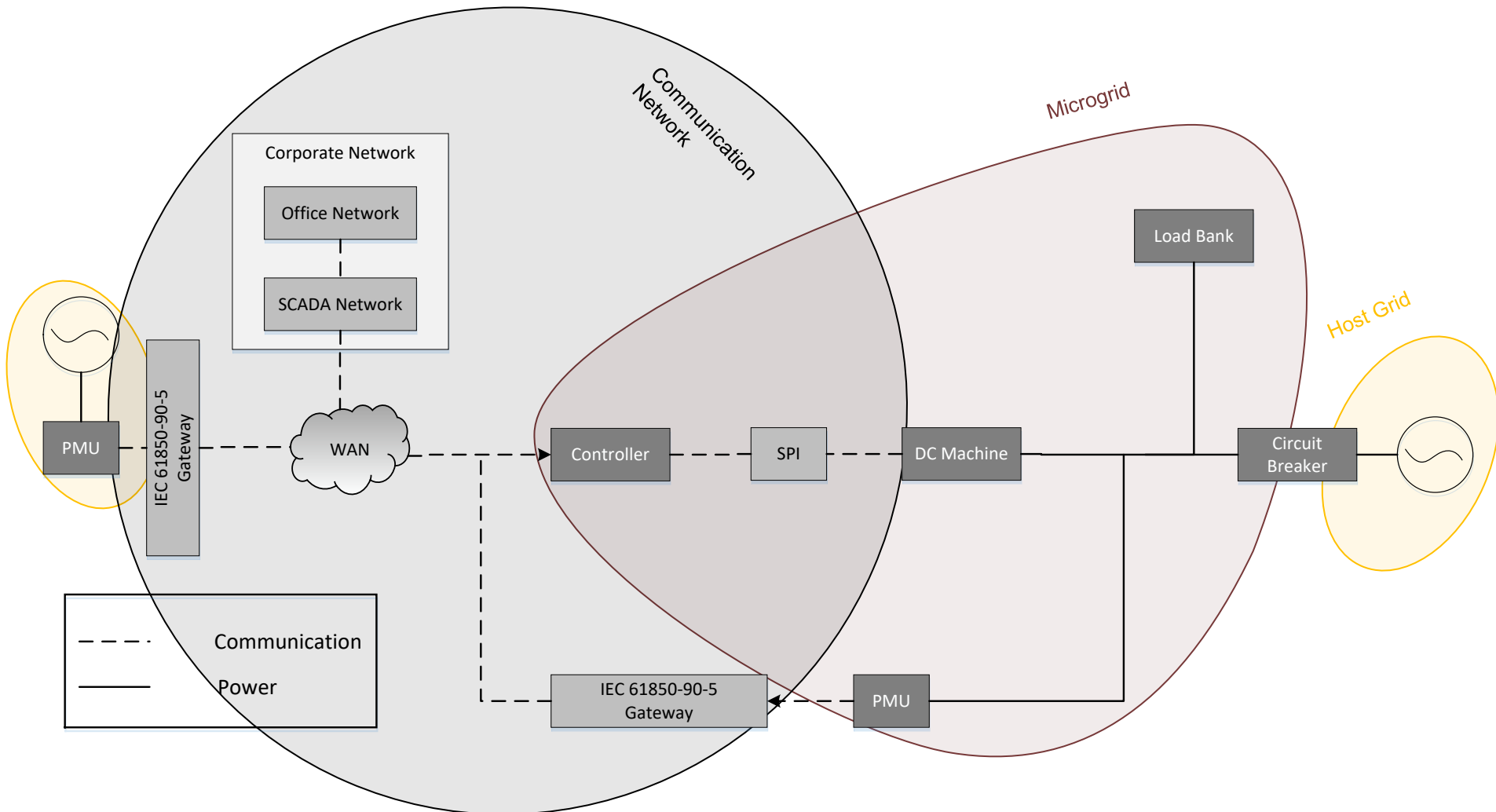
$$\dot{p}_i(t) = [f(t, r, p_i(t), p_i^N) - g(t, \vec{c}(t), \vec{p}(t))] \cdot \Theta_{p_i}(p_i(t))$$



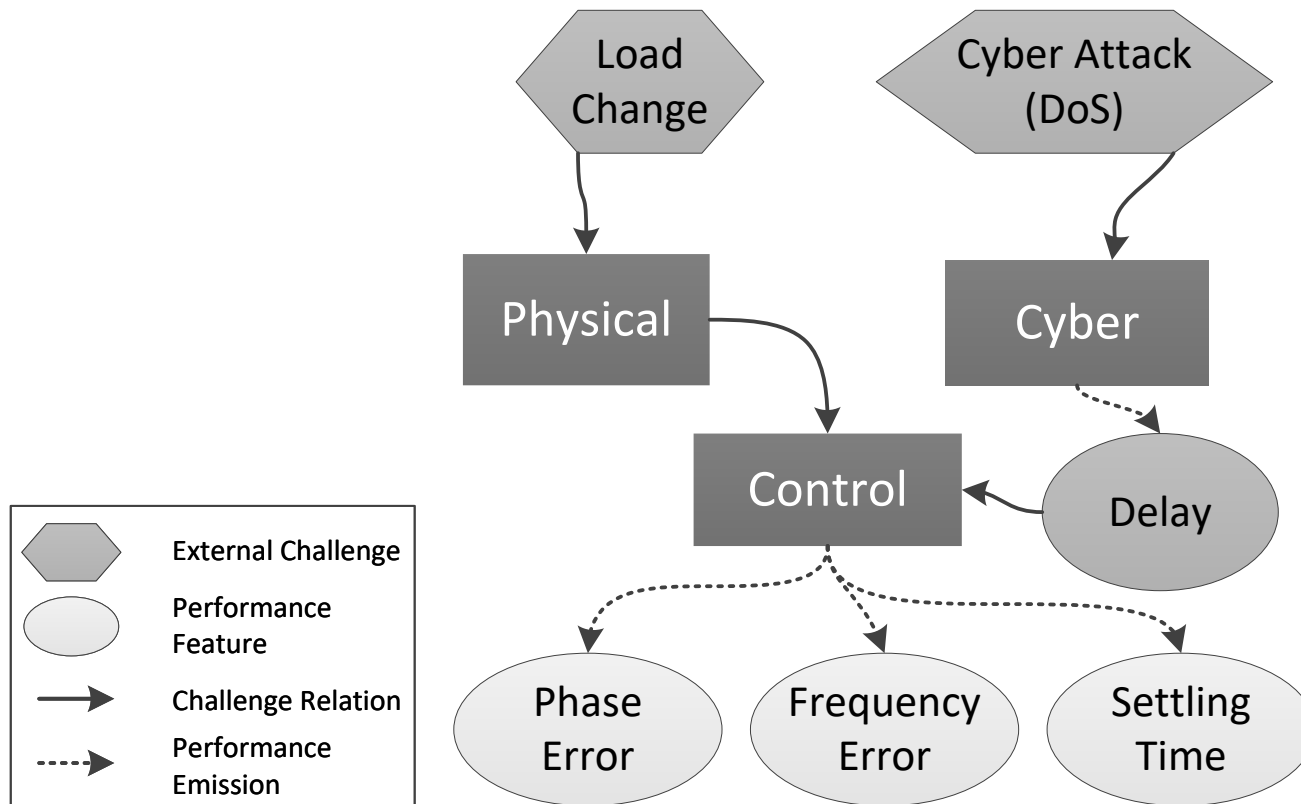
- where each performance indicator can be a challenge to another indicator.

$$\tau : \mathbb{R}^+ \rightarrow \mathbb{R}^+ \quad \forall x \in \mathbb{R}^+ \quad p(x)$$

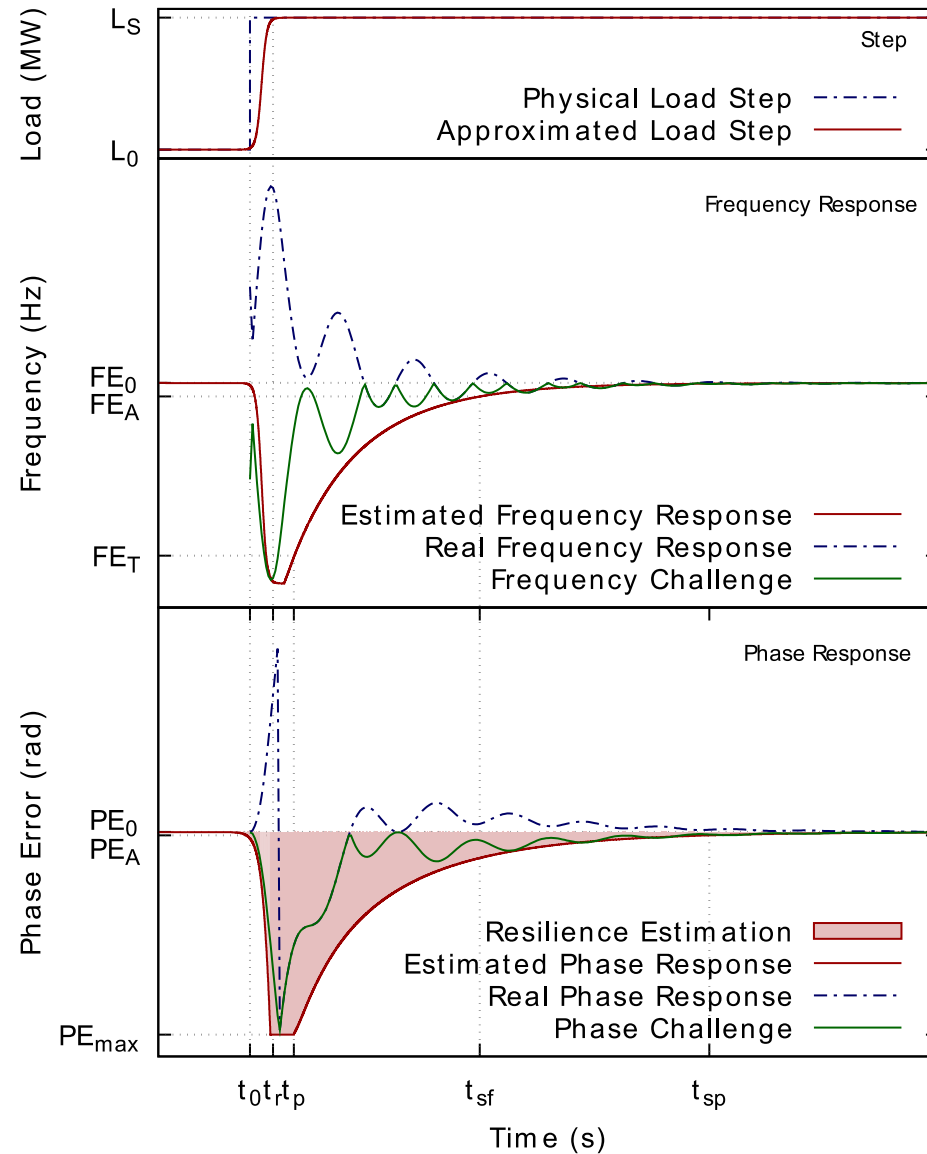
SYNCHRONOUS ISLANDING USE CASE



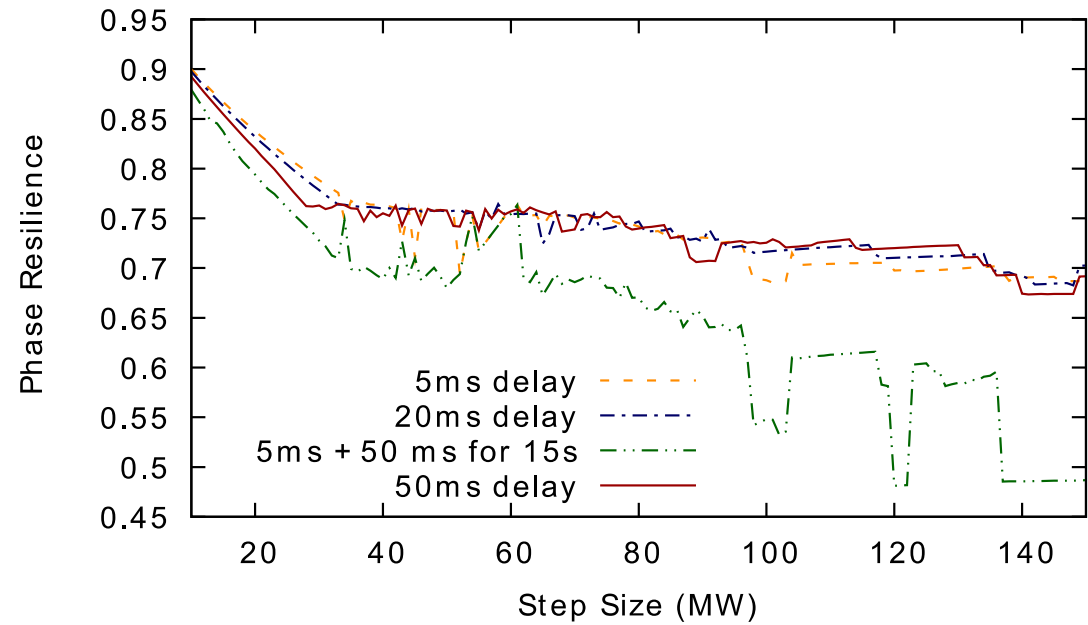
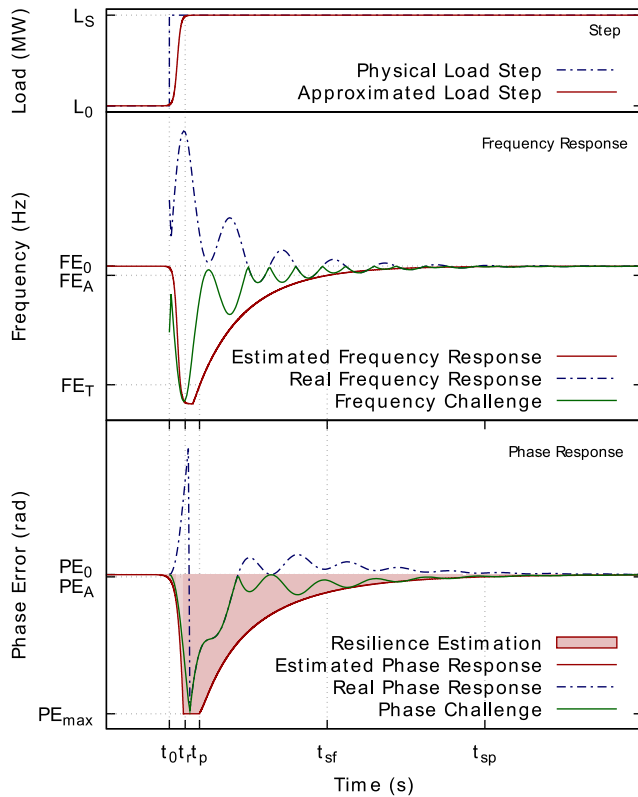
CHALLENGES AND PERFORMANCE



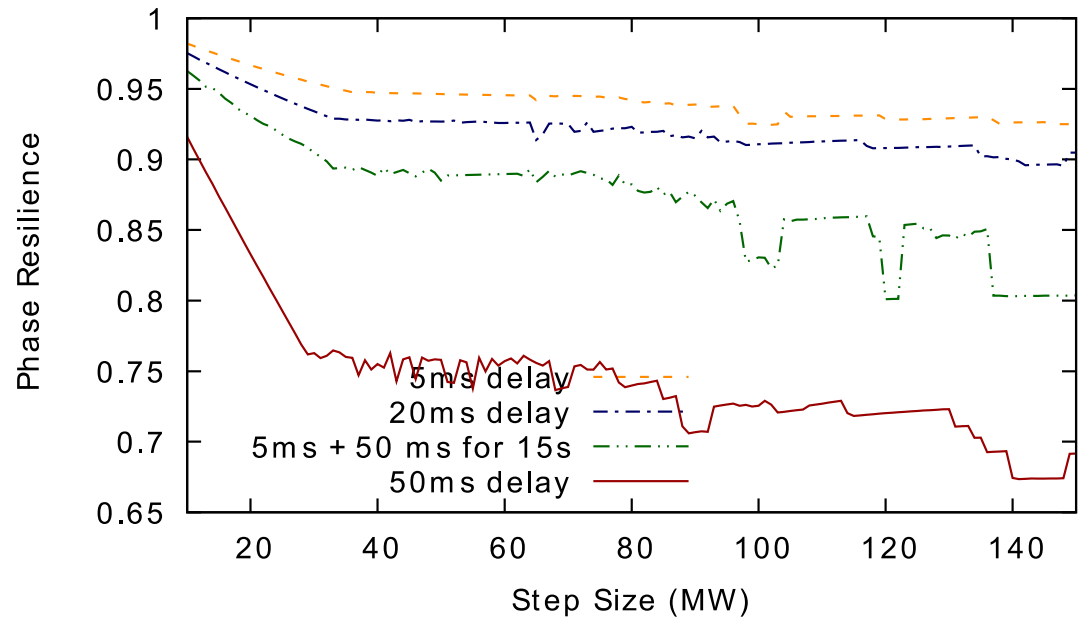
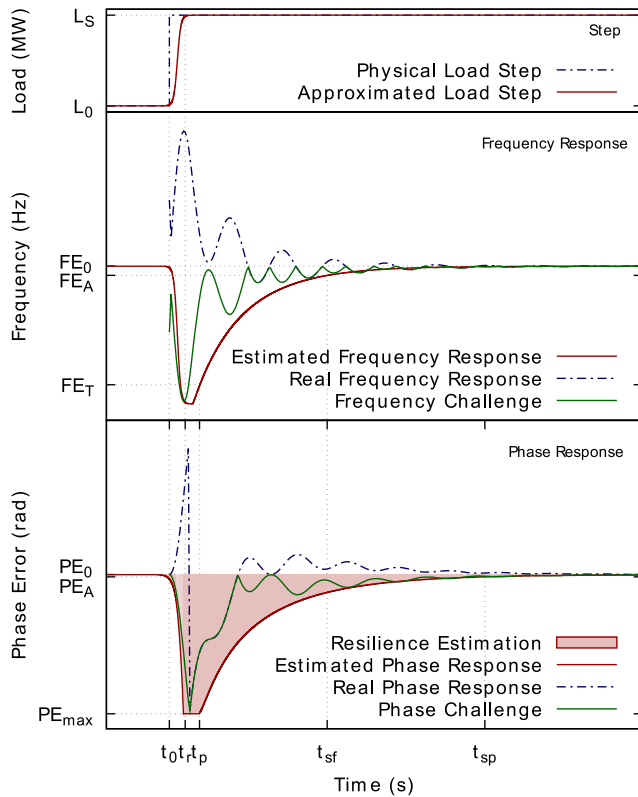
FRAMEWORK DESIGN



EVALUATION



EVALUATION



QUESTIONS?

Ivo Friedberg, 19.9.2017

