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

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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**.

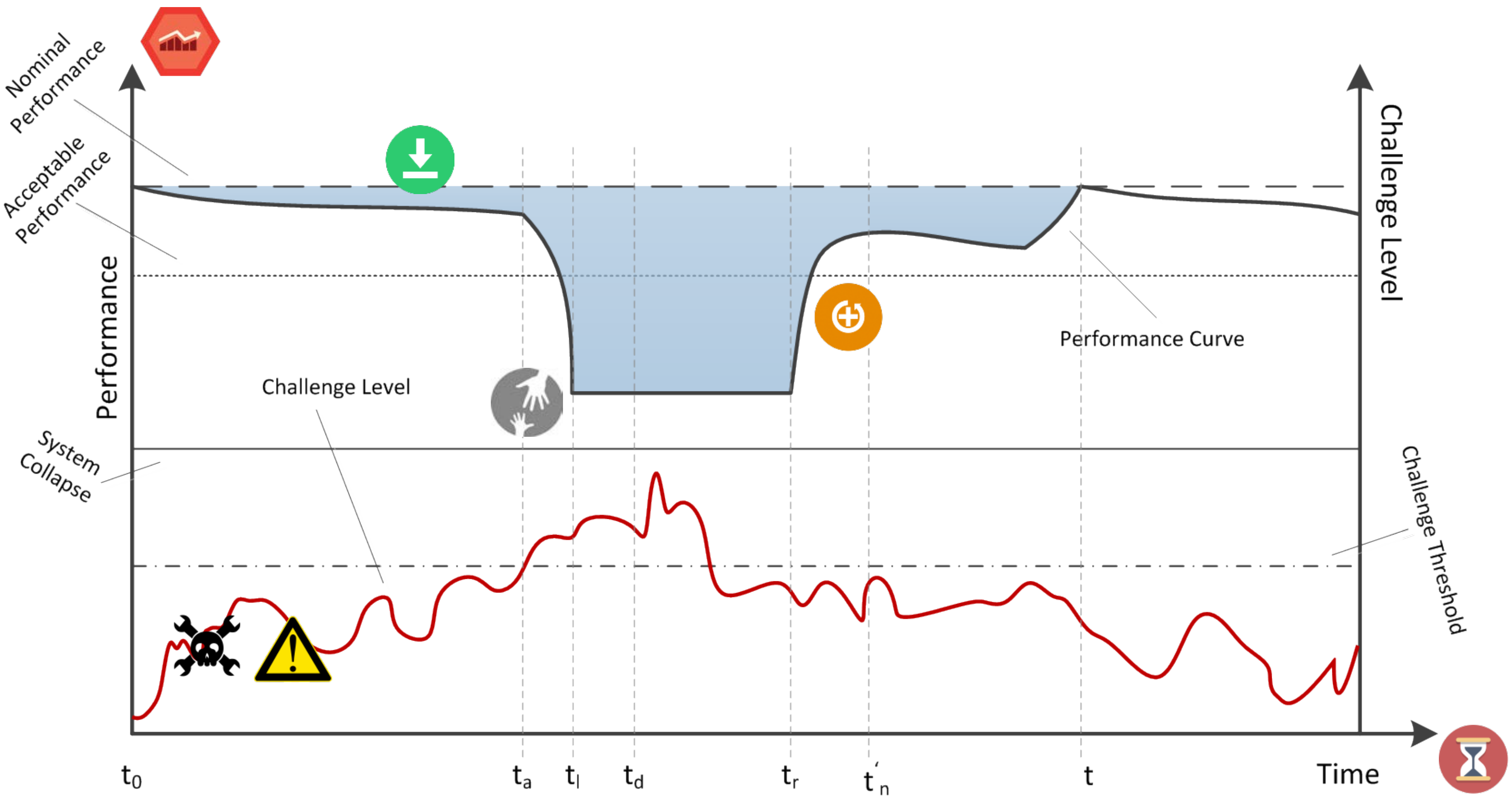
A resilient industrial control system (RICS)
is the one that is designed and operated in a way that:

- **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**.

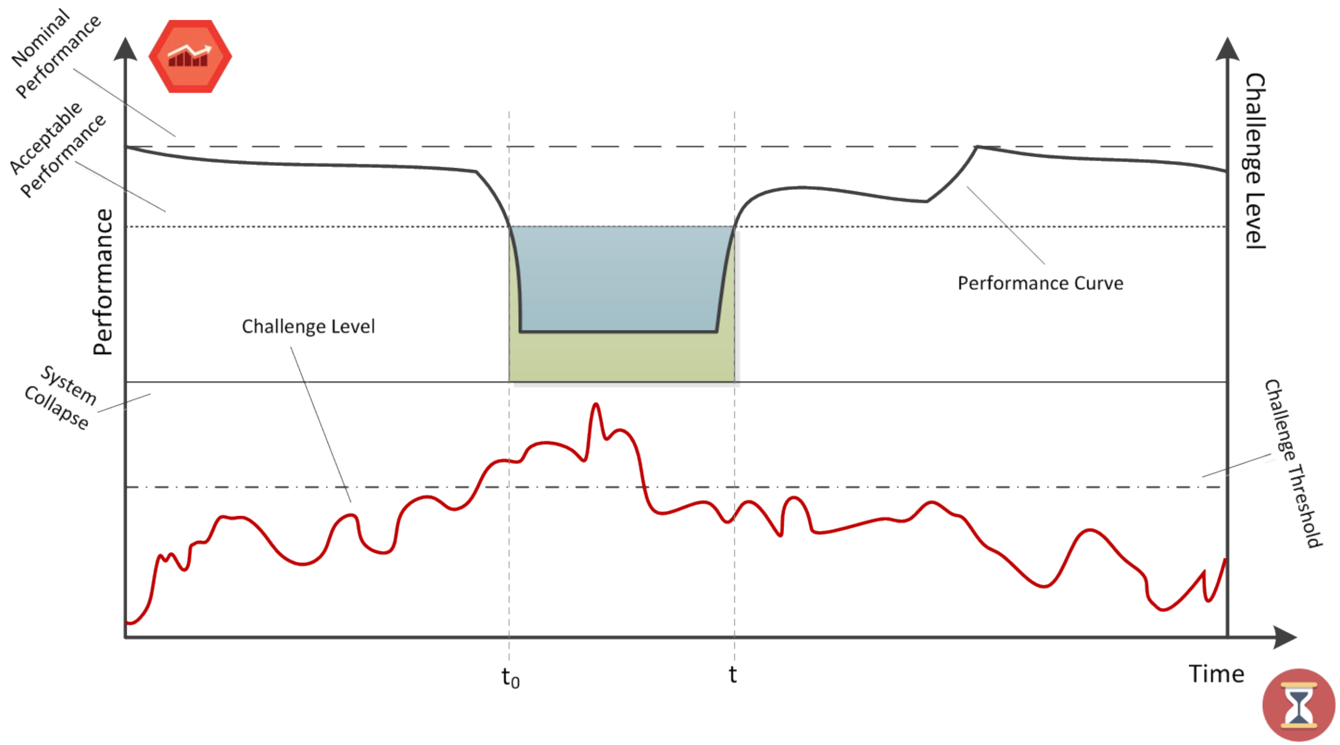
Power system cyber-physical resilience is the system's ability to **maintain continuous electricity flow** to customers given a certain load prioritization scheme. A resilient power system **responds to cyber-physical disturbances in real-time or semi real-time**, …

[illegible]

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…

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

- … under consideration of related challenges,

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

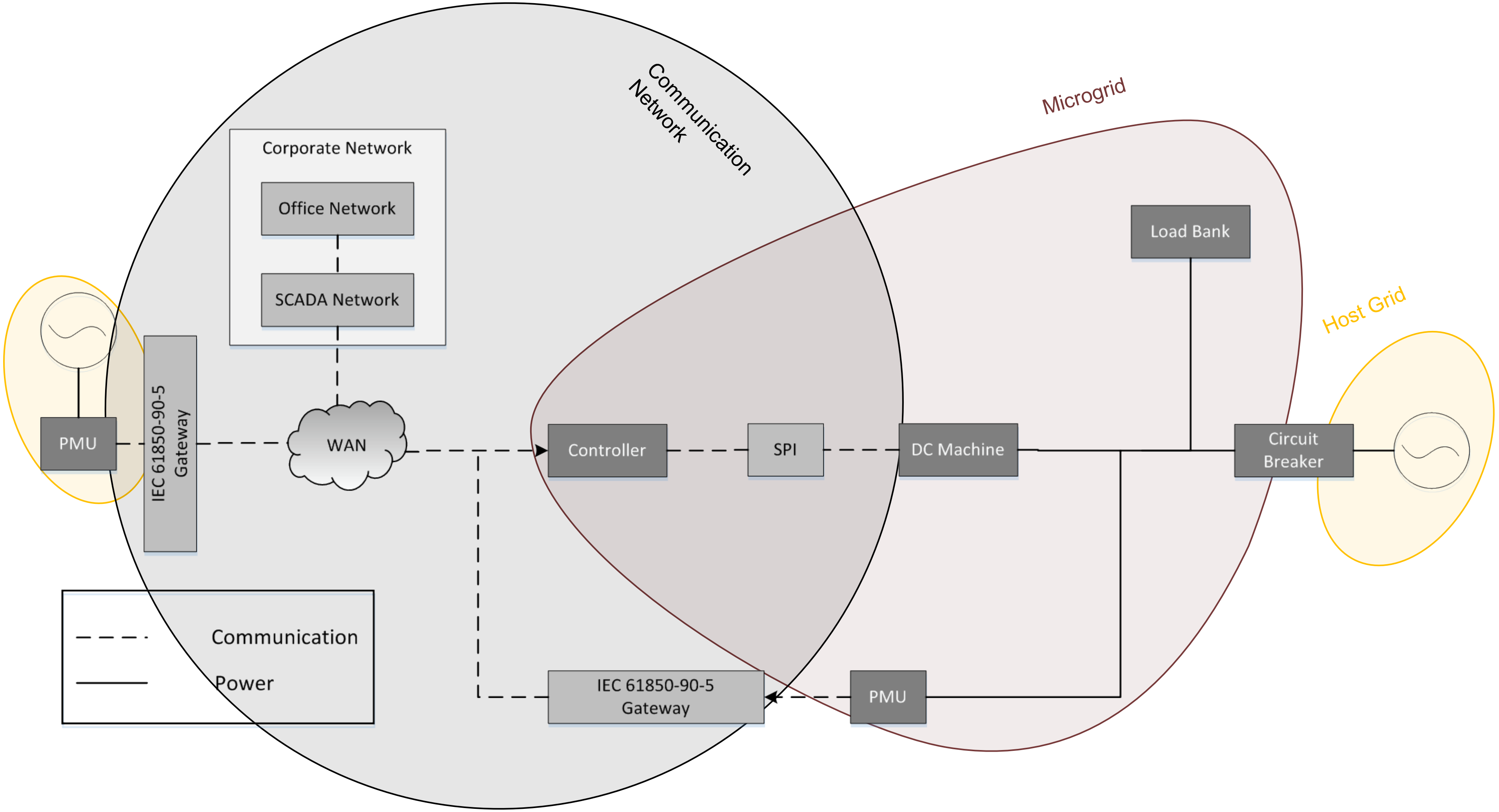



- where each performance indicator can be a challenge to another indicator.

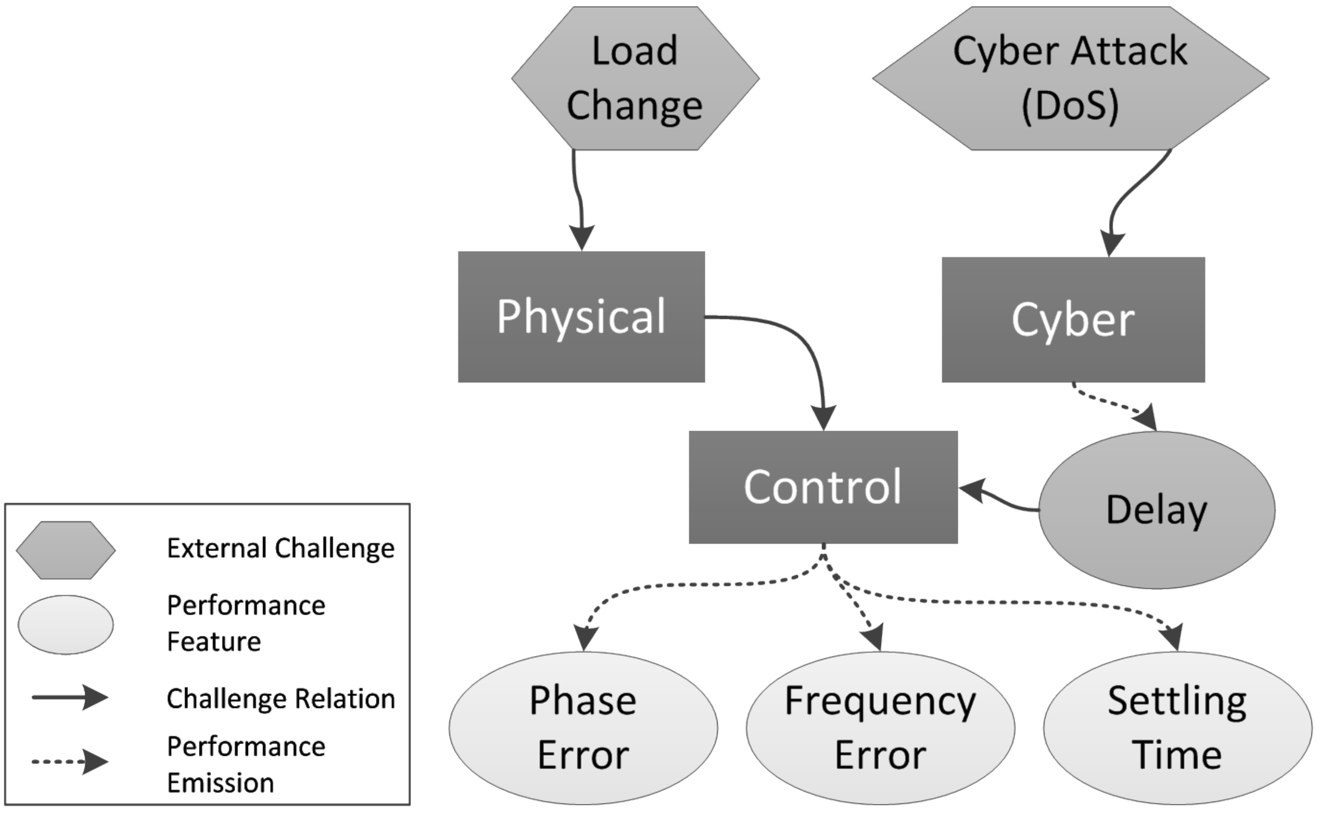
$\tau : \mathbb{R}^+$ … $\frac{1}{x}$ … $p(t))$

Performance

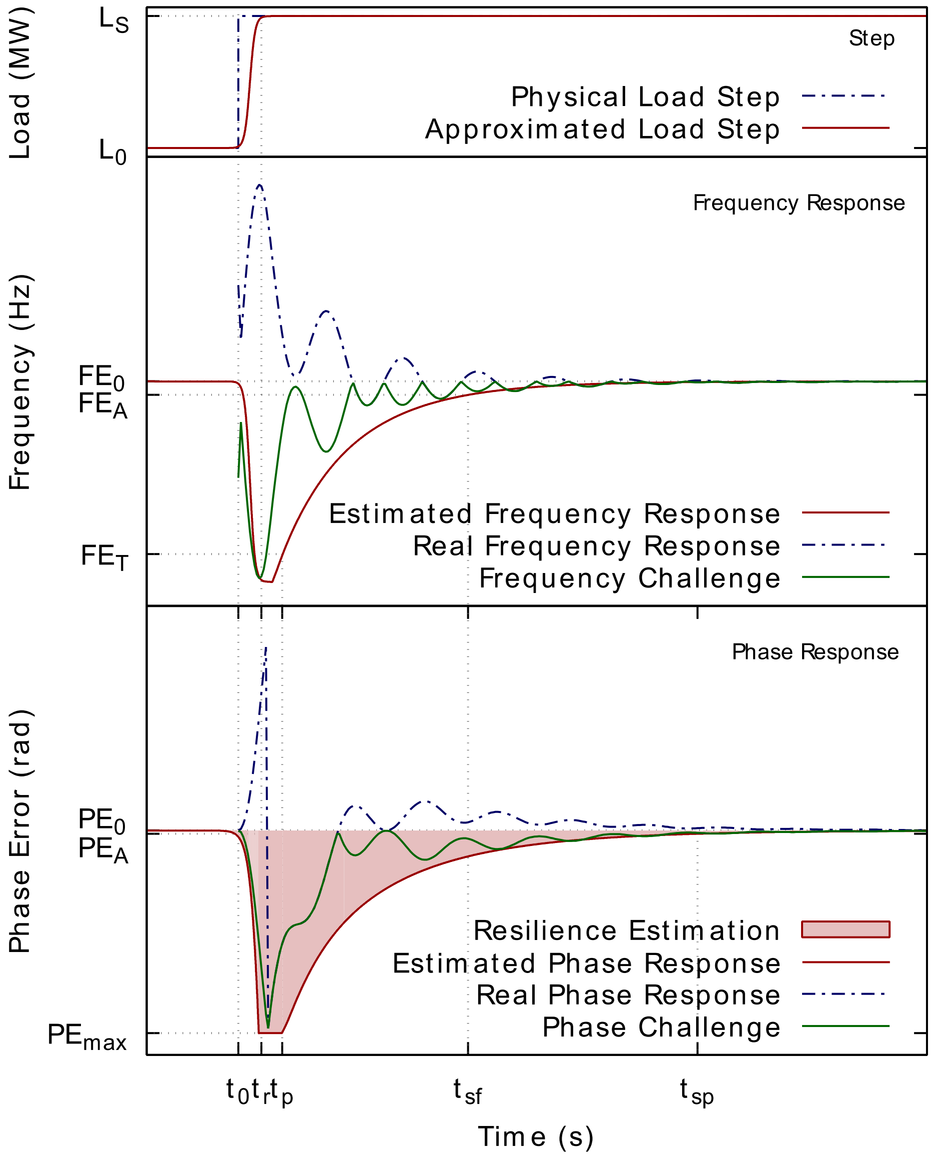
SYNCHRONOUS ISLANDING USE CASE



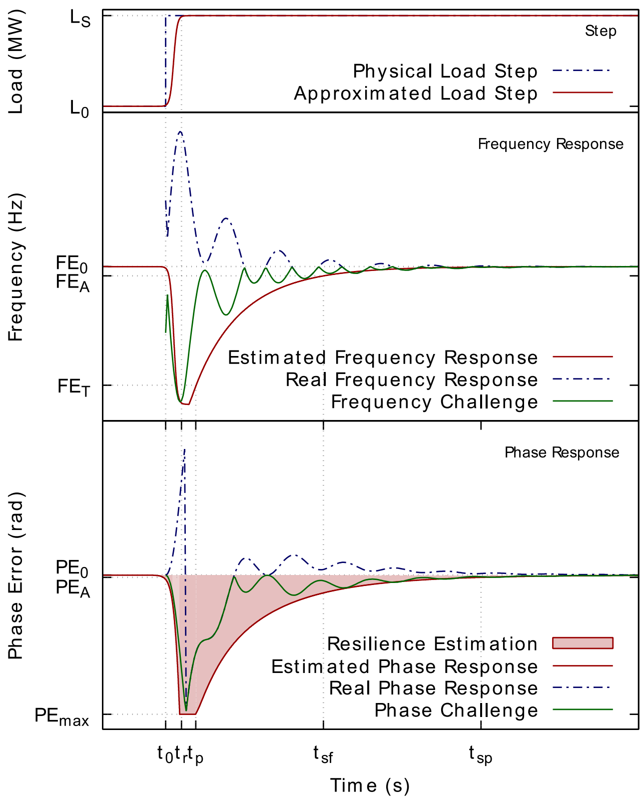
CHALLENGES AND PERFORMANCE



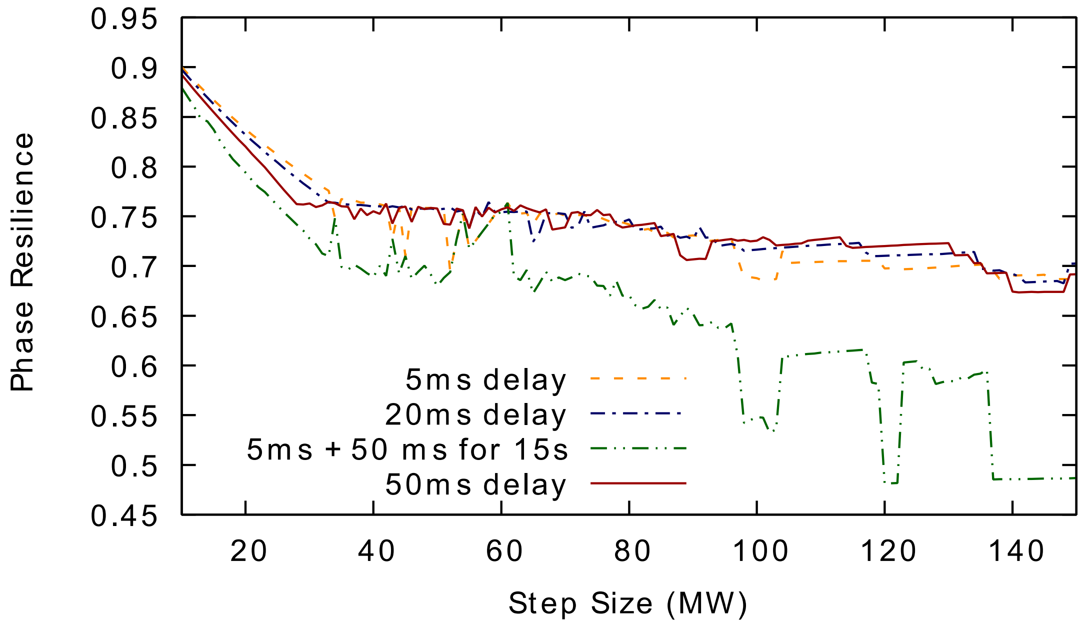
FRAMEWORK DESIGN



EVALUATION

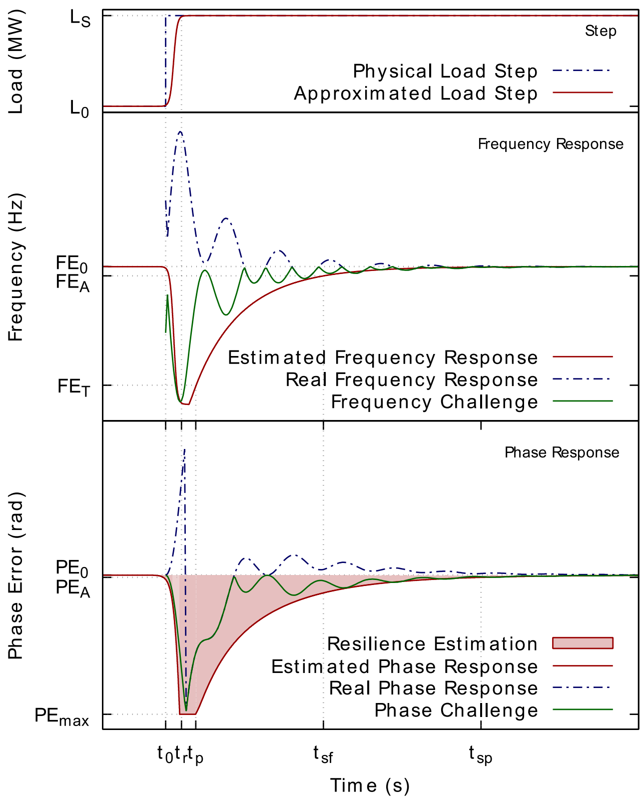


Load (MW)
L_S
L_0
Step
Physical Load Step
Approximated Load Step
Frequency (Hz)
Frequency Response
FE_0
FE_A
FE_T
Estimated Frequency Response
Real Frequency Response
Frequency Challenge
Phase Error (rad)
Phase Response
PE_0
PE_A
PE_{max}
Resilience Estimation
Estimated Phase Response
Real Phase Response
Phase Challenge
$t_0 t_r t_p$
t_{sf}
t_{sp}
Time (s)

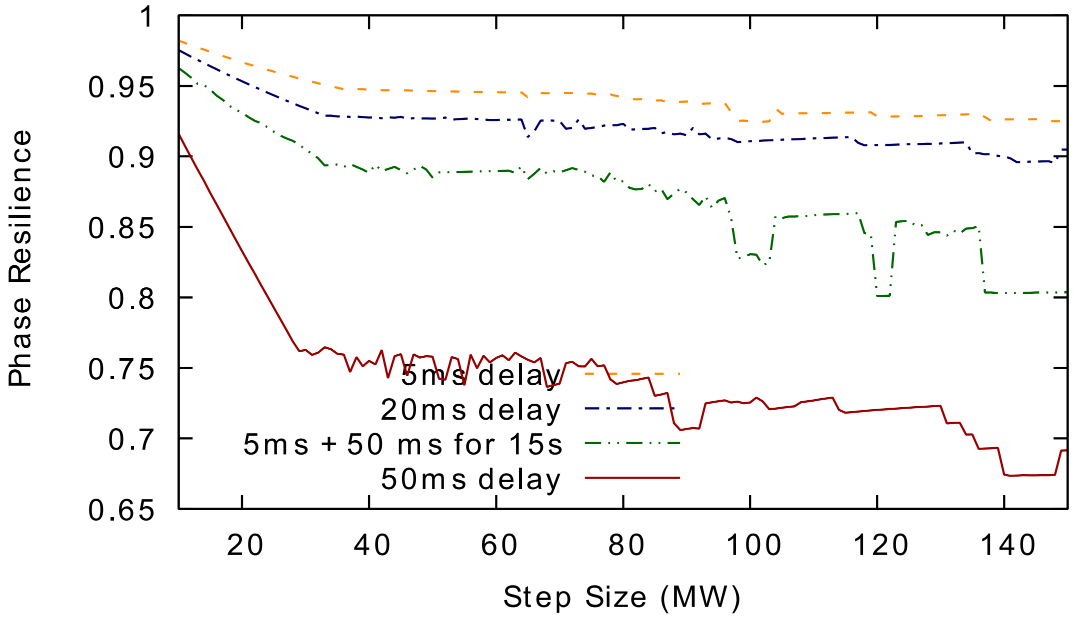


Phase Resilience
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
5ms delay
20ms delay
5ms + 50 ms for 15s
50ms delay
20
40
60
80
100
120
140
Step Size (MW)

EVALUATION



Load (MW)
L_S
L_0
Step
Physical Load Step
Approximated Load Step
Frequency (Hz)
Frequency Response
FE_0
FE_A
FE_T
Estimated Frequency Response
Real Frequency Response
Frequency Challenge
Phase Error (rad)
Phase Response
PE_0
PE_A
PE_{max}
Resilience Estimation
Estimated Phase Response
Real Phase Response
Phase Challenge
t_0 t_r t_p
t_{sf}
t_{sp}
Time (s)



Phase Resilience
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
5ms delay
20ms delay
5ms + 50 ms for 15s
50ms delay
20
40
60
80
100
120
140
Step Size (MW)

AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

QUESTIONS?

Ivo Friedberg, 09.03.2017