Early Warning and Prevention of System Stability Problems

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Outline

1. Background & Overview
2. Early Warning & Early Prevention System
3. Future Outlook and Concluding Remarks

Future challenges / problems to address in R&D

Secure Operation of Sustainable Electric Power Systems

- ***Future visions:*** a society with minimal dependency of fossil fuels
  - Requires power production to be mainly based on renewable energy sources (RES)
  - Production becomes subject to prevailing weather conditions (fluctuations) and behind inverters

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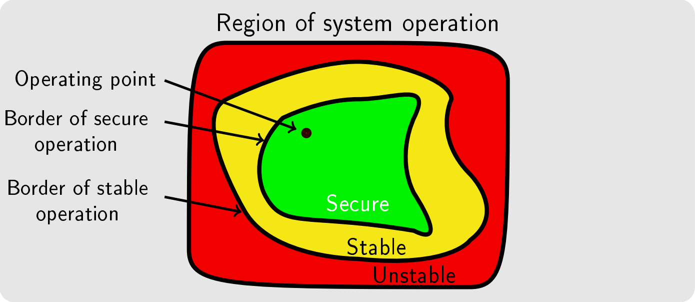

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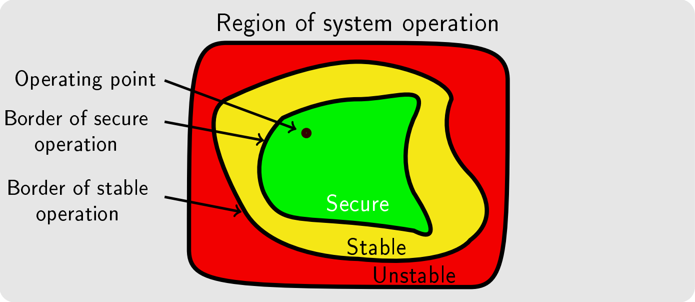
- Historically, security assessment is based on off-line analysis
  - Time consuming $\Rightarrow$ Insufficient



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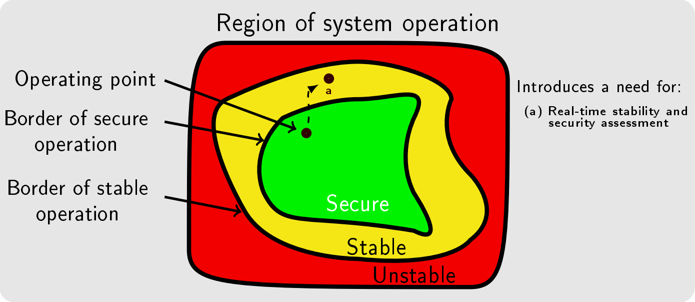

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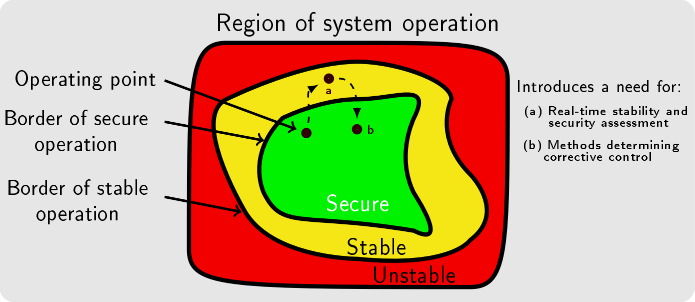

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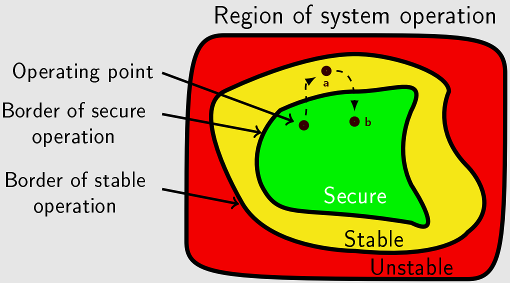


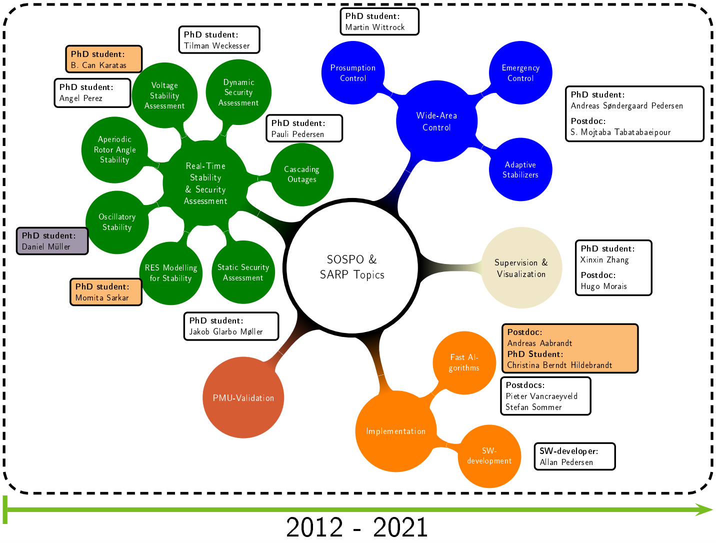
Introduces a need for:

(a) Real-time stability and security assessment

(b) Methods determining corrective control

PMUs seen as an enabling technology

DTU's major R&D topics addressing secure system operation



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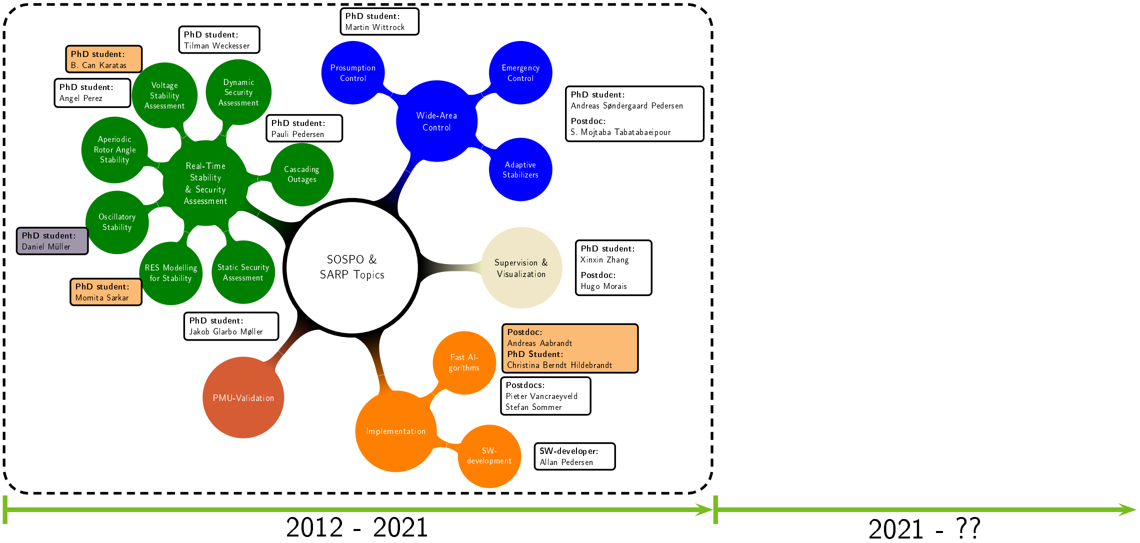

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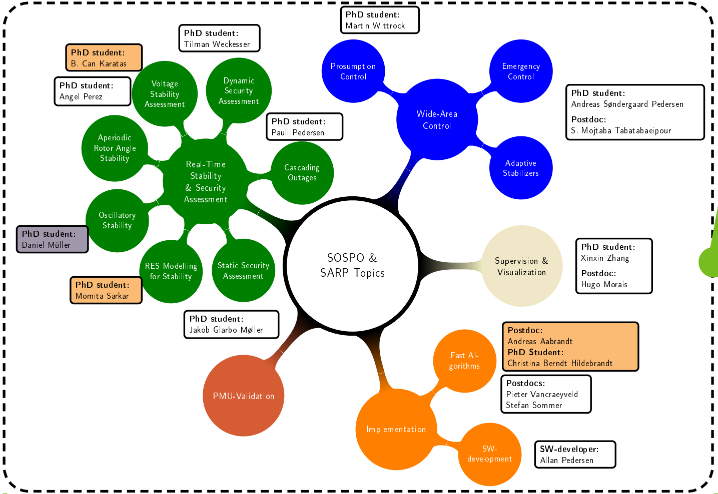

2012 - 2021

2021 - ??

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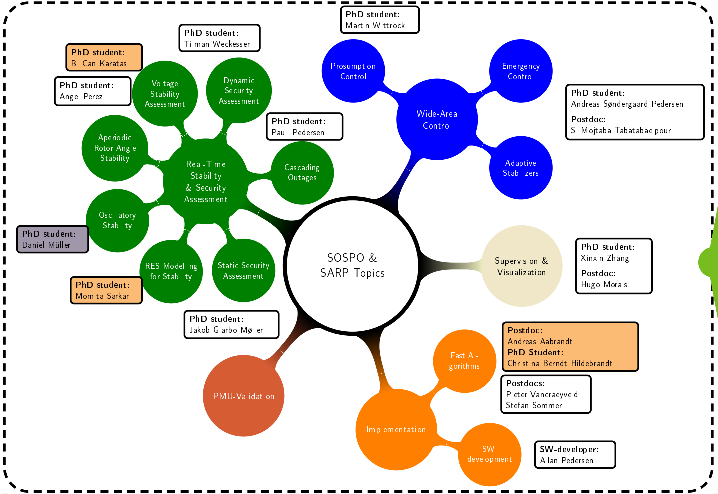
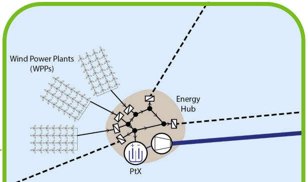


ENERGINET

Real-Time Online Platform (towards TRL 8-10)



Offshore Energy Islands
Stable and secure operation

2012 - 2021

2021 - ??

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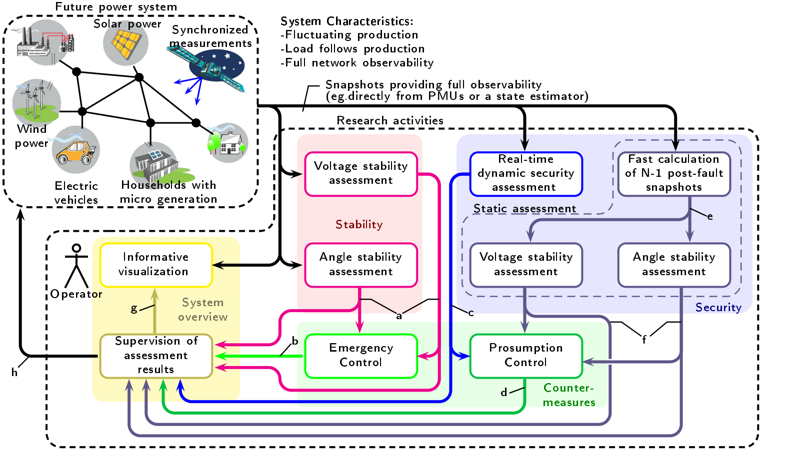
Early Warning & Early Prevention System

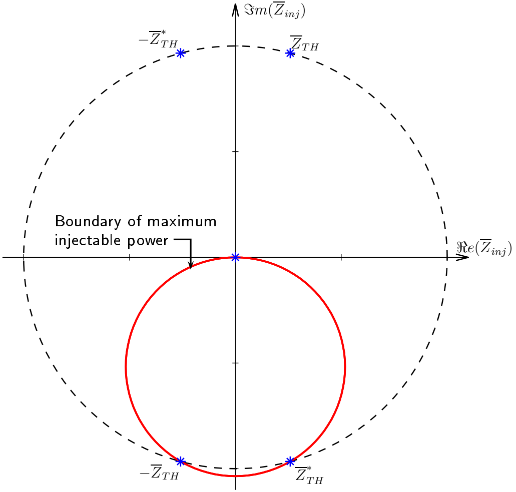
Envisioned approach for secure and stable operation of high RES systems



a: Stability assessment information
b: Suggested instability countermeasure
c: N-1 dynamic security information
d: Suggested insecurity countermeasure
e: Multiple N-1 steady state snapshots
f: N-1 static security information
g: Selected data for visualisation
h: Applied wide-area countermeasure

The ASSRAS Assessment Method - Early Warning

Assessment of Aperiodic Small Signal Stability: Stability Boundary



Boundary:

$$Z_{inj} = -\frac{Z_{th}\sin\theta}{\sin\phi_{th}}$$

The ASSRAS Assessment Method: Assessment Criteria

Assessment of Aperiodic Small Signal Stability

Assessment Criteria:

$$\left| \frac{\overline{Z}_{inj} \cdot (2 \sin \phi_{th}) + j \cdot Z_{th}}{Z_{th}} \right| \begin{cases} > 1 & \text{Stable operation} \\ = 1 & \text{On the stability boundary} \\ < 1 & \text{Unstable operation} \end{cases} \quad (1)$$

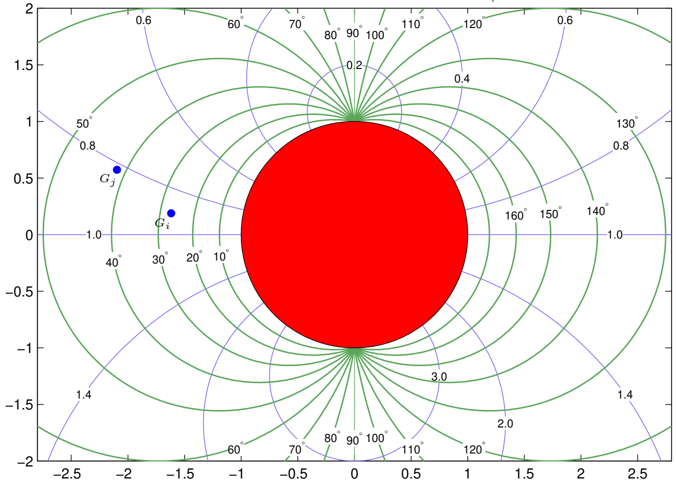
Outline of Aperiodic Small Signal Stability Assessment:

foreach *System PMU-Snapshot* **do**
  foreach *Generator* $j = 1 : K$ **do**
    Determine the injection impedance $\overline{Z}_{inj,j}$ seen from G_j;
    Determine the Thevenin impedance $\overline{Z}_{th,j}$ seen from G_j;
    Apply (1) to assess the generator aperiodic small signal stability;
  end
end

Informative Visualisation

Visualizing Multiple Operating Points in Normalized Impedance Plane

Curves of Constant $\Delta\delta$ and Constant V/E



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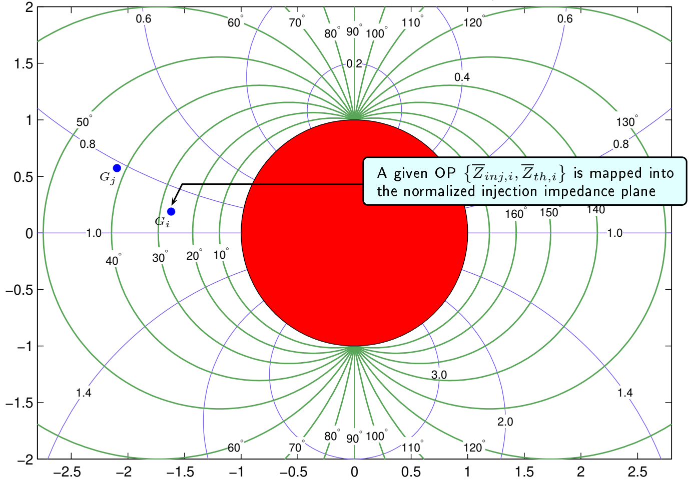

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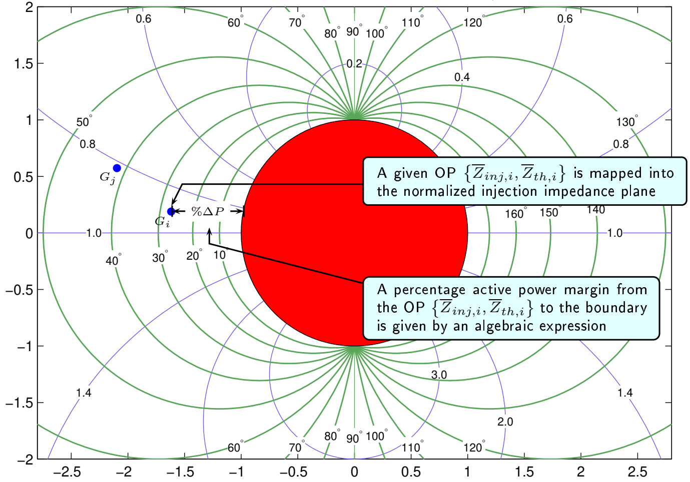

Demonstration of the ASSRAS Method

Early Warning for the 2003 DK-SW Blackout

Demo I: 2003 Blackout in E-DK and S-SW

Overview

- Simulation of the 2003 blackout in E-DK and S-SW was carried out for the purpose of testing the method on a realistic case
  - Output used to generate synthetic PMU measurements
  - Used to test the performance of the method

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  - Detailed model of E-Denmark combined with a simplified model for the of the nordic system
  - Size of the extended system 488 nodes and 672 edges

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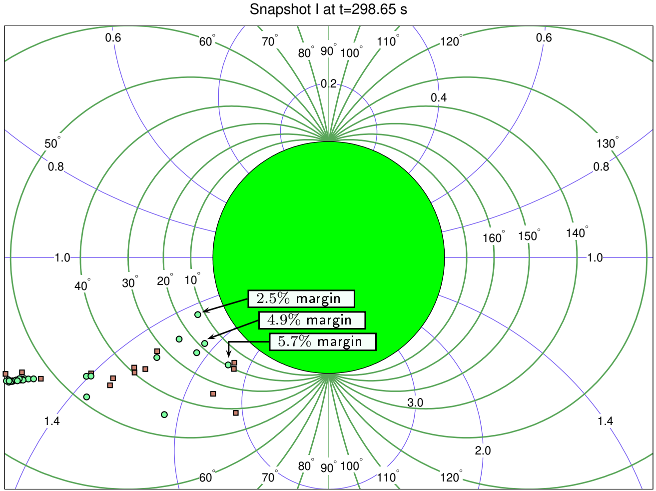
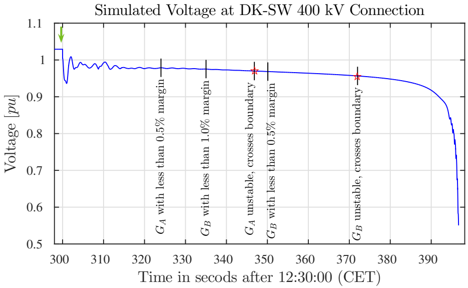
  - Size of the extended system 488 nodes and 672 edges
- Assessment of 144 generator states in less than $1.0ms$

Demo I: 2003 Blackout in E-DK and S-SW (Results)





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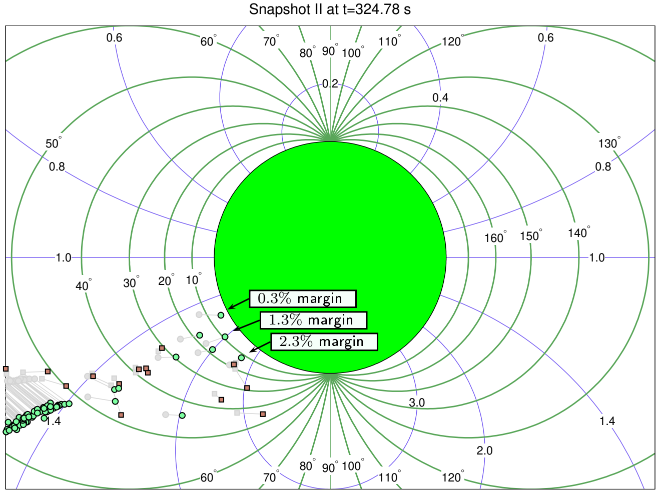

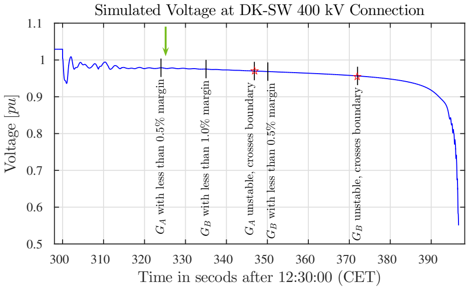

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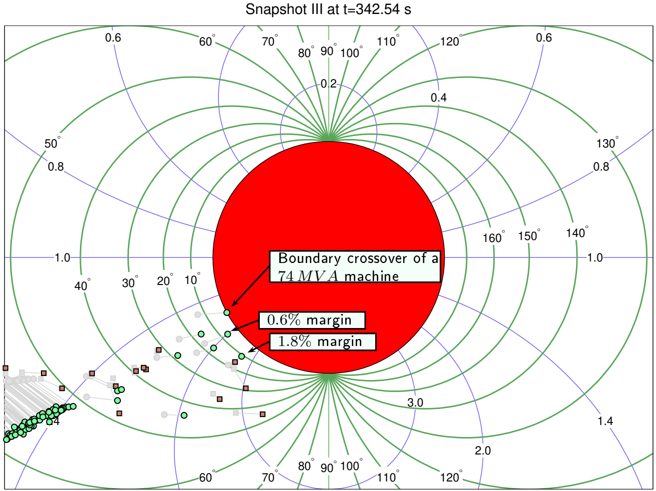

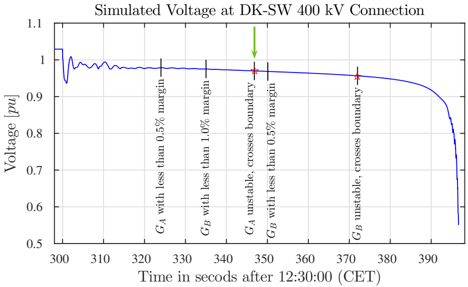

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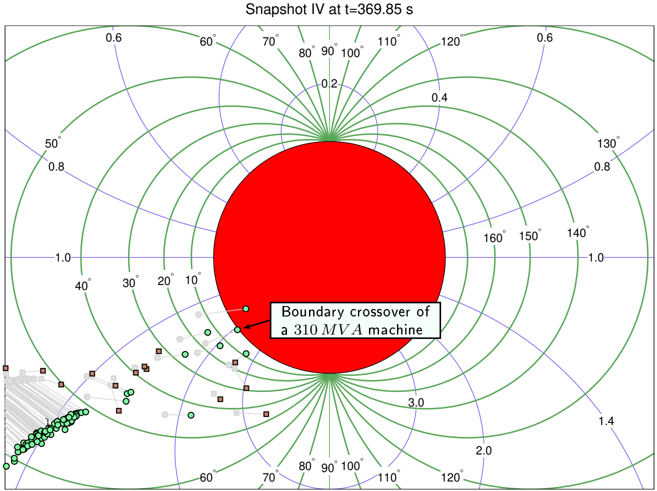

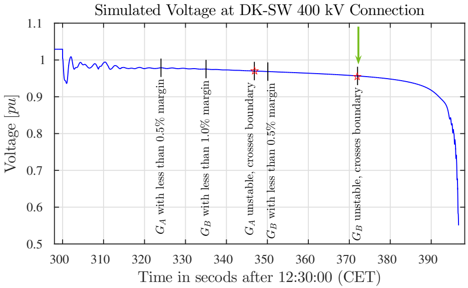

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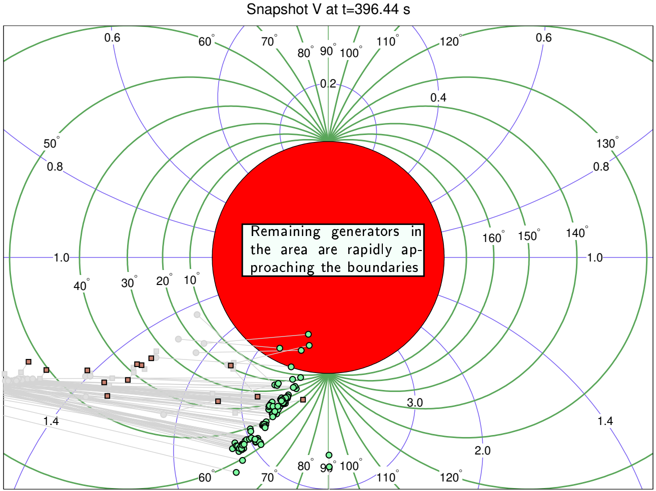
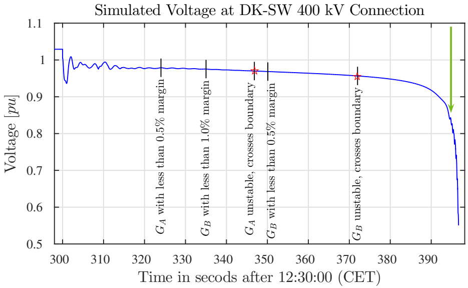
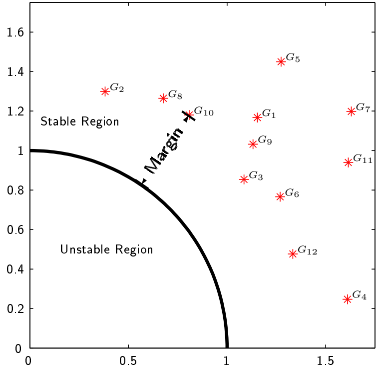




Prevention Against Emerging ASSRAS Blackouts

Usefull properties of element-wise stability assessment

- Element-wise assessment of a particular mechanism of instability
  - Individual assessment of each relevant system element (a generator or a node)
  - Focussing on an assessment of one particular stability mechanism
  - The system model is reduced such that only factors that have a significant influence on the stability mechanism are included
  - Possibility for assessment times suitable for real-time operation



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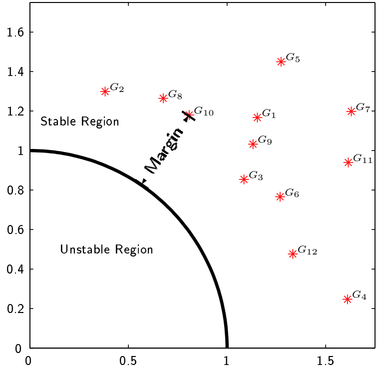

- Provides both a proximity-to-instability information and the mechanism of instability (where and what)

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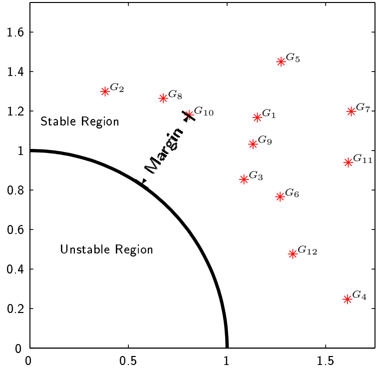

- Provides both a proximity-to-instability information and the mechanism of instability (where and what)
- ASSRAS: margin to maximum injectable active power
  - obvious countermeasure to reduce generator's active power output

Demonstration of the ASSRAS Method

Early Warning & Prevention for the 2003 DK-SW Blackout
(Play Video)

Test Case: 2003 Blackout in E-DK and S-SW

Summary of results - effect on voltages and messages issued by the EWEP system

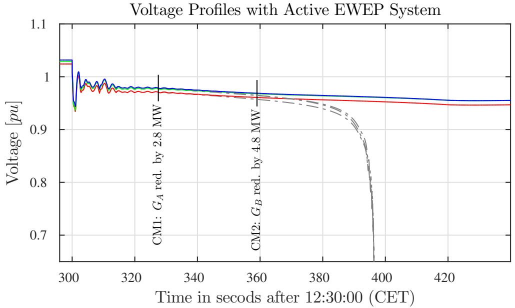

Figure: System response with activated EWEP system. Two countermeasures are applied which stabilize the system. The grey dashed lines represent the original system response leading to instability.

322s	EW: Margin for GA below 0.5%
327s	EW: G_A below trigger margin
327s	EP: G_A reduced by 2.8 MW, G_C increased by 2.8 MW
335s	EW: Margin for G_B below 1.0%
351s	EW: Margin for G_B below 0.5%
358s	EW: G_B below trigger margin
358s	EP: G_B reduced by 4.8 MW, G_D increased by 4.8 MW

Table: Early warning (EW) messages and early prevention (EP) countermeasures issued by the EWEP system

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Concluding Remarks - Summary

- Overview of DTU's R&D in methods enabling construction of EWEP systems
- The development continues in two branches:
  1. Energinet (the Danish TSO) is developing real-time platform that will enable online demonstration/operation of such solutions (pushing from TRL 7 to TRL 10)
  2. Academic research on how to ensure stable and secure operation of offshore energy islands
- Example of Early-Warning and Early-Prevention methods:

The ASSRAS Assessment Method (Early Warning) [1, 2, 3]

The ASSRAS Countermeasure Method (Early Prevention) [4]

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The ASSRAS Assessment Method (Early Warning) [1, 2, 3]

- Extremely fast assessment due to algebraically derived criteria and effective algorithms
  - Assesses 1325 generators in ≈ 10.000 bus system in less than $2ms$
- provides proximity to, location and the nature of the emerging instability

The ASSRAS Countermeasure Method (Early Prevention) [4]

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The ASSRAS Countermeasure Method (Early Prevention) [4]

- Determines necessary remedial actions against ASSRAS instability (voltage collapse)
  - Very fast identification - purely algebraic approach
  - Introduction of a minimum security margin
  - Stability restoration through power generation re-dispatch

References

[1] H. Jóhannsson, A. H. Nielsen, and J. Østergaard.
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[2] H. Jóhannsson, A. H. Nielsen, and J. Østergaard.
Wide-Area Assessment of Aperiodic Small Signal Rotor Angle Stability in Real-Time.
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[5] C.H.L Jørgensen, J.G.Møller, S. Sommer and H.Jóhannsson.
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