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Atlanta, Georgia USA

Engineering Analysis Task Team 23 March 2016 15:00-18:00

Novel methods to assess secure power transfer capabilities

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Main fields of research:

Power system dynamics, stability, security and reliability
Power system network planning and operation
Blackout mitigation, Smart transmission grid solutions, SIPS, WAMS

Relevant ongoing activities:

Aggregated load models for the Nordic TSOs power system planning model
CloudGrid - Transnational Smart Grid Lab R&D project funded by ERA-Net Smart grid +

Professional background:

Since 2012: STRI, Manager and senior specialist network studies, Göteborg Sweden
2007-2012: SINTEF Energy, Research scientist power system dynamics, Trondheim Norway
2004-2007: ABB Switzerland, Harmonic filter specialist, Baden Switzerland
2002-2003: ABB Power Systems, HVDC engineer, Ludvika Sweden

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Outline

- Introduction
- Novel indicators of secure transfer
  - kmin – indicator
  - N-k secure operating region
- Novel methods to assess secure transfer
  - EAC of PTC concept
- Summary

Introduction

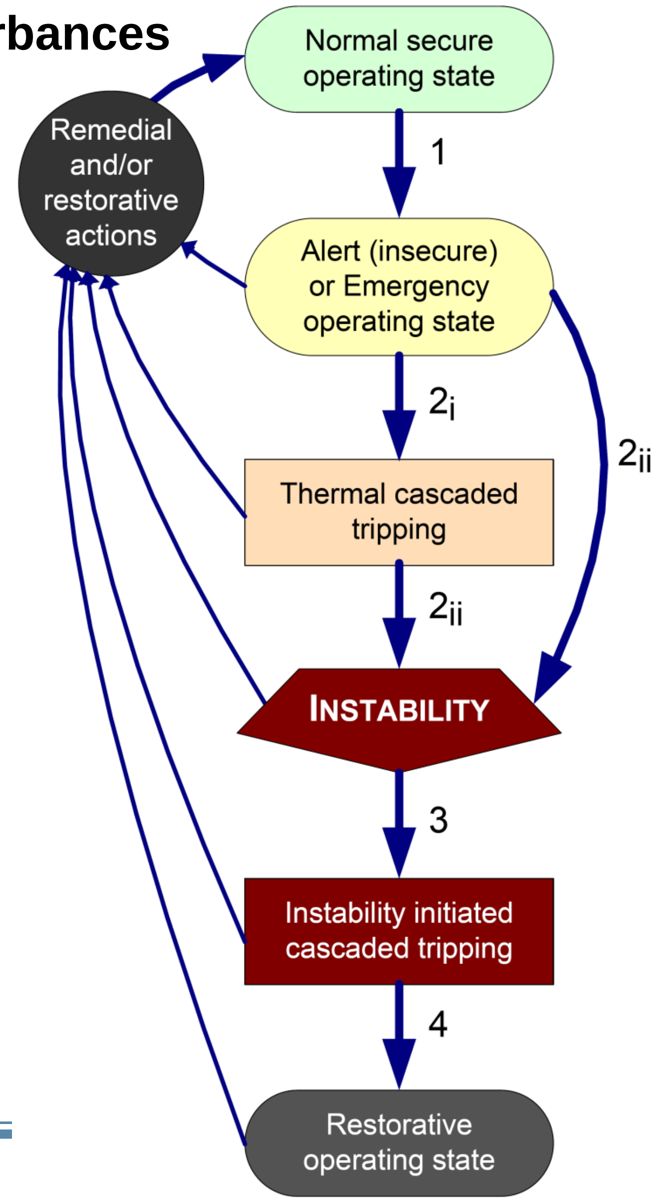
Why need for novel assessment methods of secure power transfer?

- Large disturbances –
  Extraordinary events –
  High Impact
  Low Probability
- High impact on society:
  - SE 2003: 2 billion SEK
  - US 2003: 10 billion USD
- Difficult to predict extent and frequency - many uncertainties
- Difficult to prevent the unpredictable

Introduction

Generic sequence of Large disturbances

1. Trigger: failure with unforeseen impact. Actions needed to prevent deterioration.
2. Depending on limiting factors, the next phase is:
   i. Thermal overloading. Actions required to prevent instability.
   ii. Instability. Actions imperative to regain control.
3. Instability initiated cascade. Very fast. Widespread impact. Automatic actions may limit the extent.
4. Restorative state. Unsynchronised islands. Blackout. Restoration needed to regain normal operation.



Novel indicators of secure transfer

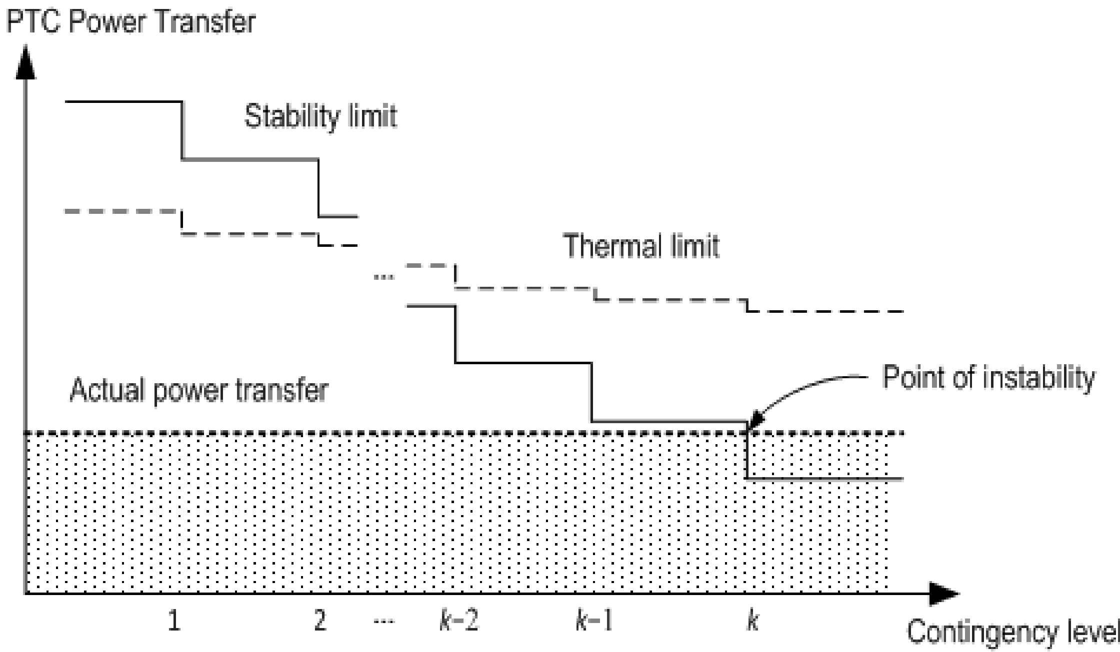
k_{min} indicator

Quantifying risk of large disturbances using critical contingency level:

$$k_{min} = min(s_i),\ all\ i$$

with *i:* the set of contingencies that lead to an unstable state

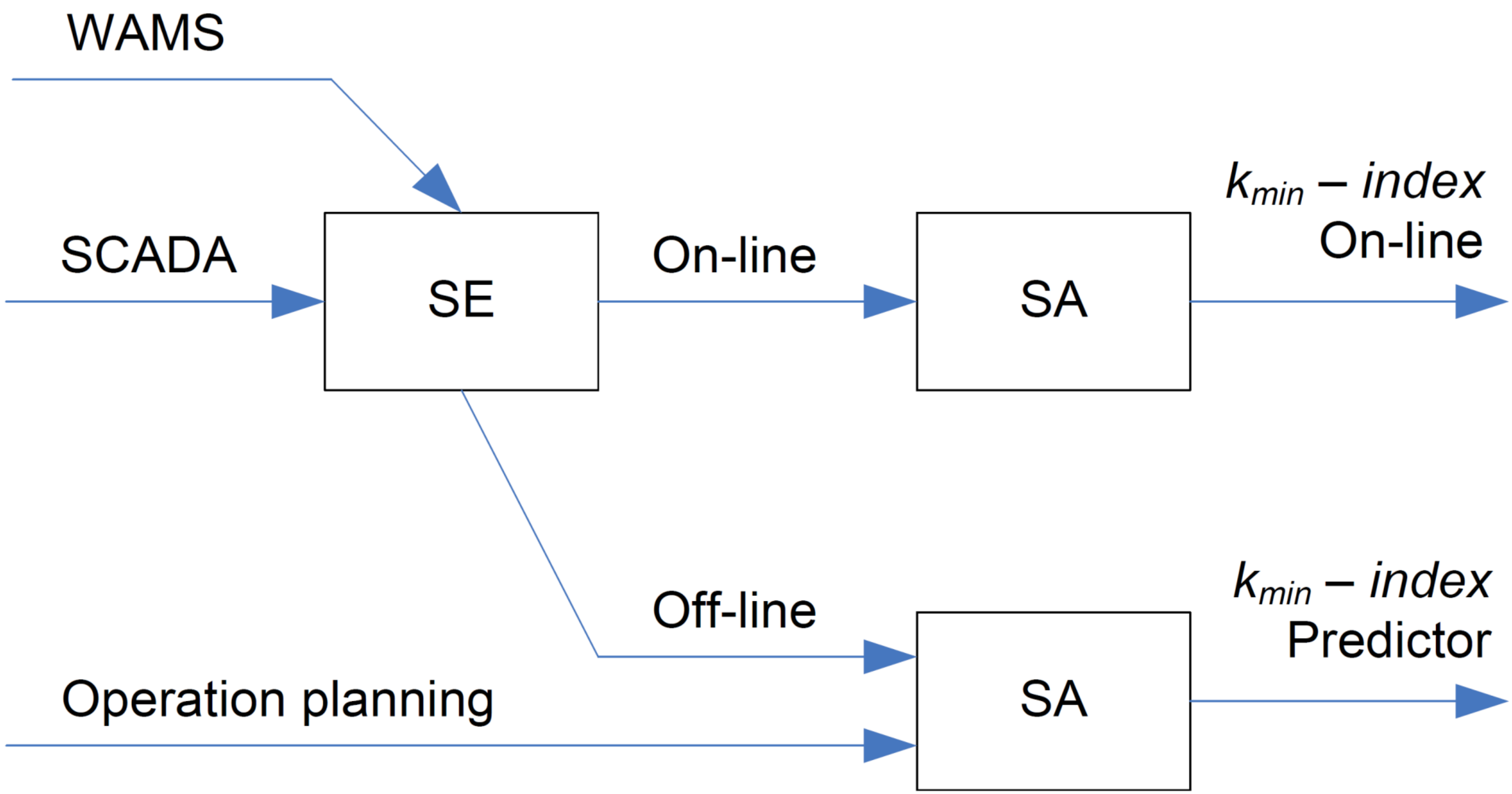
s: the contingency level of each *i*



Novel indicators of secure transfer

k_{min} indicator

Utilisation in power system operation:



Novel indicators of secure transfer

k_{min} indicator

Case study of historical events:

- Blackout in Sweden and Denmark 23 September 2003
  - Independent faults, $k_{min} \leq 3$
- Blackout of Italy 28 September 2003
  - Thermal overload, $k_{min} \leq 2$
- Disturbance in Europe 4 November 2006
  - Manual operation, $k_{min} \leq 3$
- Blackout in Brazil 10 November 2009
  - Extreme weather, $k_{min} \leq 3$

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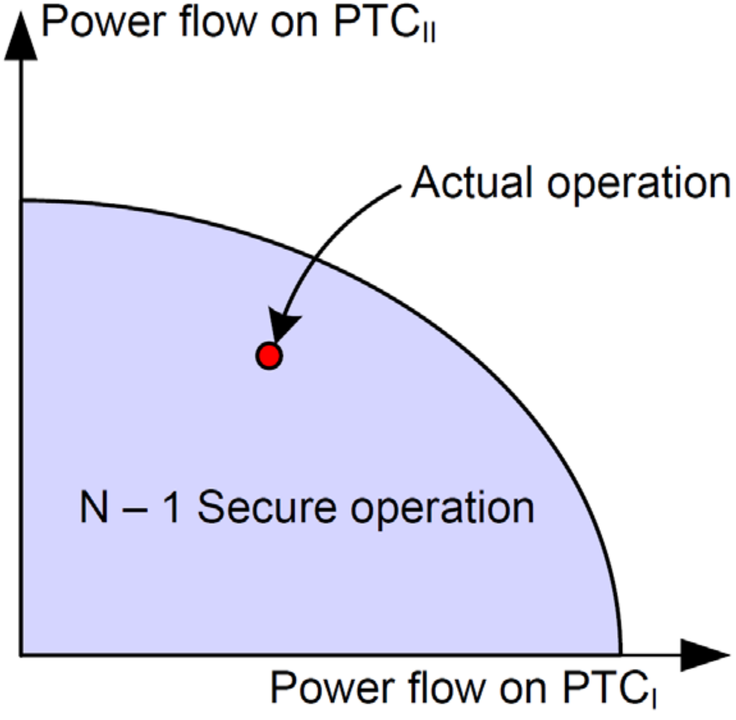
Novel indicators of secure transfer

N-k secure operating region

Assessment and visualisation of a secure operating domain

I: Secure operating area
and actual operating point



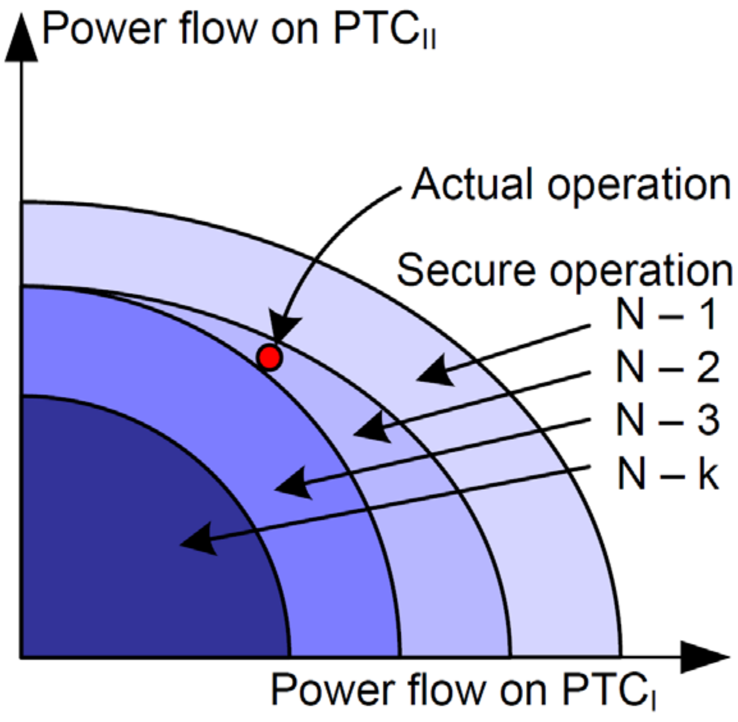
Novel indicators of secure transfer

N-k secure operating region

Assessment and visualisation of a secure operating domain

I: Secure operating area
and actual operating point

II: *N-k* security



Novel indicators of secure transfer

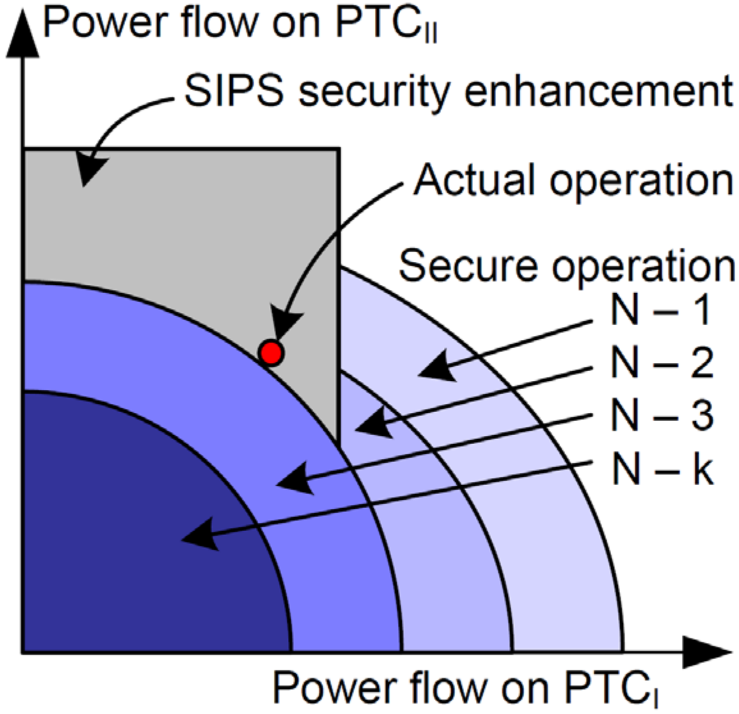
N-k secure operating region

Assessment and visualisation of a secure operating domain

I: Secure operating area
and actual operating point

II: *N-k* security

III: Security enhancement
by automatic actions



Novel methods to assess secure transfer

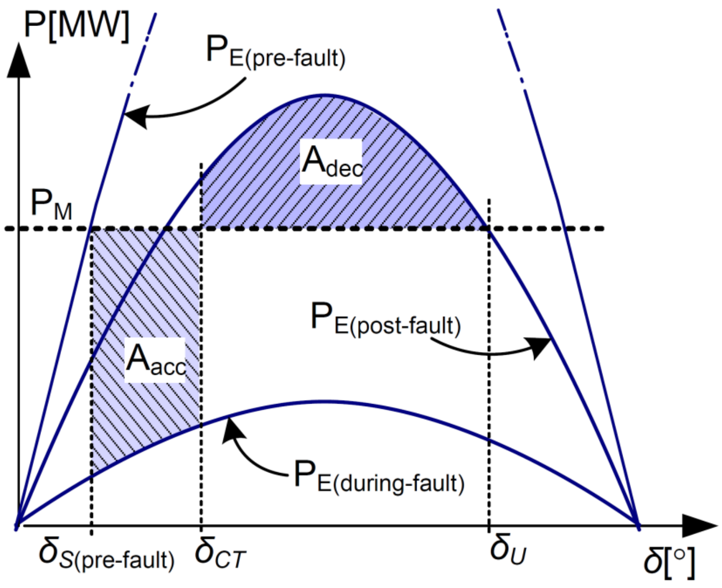
EAC on PTC concept

- Development of the EAC on PTC concept
  - Based on the Equal-Area Criterion (EAC)
  - Applied on Power Transfer Corridors (PTC)
  - Utilising power flow and angle over the PTC (assuming PMU installations)
- Development of SIPS design procedure using the EAC on PTC concept
  - Proof of concept based on case study of the IEEE RTS
  - Identification of complexities regarding the assessment of mechanical power

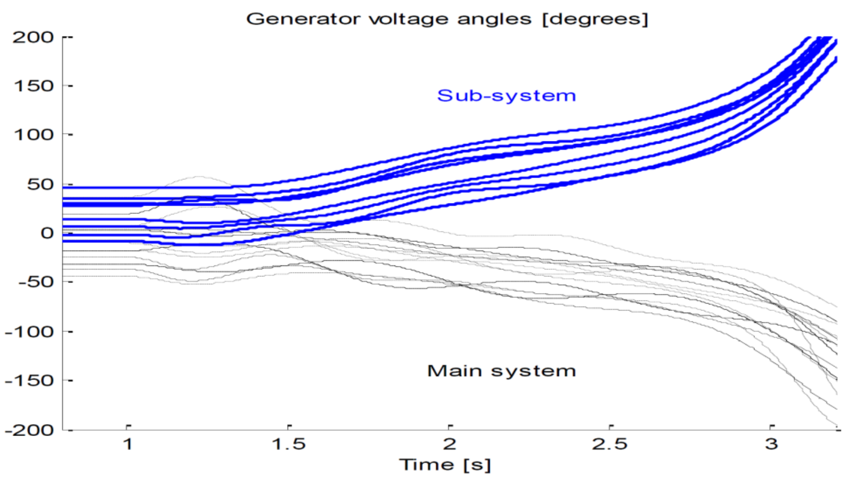
Novel methods to assess secure transfer

EAC on PTC concept

Equal-Area Criterion



Cluster of critical machines



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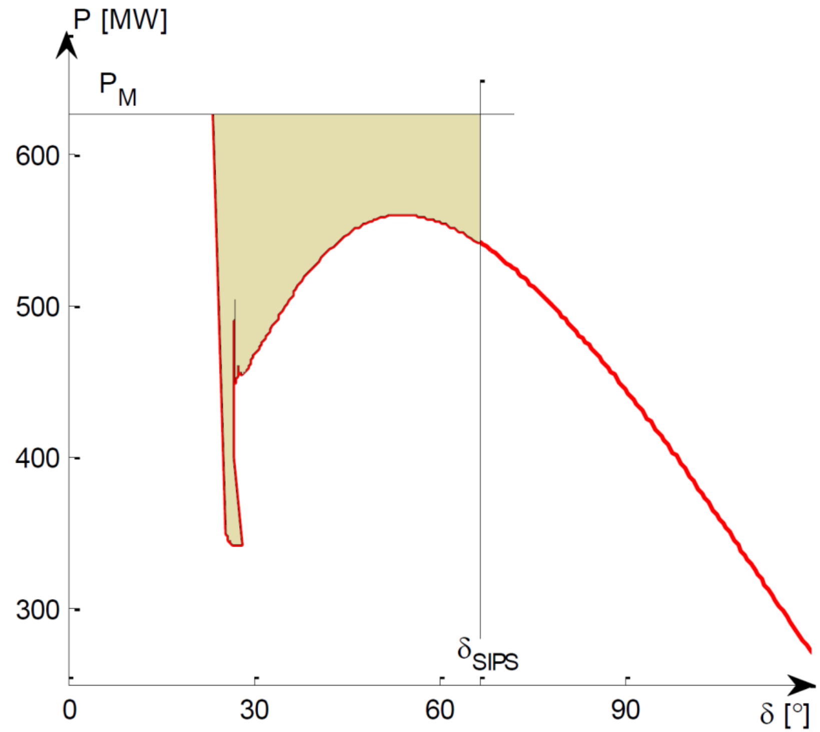
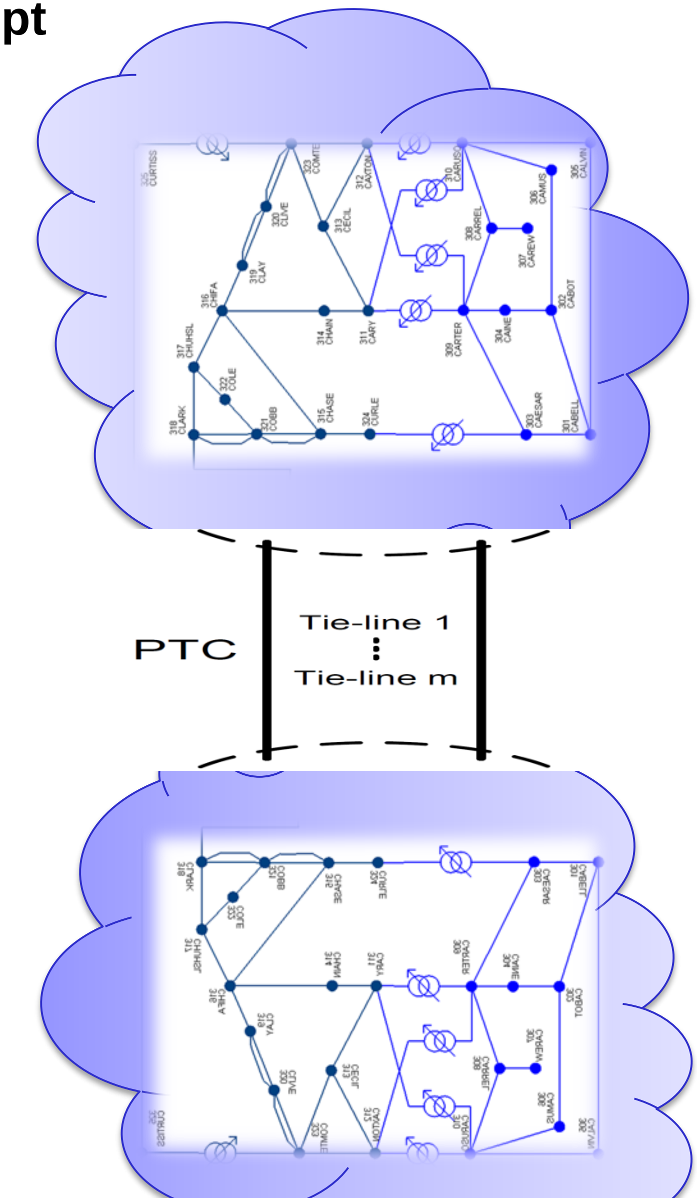
Novel methods to assess secure transfer

EAC on PTC concept

Cluster of critical machines
within one sub-system

PTC P-δ characteristics

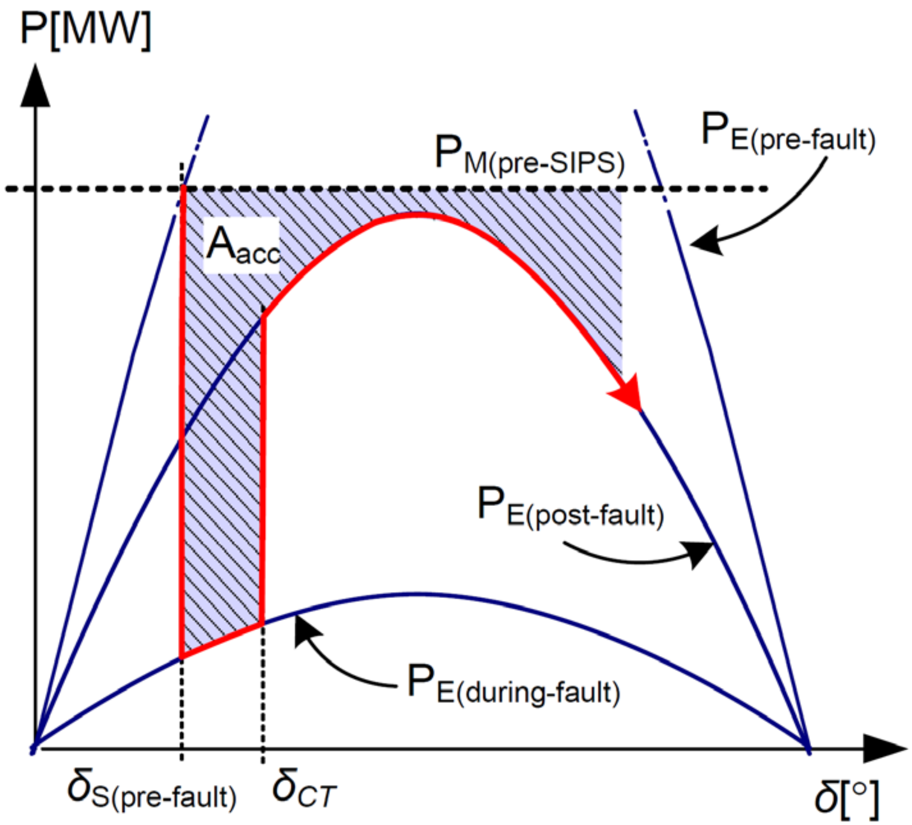




Novel methods to assess secure transfer

EAC on PTC concept

SIPS design using the EAC on PTC concept

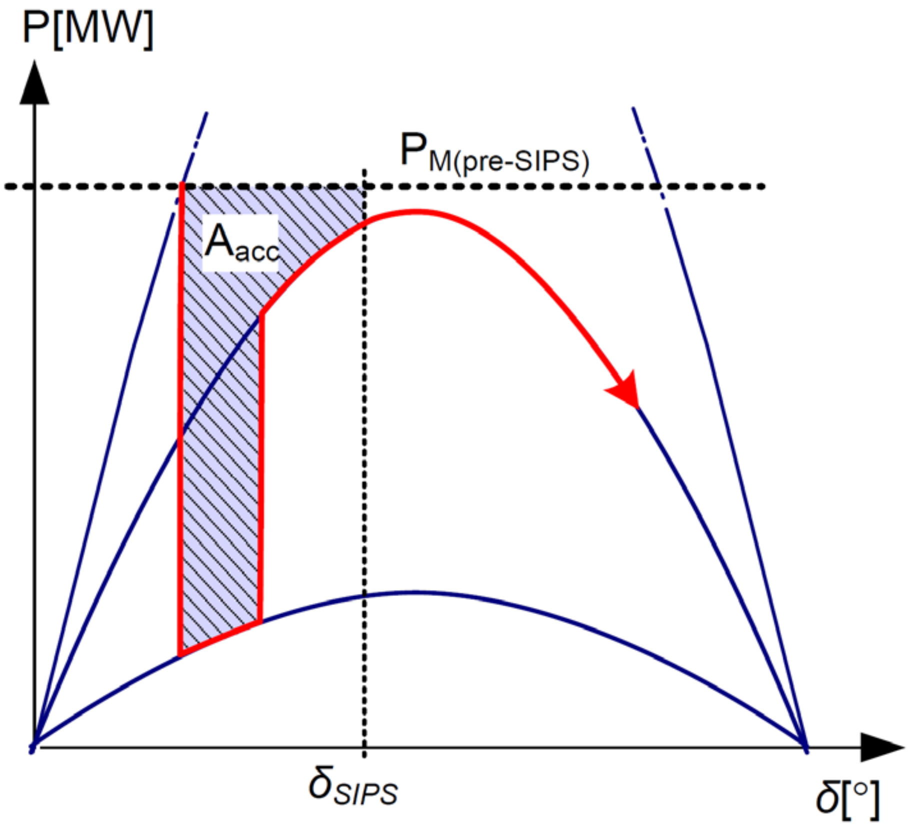


Critical contingency
without SIPS

Novel methods to assess secure transfer

EAC on PTC concept

SIPS design using the EAC on PTC concept

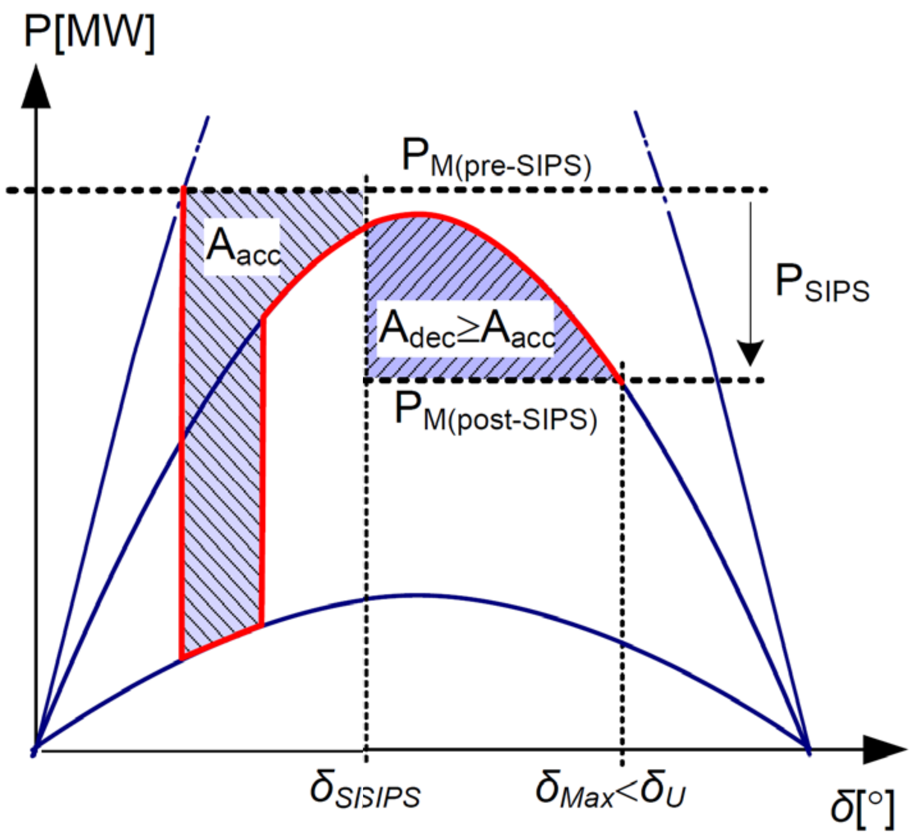


Identification of SIPS action time and angle

Novel methods to assess secure transfer

EAC on PTC concept

SIPS design using the EAC on PTC concept

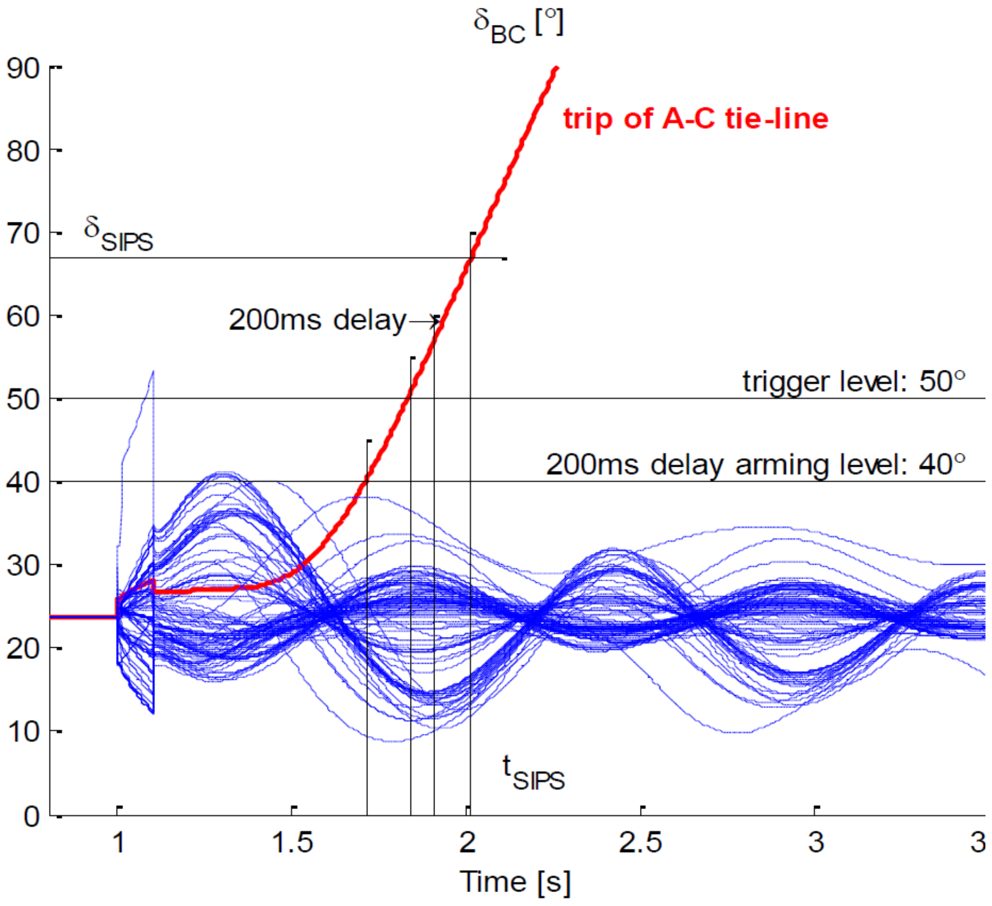


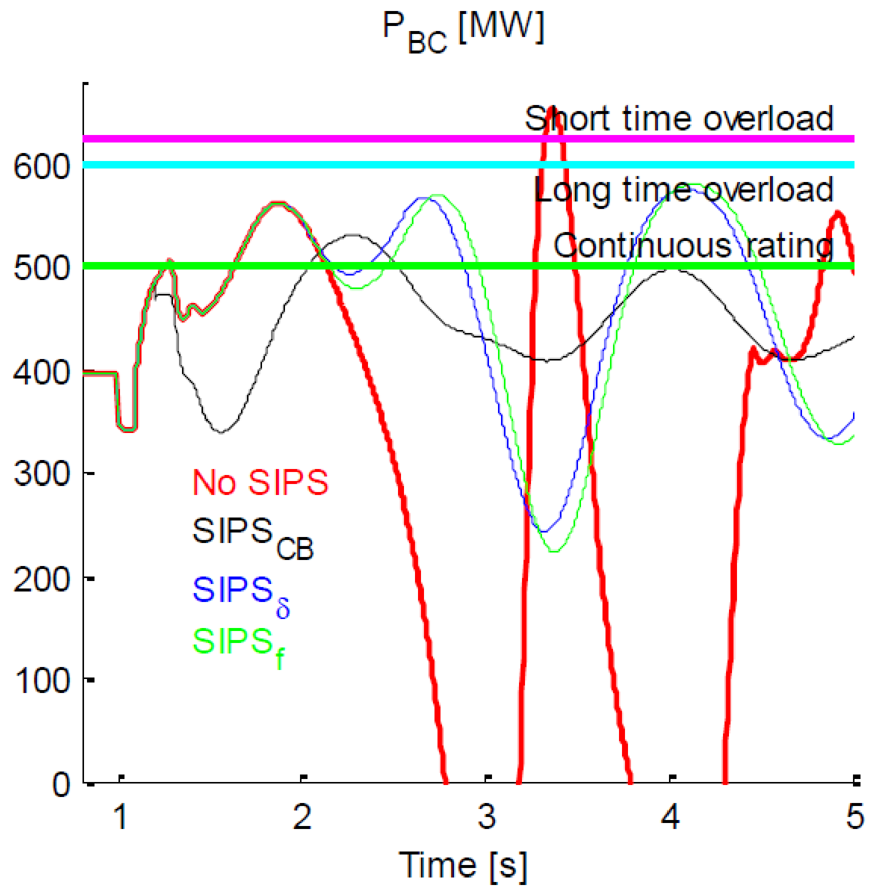
Identification of SIPS impact requirements

Novel methods to assess secure transfer

EAC on PTC concept

SIPS design using the EAC on PTC concept

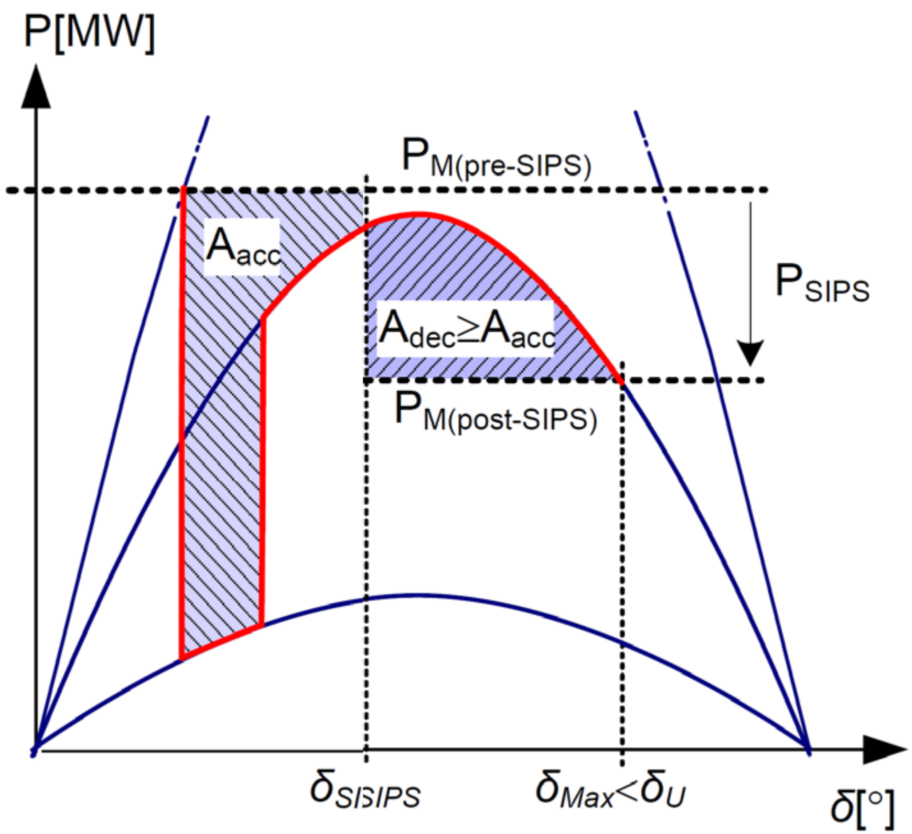


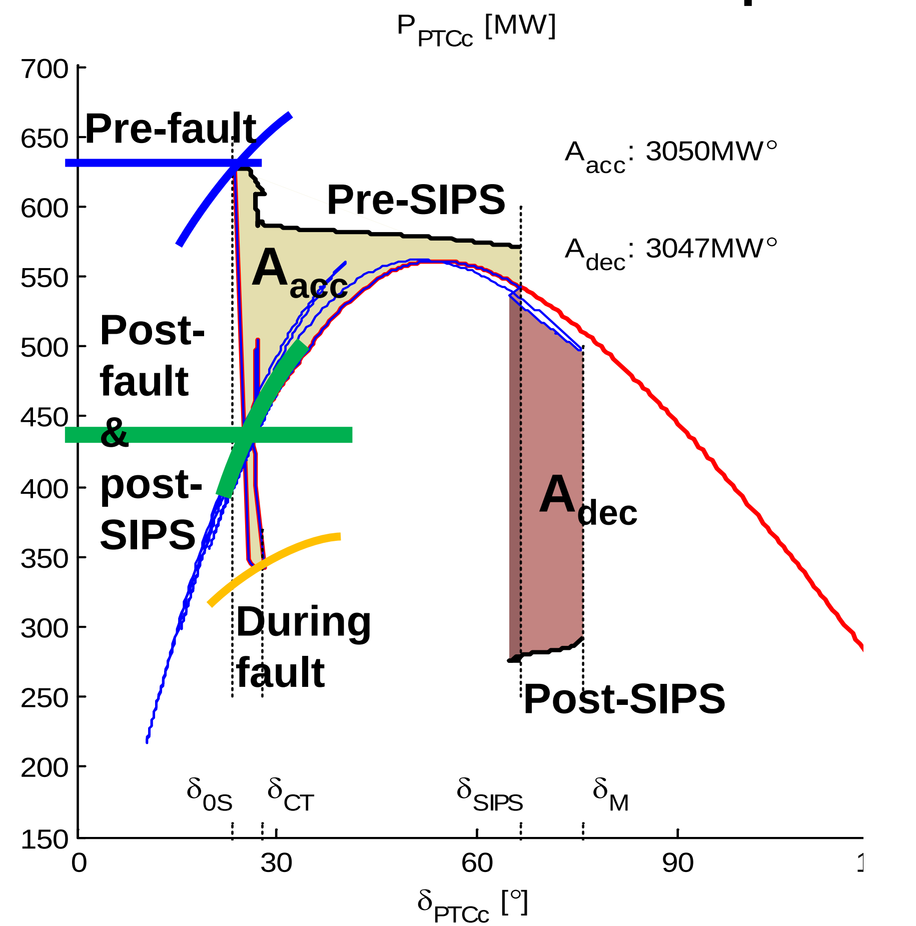


Novel methods to assess secure transfer

EAC on PTC concept

SIPS design using the EAC on PTC concept





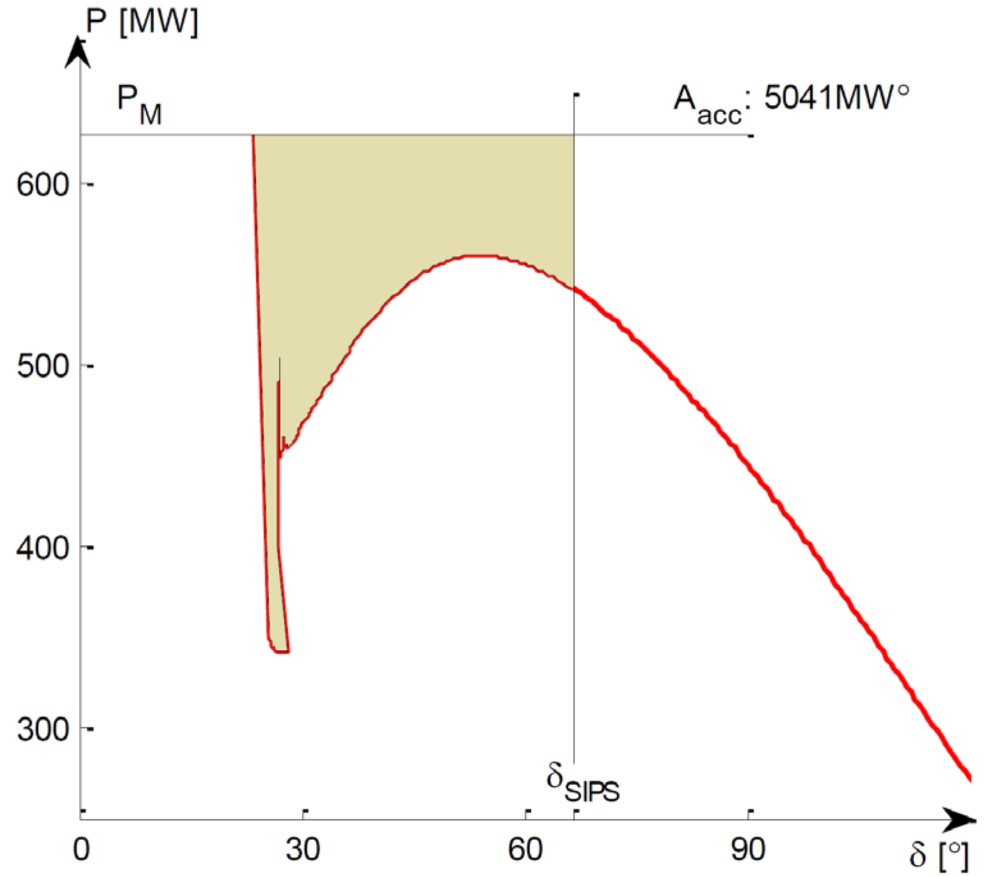
Novel methods to assess secure transfer

EAC on PTC concept

Complexity of the P_M assumption

Assumption 1:

Constant P_M



Novel methods to assess secure transfer

EAC on PTC concept

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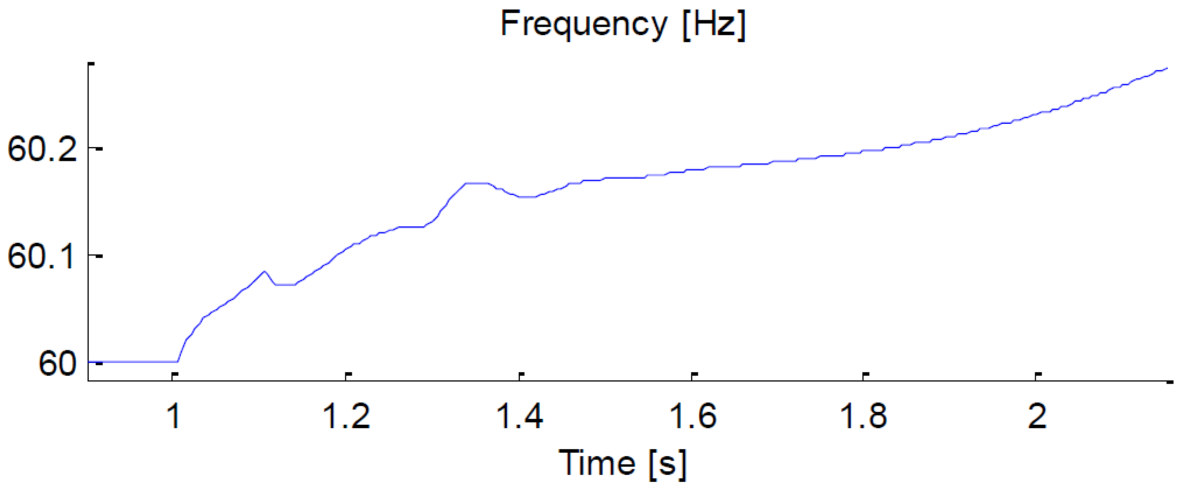

Novel methods to assess secure transfer

EAC on PTC concept

Complexity of the P_M assumption

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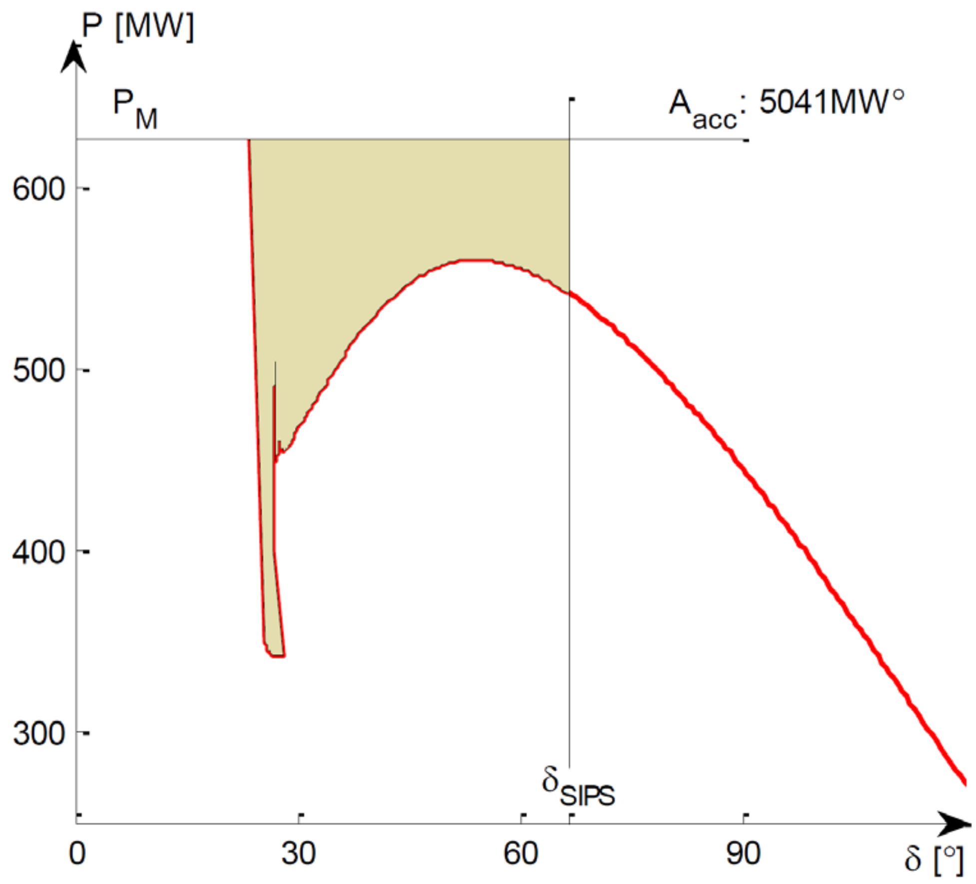


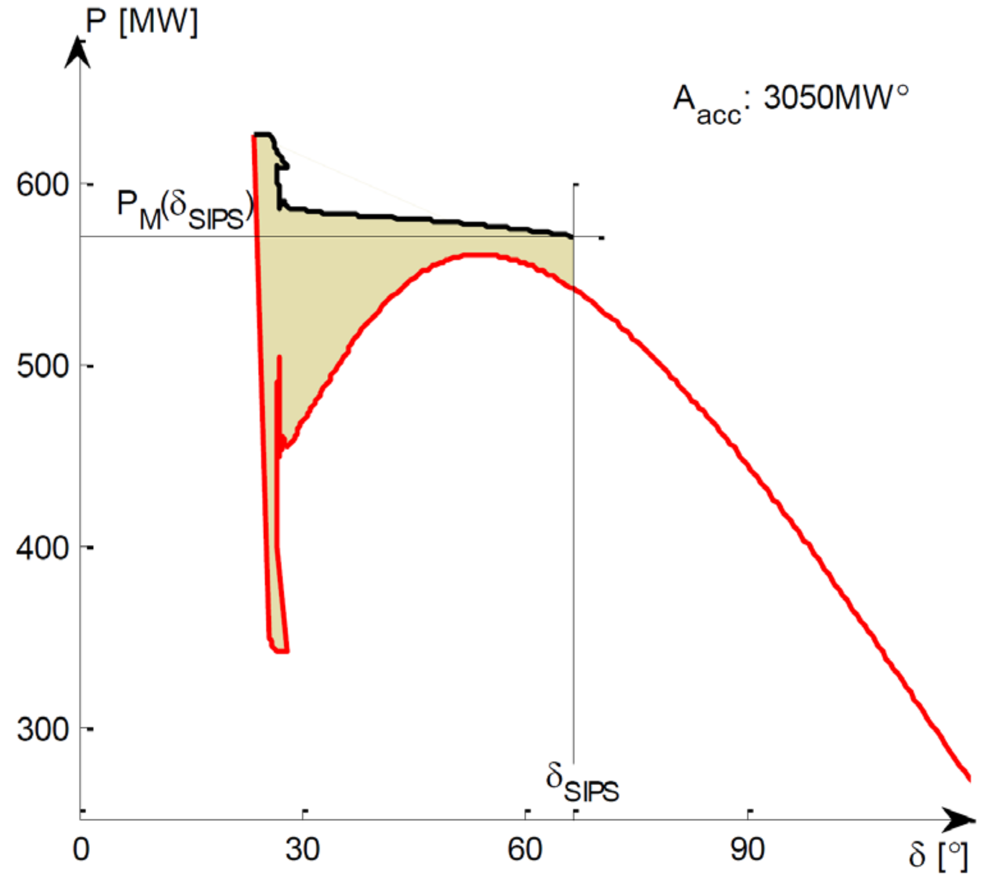
Novel methods to assess secure transfer

EAC on PTC concept

Complexity of the P_M assumption

Assumption 2:

P_M ($\Delta\omega$)



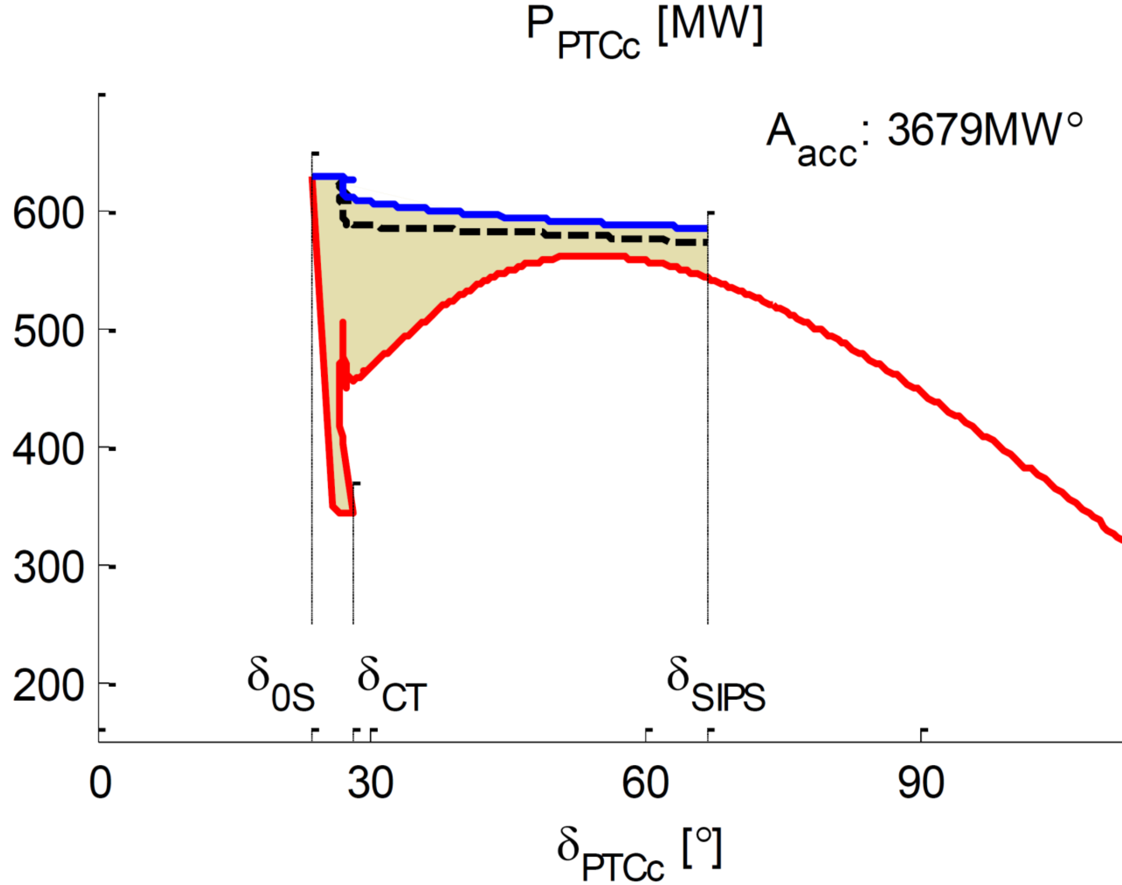
Novel methods to assess secure transfer

EAC on PTC concept

Complexity of the P_M assumption

Assumption 3:

Scalable from measured P_M



Summary

This work has provided new insights into and perceptions of the behaviour and characteristics of extraordinary events

Novel solutions for prediction of large disturbances include development of

- k_{min} vulnerability indicator and
- N – k secure operating region.

Novel methods for assessment of secure power transfer capability to prevent large disurbances

- The EAC on PTC concept.

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Summary

This work propose conceptual solutions for decreasing risk of extraordinary events.

Development of tools and techniques is needed for these solutions to support operation of the power system, e.g.:

- Tools for online multi-level dynamic contingency analyses
- Solutions to limit the no. of simulations to identify critical contingencies.
- Novel operating criteria, considering risk of extraordinary events?

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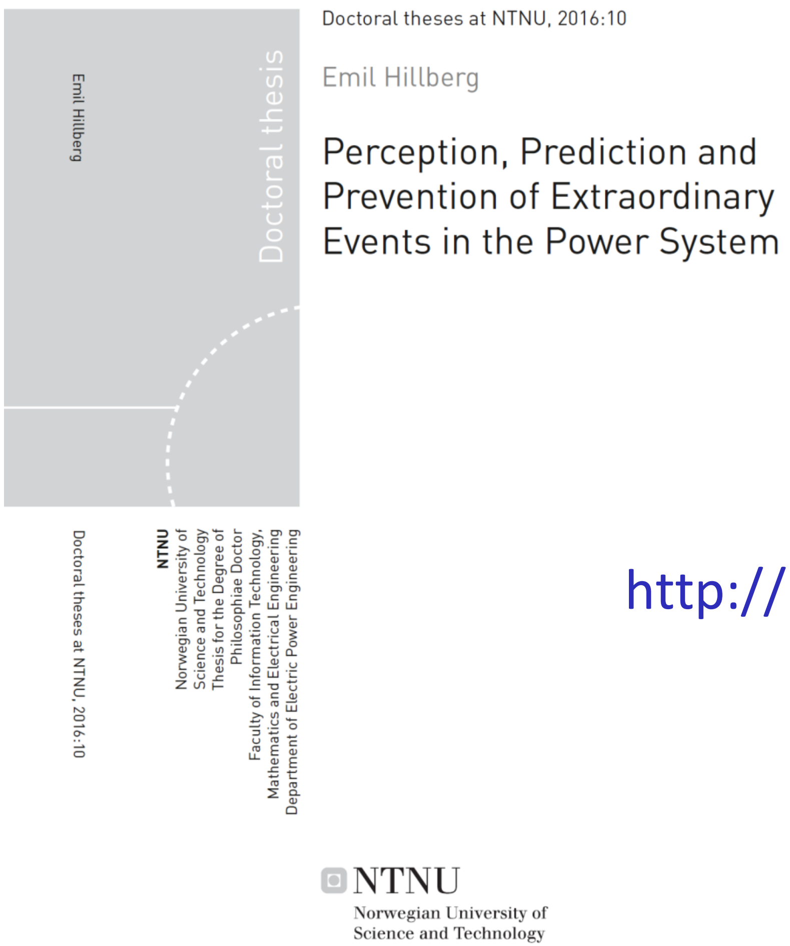
Further reading


Doctoral theses at NTNU, 2016:10

Emil Hillberg

Perception, Prediction and Prevention of Extraordinary Events in the Power System

Emil Hillberg

Doctoral thesis

Doctoral theses at NTNU, 2016:10

NTNU
Norwegian University of Science and Technology
Thesis for the Degree of Philosophiae Doctor
Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Electric Power Engineering

NTNU
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Available at:

http://hdl.handle.net/11250/2375233

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