Technical University of Denmark

Defence plans and restoration: various areas for improvement identified by the project

Sørensen, Poul Ejnar; Das, Kaushik; Llopis, Regina ; Gaitán, Vicens; Halat, Milenko ; Zamarreño, Luis María ; De Boeck, Steven; Van Hertem, Dirk; Hillberg, Emil ; Turunen, Jukka ; Vanfretti, Luigi; Leelaruji, Rujiroj ; Trovato, Vincenzo ; Vieyra, Rodrigo Andres Moreno ; Seca, Luis ; Moreira, Carlos; Madureira, André

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iTesla
Innovative Tools for Electrical System Security within Large Areas

Defence plans and restoration

Various areas for improvement identified by the project

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Regina Llopis, Vicens Gaitán, and Milenko Halat, AIA
Luis María Zamarreño, Gridquant
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Emil Hillberg and Jukka Turunen, Statnett
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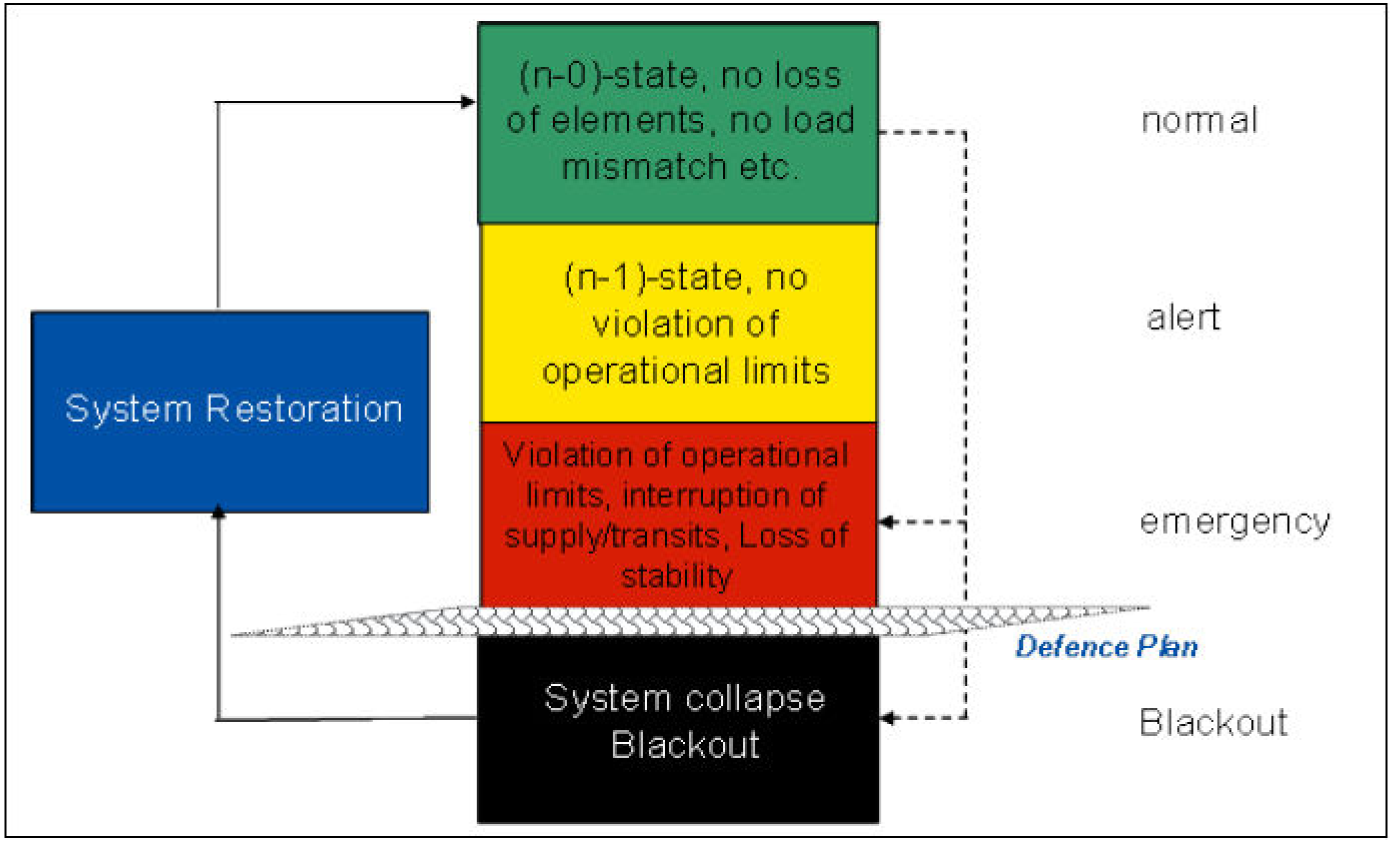
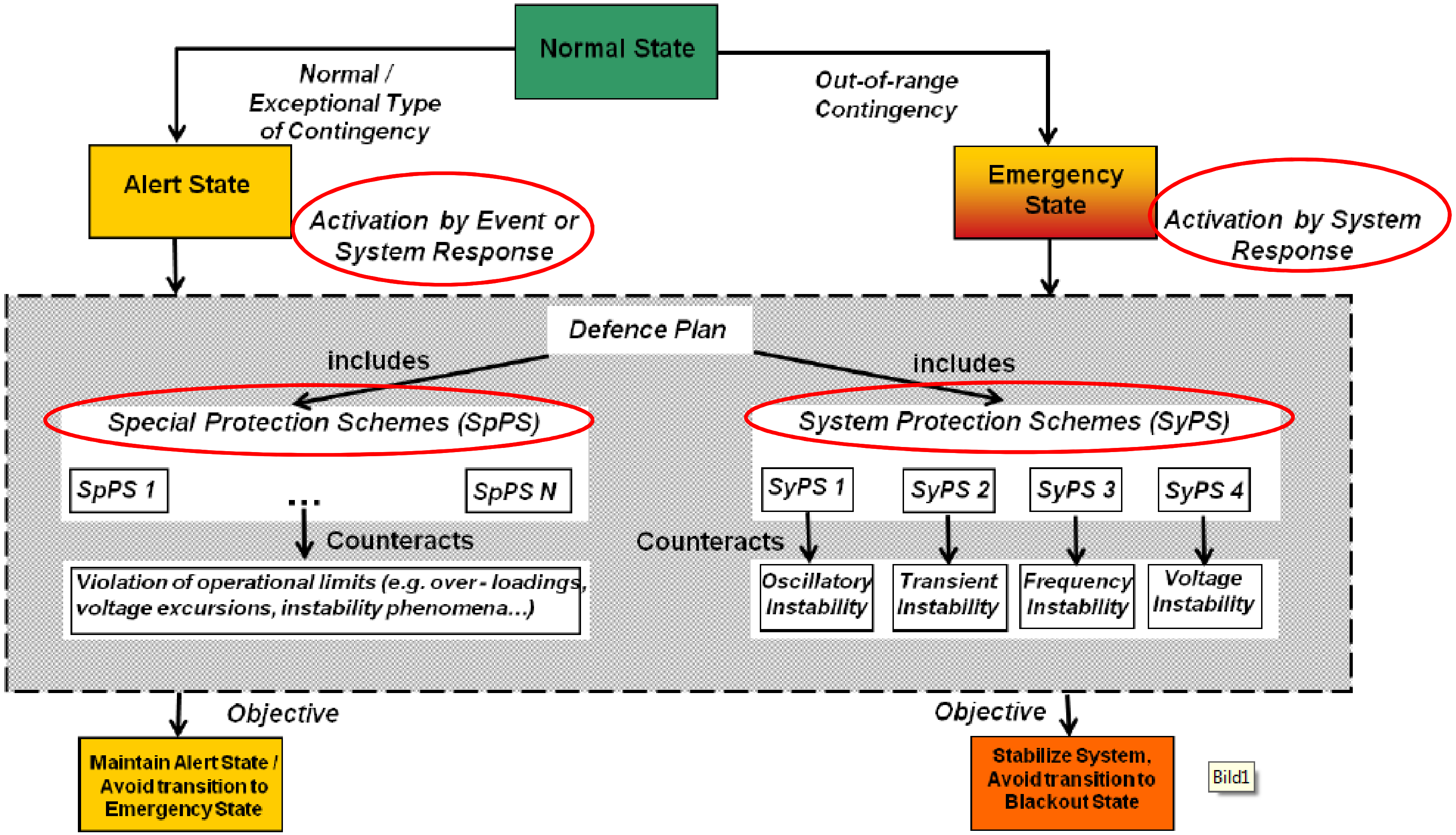
Vincenzo Trovato and Rodrigo Andres Moreno Vieyra, Imperial Collage
Luis Seca , Carlos Moreira,and André Madureira , INESC Porto

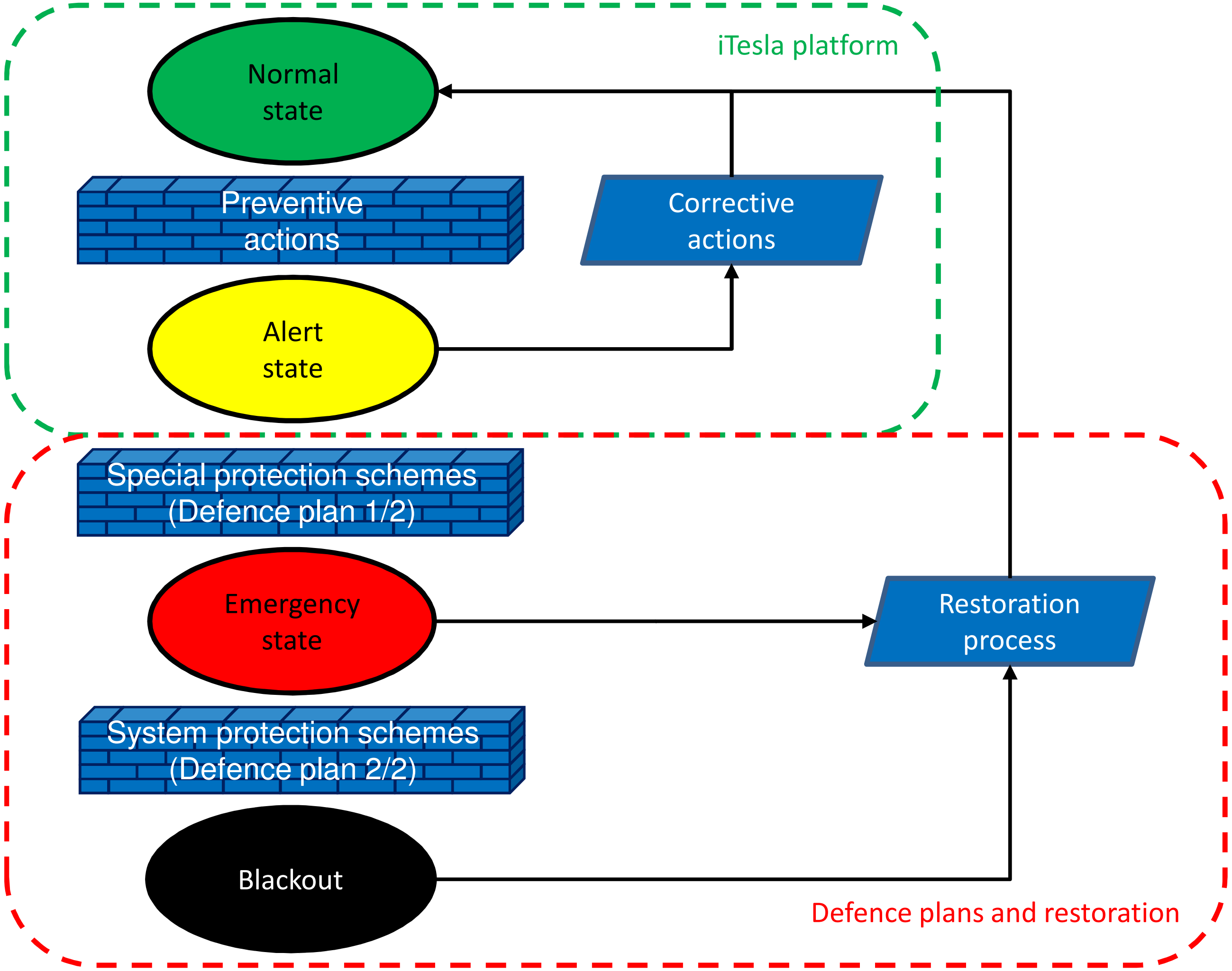
CIGRE Task Force C2.02.24 definition (2007)



ENTSO-E Special Protection Schemes (2012)



Extended definitions

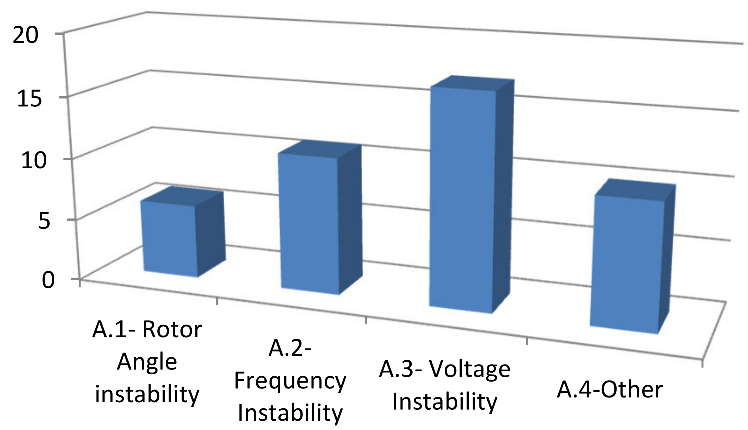


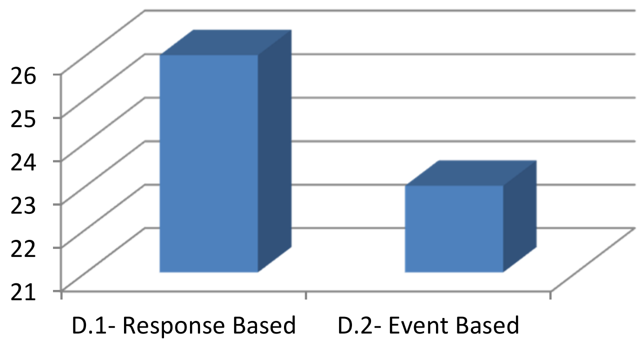
Workplan defense / restoration

- Defense plans
  - Weak points in existing plans (AIA / KUL)
  - Role of renewable generation plants (DTU)
  - Pan-European coordination (KUL)
  - Use of PMUs (Statnett / KTH, Tractebel)
  - Use of distributed energy resources (Imperial / KUL / DTU)
- Restoration
  - Coordinated restoration (AIA / Tractebel)
  - Use of renewable generation plants (INESC)

iTesla TSO survey

TSO	Country	Survey	Visit
ELIA	Belgium	☑	☑
IPTO	Greece	☑	
National Grid	UK	☑	☑
Statnett	Norway	☑	
REN	Portugal	☑	☑
RTE	France	☑	☑





Most SPS triggering are response-based.

Voltage Stability is the main concern, but there is a considerable number of "other" instabilities

Wind power in defence plans and restoration

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4 November case

- Event:
  - Split into 3 areas
  - North-East with surplus generation (incl wind) causing overfrequency

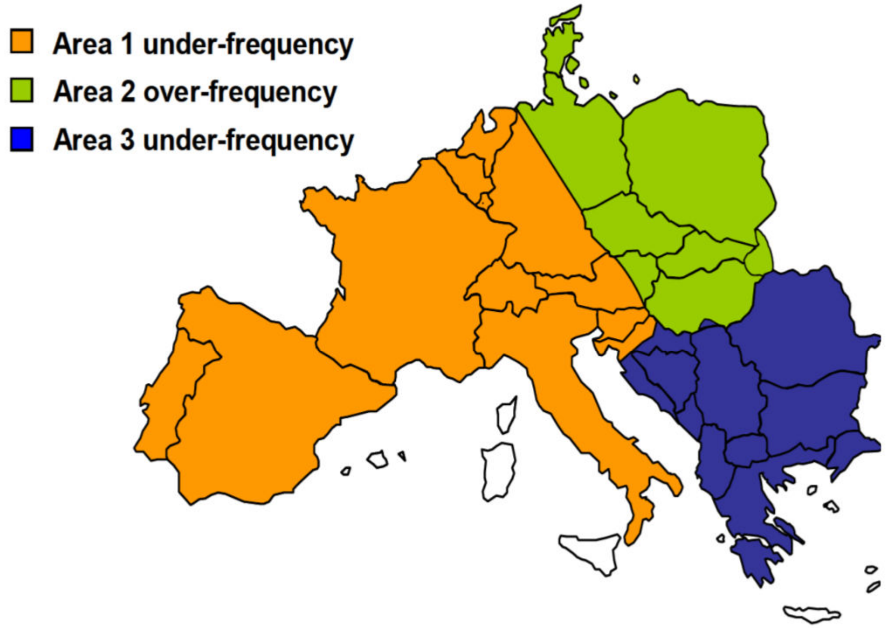


Figure 4: Schematic map of UCTE area split into three areas

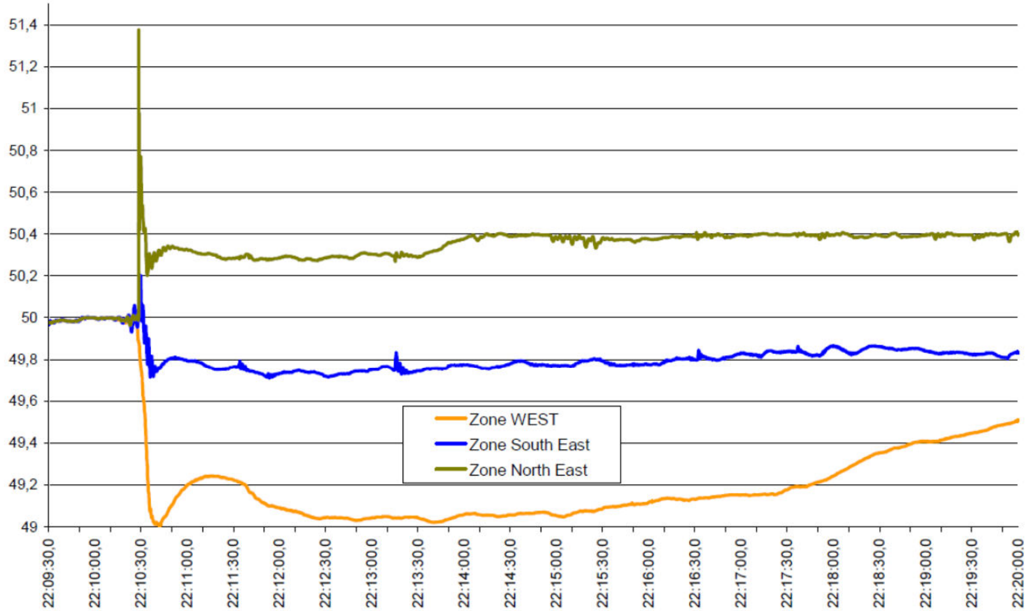


Figure 6: Frequency recordings after the split

*Final Report "System Disturbance on 4 November 2006," UCTE

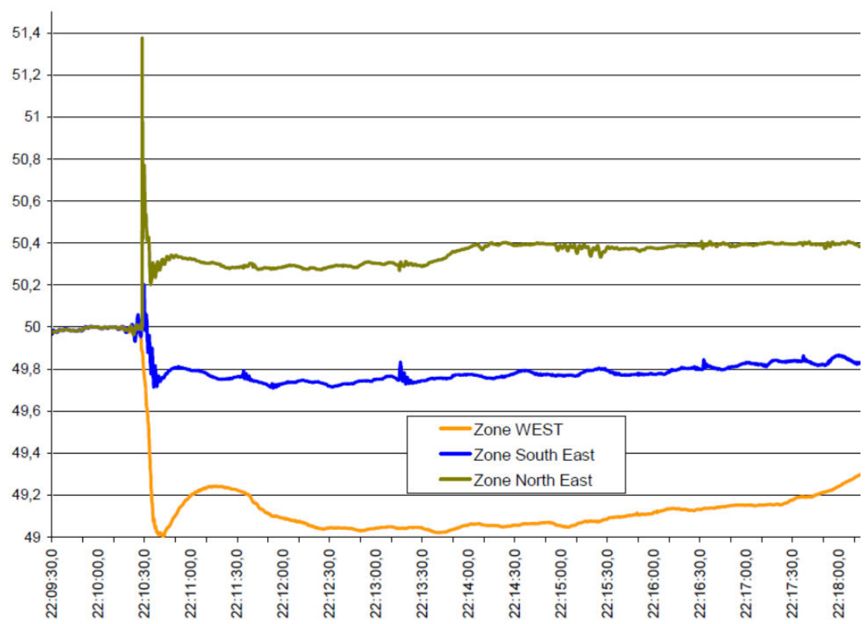
Emergency frequency control
Validation case

- Starting point: Synthetic model of Europe – from Pegase
- Snapshot before events:

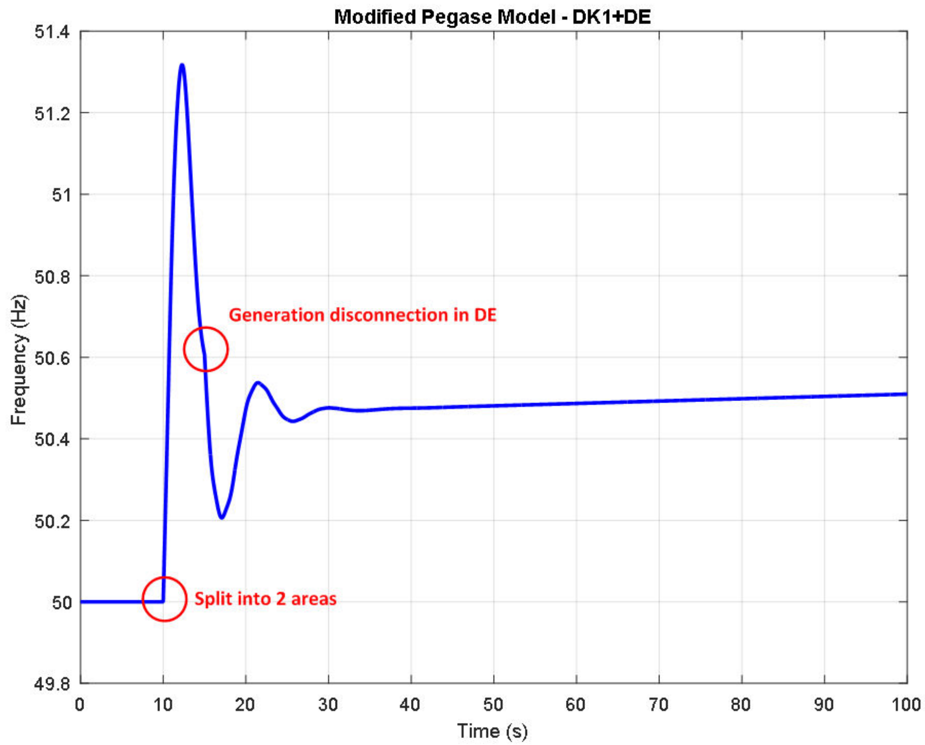
	Germany	Denmark
Conventional generation (GW)	45.5	2.0
Wind generation (GW)	8.4	1.0
Load (GW)	41.2	3.5
Losses (GW)	2.7	0.1
Imbalance (GW)	10.0	-0.6

Synthetic case – base simulation

- Events:
  - Split into 2 areas (Germany+DK1 surplus generation 9.4 GW) at 10sec.
  - Generator disconnection (3.3 GW) in Germany at 15 sec.

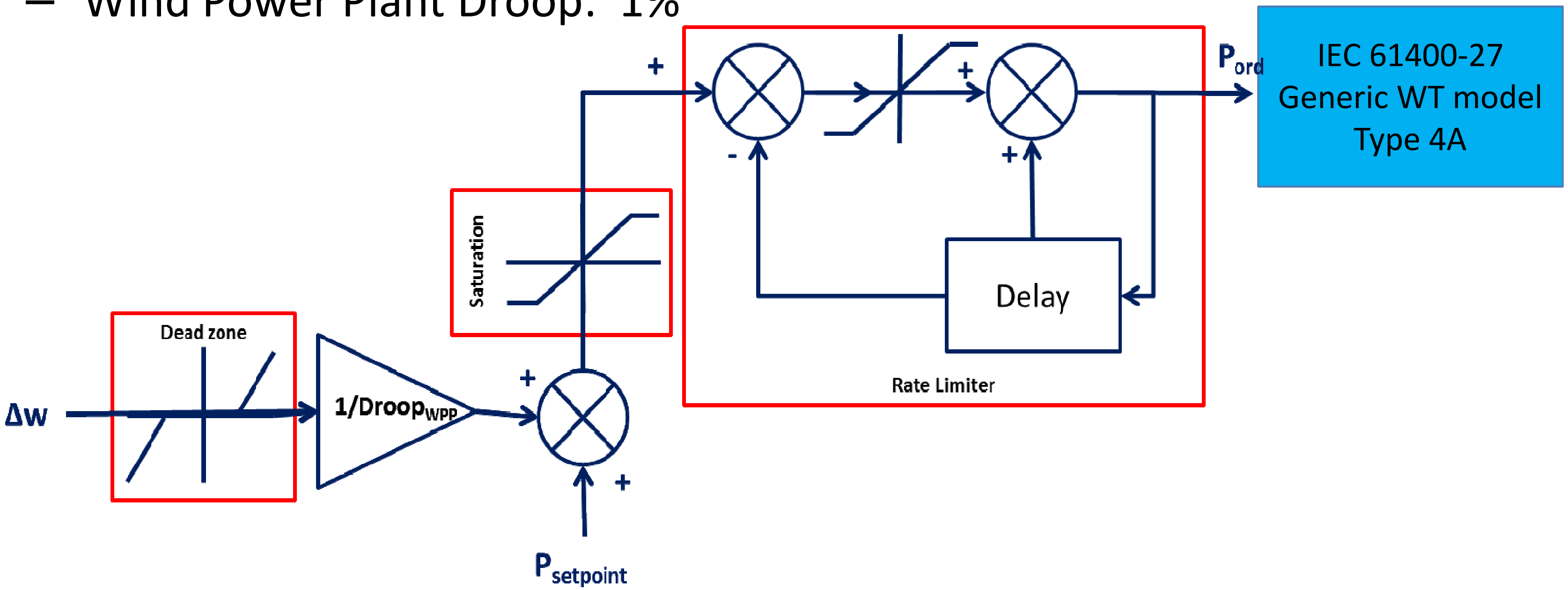


*ENTSO-E Final Report "System Disturbance on 4 November 2006,"

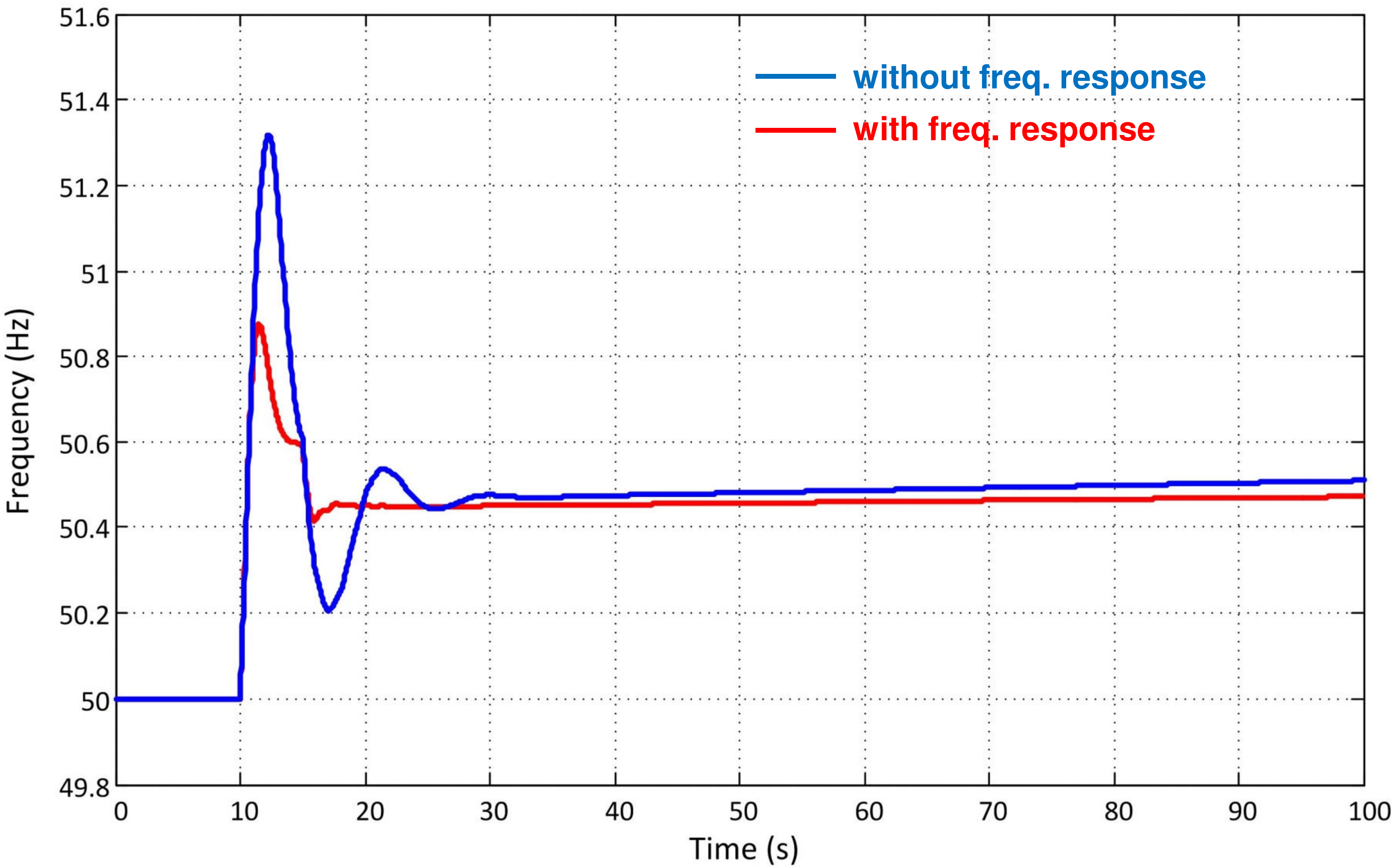


Wind power emergency control

- Model parameters (”optimized” using simplified Matlab model with 20% wind power penetration):
  - Ramp Rate Capability: 1p.u./s
  - Activation frequency: 50.4 Hz
  - Wind Power Plant Droop: 1%

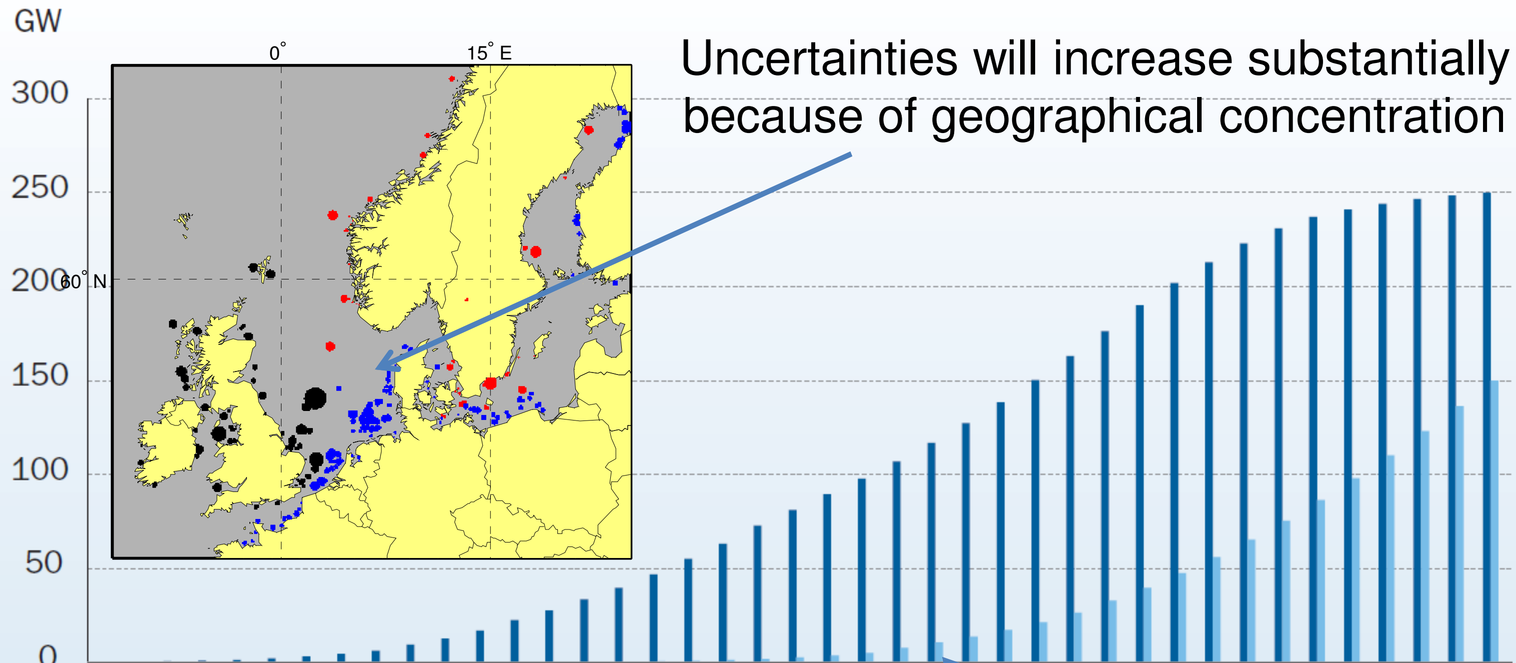


Effect of wind power emergency control



Onshore and offshore wind power development scenarios

FIG 6.1 CUMULATIVE ONSHORE AND OFFSHORE WIND POWER IN THE EU (1990-2030)



Uncertainties will increase substantially because of geographical concentration

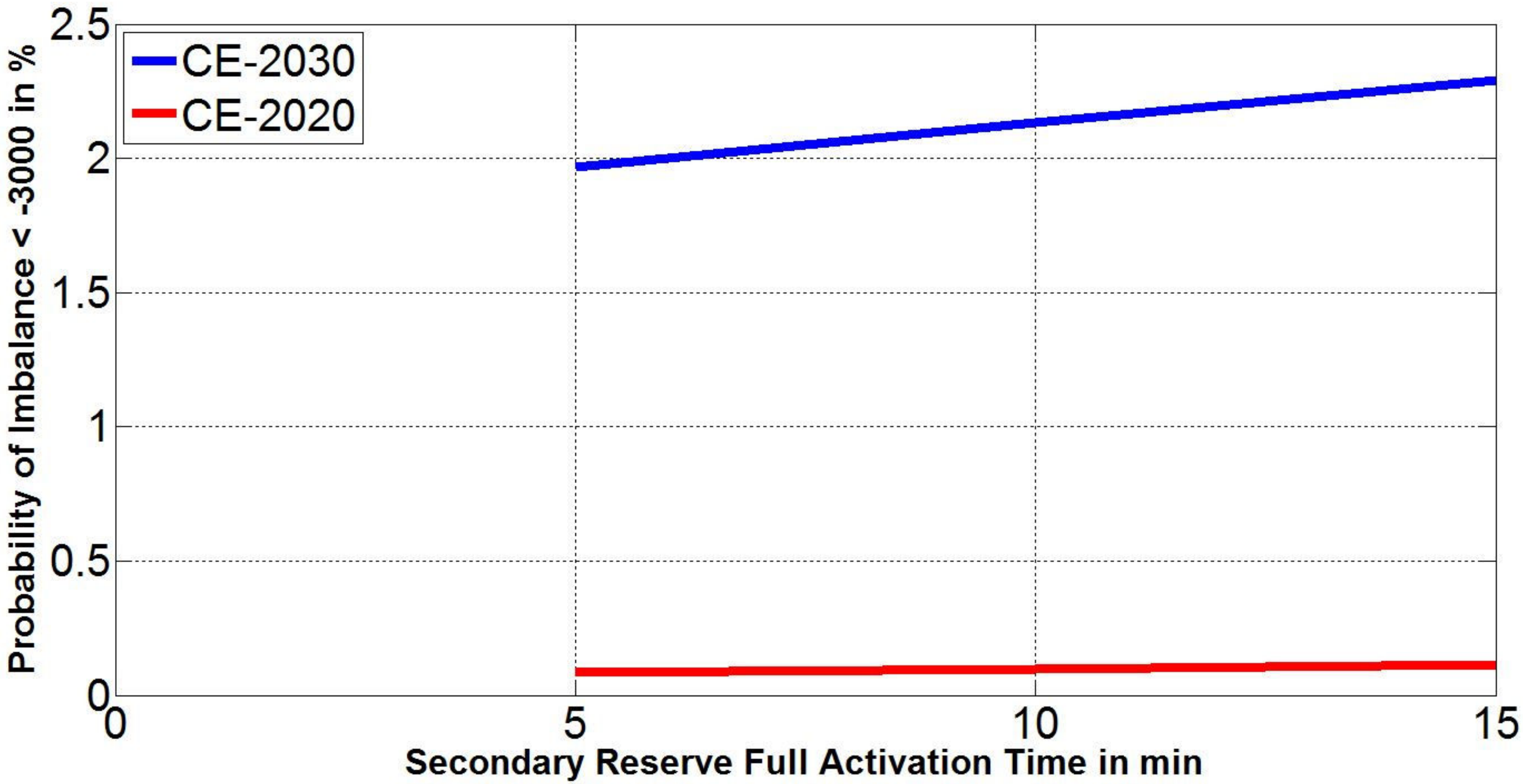
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Onshore	0.4	0.6	0.8	1.2	1.7	2.5	3.4	4.7	6.4	9.6	12.9	17.2	22.8	28.0	33.8	39.8	47.1	55.4	63.2	73.0	81.4
Offshore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.6	0.7	0.9	1.1	1.5	2.1	2.9
Total	0.4	0.6	0.8	1.2	1.7	2.5	3.5	4.8	6.5	9.7	12.9	17.3	23.1	28.5	34.4	40.5	48.0	56.5	64.7	75.1	84.3

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Onshore	89.6	98.0	107.1	117.0	127.5	138.6	150.4	163.0	176.4	190.0	202.0	213.0	223.0	231.0	237.0	241.0	244.0	246.5	248.5	250.0
Offshore	3.9	5.3	8.1	10.9	14.0	17.4	21.6	26.7	33.1	40.0	47.7	56.2	65.5	75.6	86.5	98.1	110.4	123.2	136.4	150.0
Total	93.6	103.3	115.2	128.0	141.5	156.0	172.0	189.7	209.5	230.0	249.7	269.2	288.5	306.6	323.5	339.1	354.4	369.7	384.9	400.0

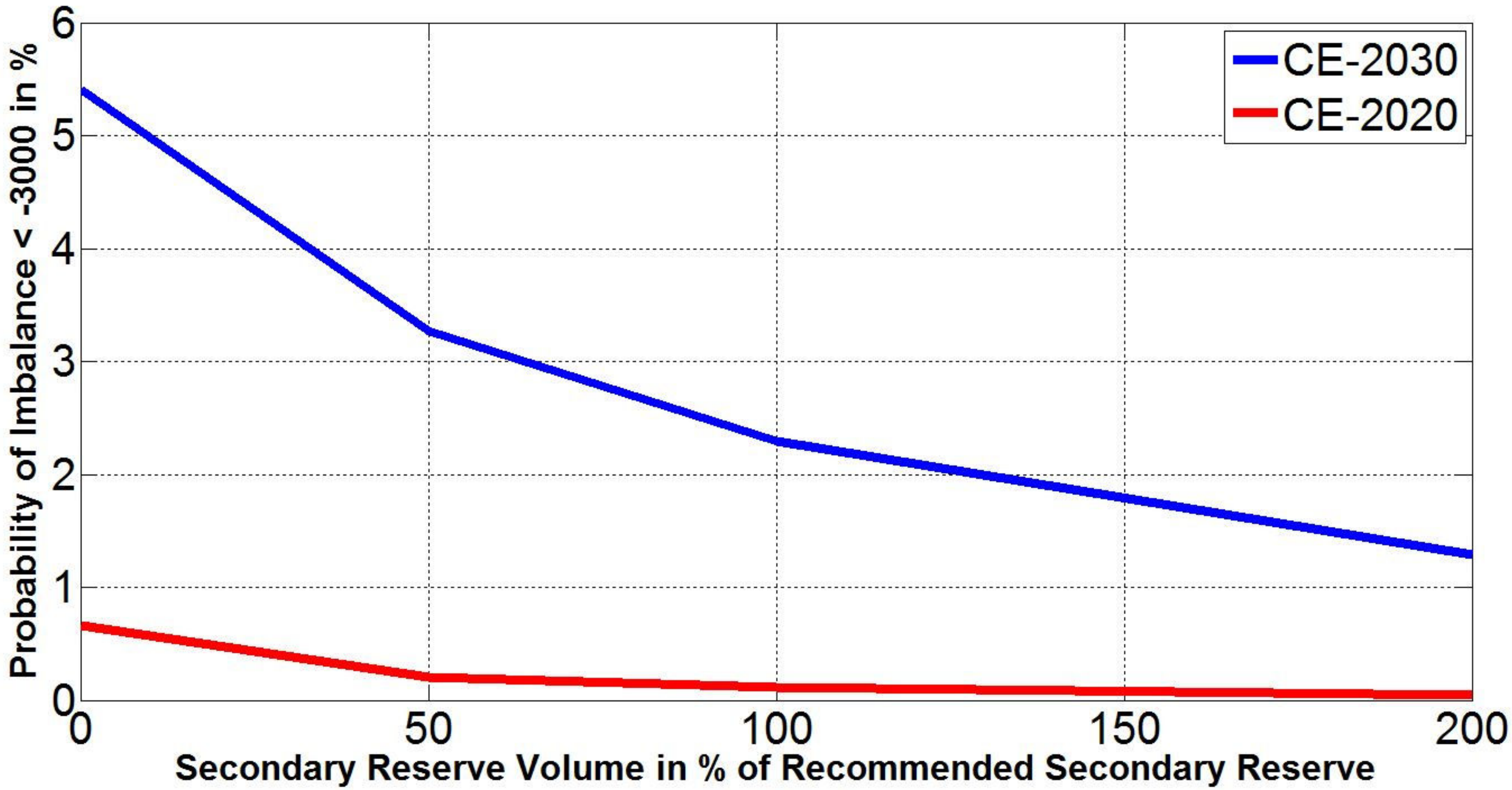
Source: EWEA 2011

Actual:offshore 8 GW end 2014

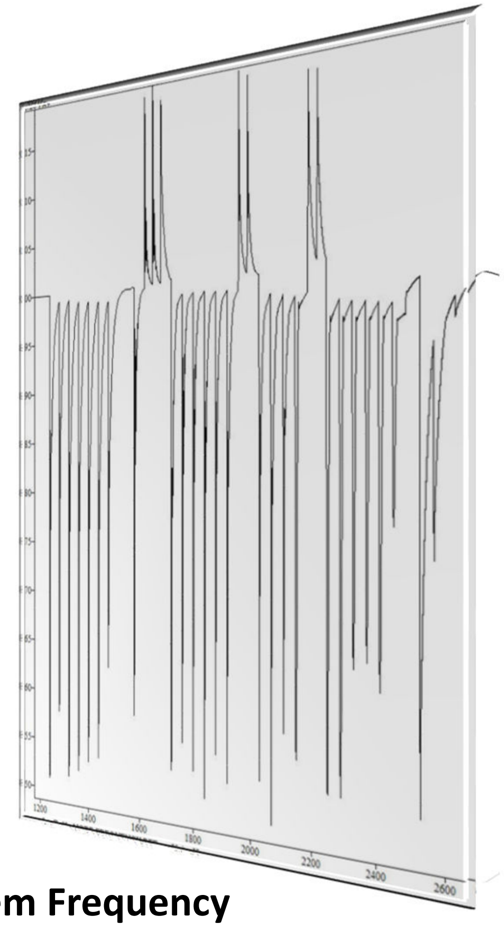
Effect of secondary reserve *response time*



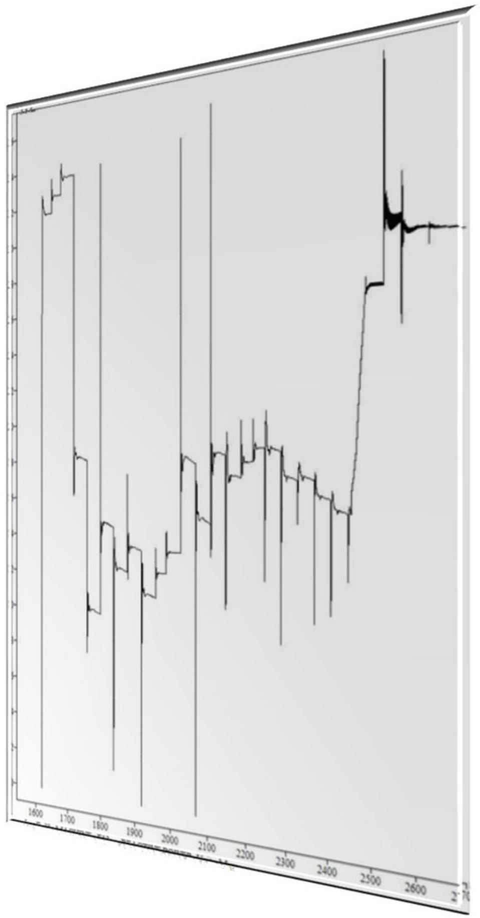
Effect of secondary reserve *volume*



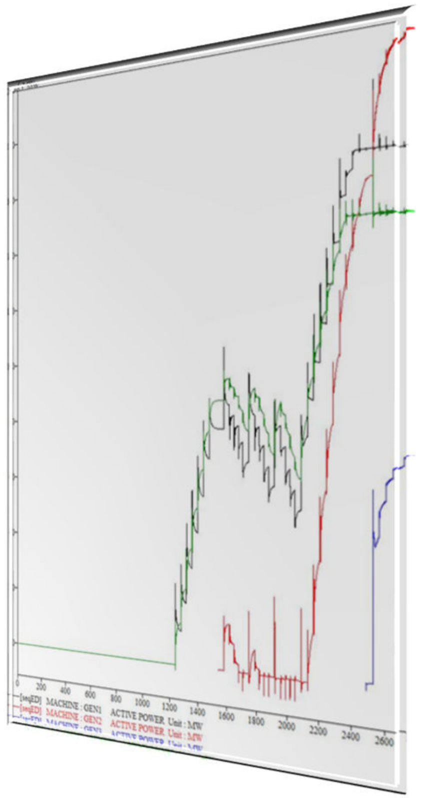
- Some results – Portuguese test case



System Frequency



Wind park Active Power



Conventional Units Active Power

Conclusions & Recommendations

Simulation on a synthetic Pan-European case confirms the positive impact of ensuring wind power emergency control in overfrequency cases

Simulation of Continental European wind power scenarios in 2020 and 2030 shows that increasing the volume of secondary reserves (LFC) can contribute to reduce the risk of temporary imbalances caused by wind power uncertainties – whereas reduction of secondary reserve response time has only little impact.

Using wind power can reduce the time required for restoration of power system

Coordinated Control of HVDC
&
Impact of PV on UFLS Schemes

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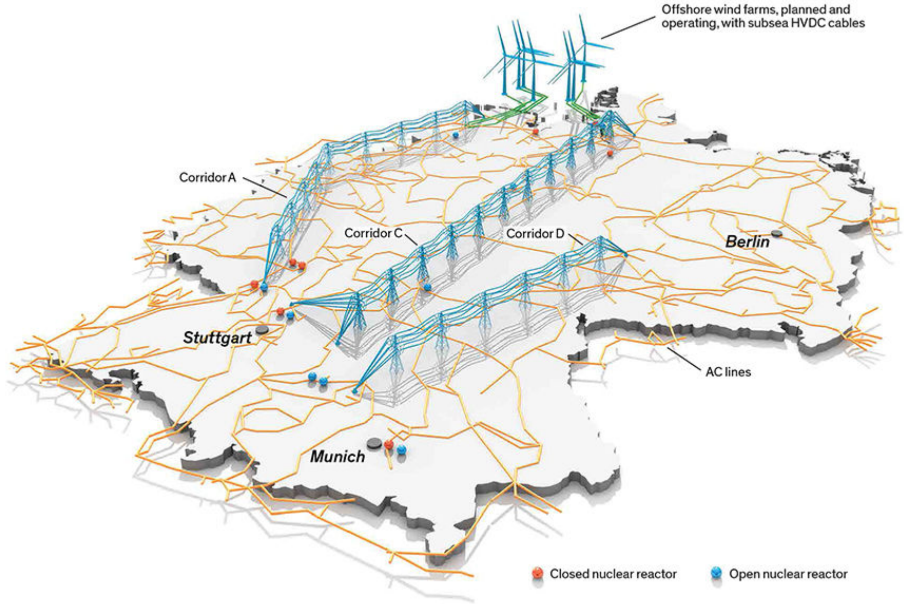
KU LEUVEN

Coordinated Control of Embedded HVDC

In the future power system more controllable device (PST, HVDC)

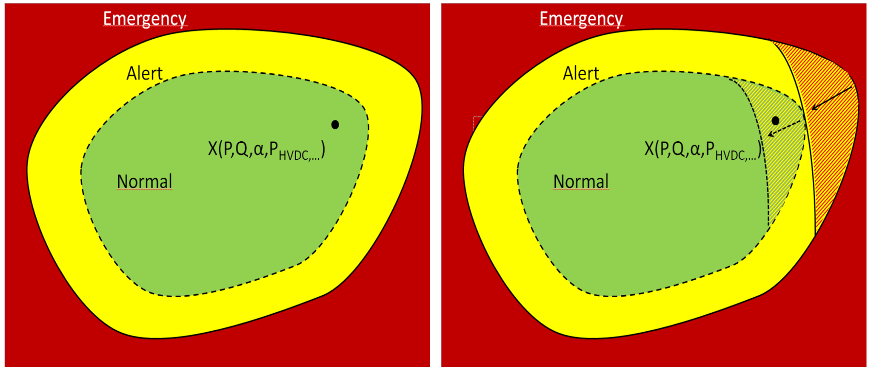
- Embedded HVDC:
  - INELFE
  - ALEGRO
  - Corridors Germany
  - UK bootstraps
  - Cobra
  - Sweden
  - …



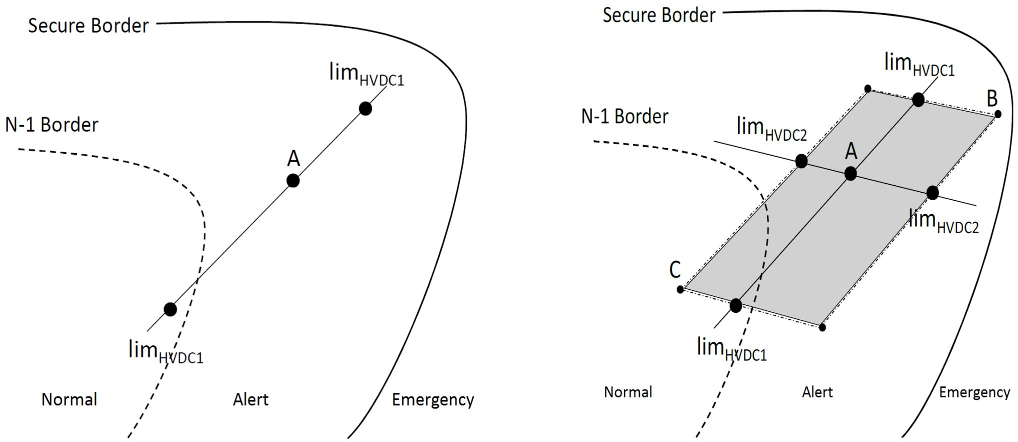
- How can embedded HVDC links contribute during emergency situations?
- Can they bring the disturbed system back to a stable operation point?
- Focus on avoiding cascading due to overloads and inter-area oscillations

Potential of coordinated control with embedded HVDC

- Outage shifts the operation point to the alert or emergency state

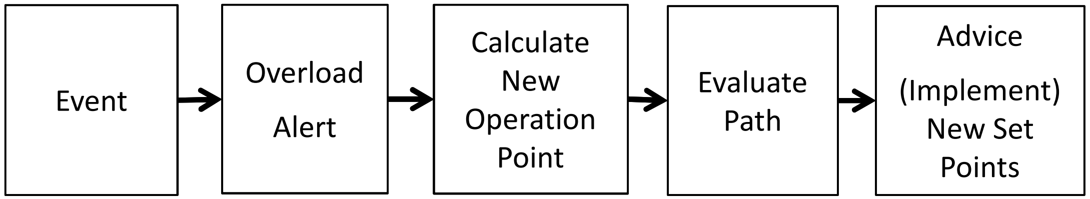


- Coordinated control of the embedded HVDC lines allows to shift the operating point back in a larger operating space



Methodology to manage overloads with HVDC

- Tool to manage overloads and to prevent potential cascading events

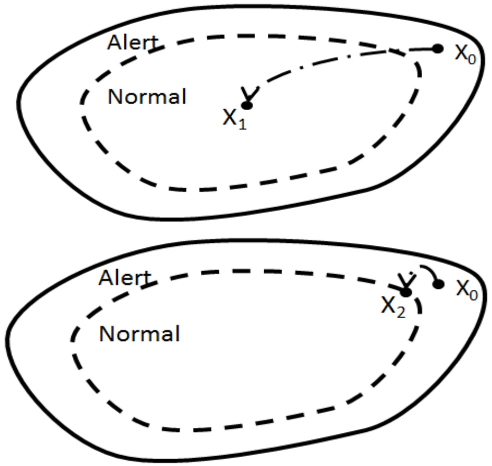


- Different objectives:
  - Optimal AC branch relieve:

$$\sum_{j}^{\text{AC Branch}} w_j * \left(\frac{F_{j,actual}}{F_{j,lim}}\right)^n$$

  - Minimal DC set-point change:

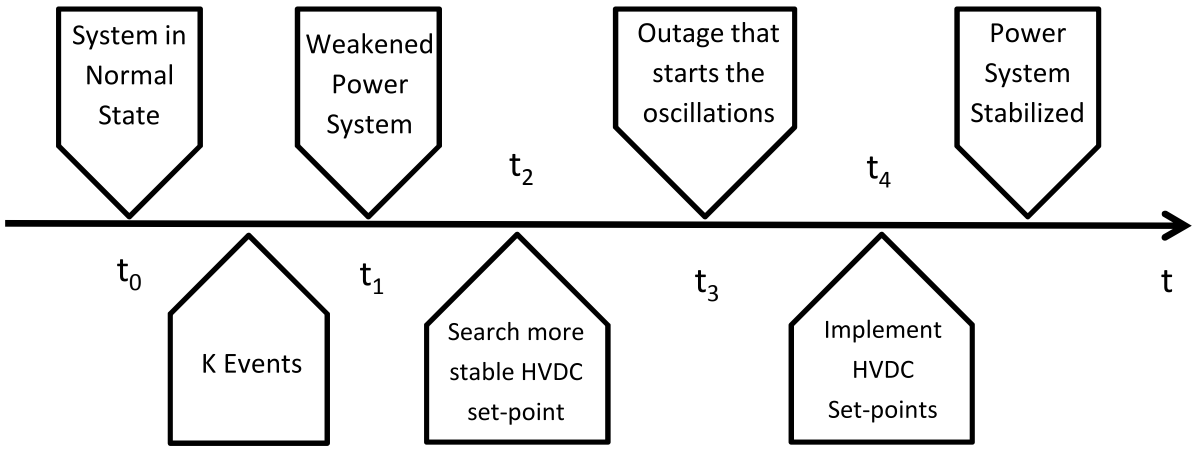
$$\sum_{i}^{\text{HVDC}} w_i * \left(\frac{X_{i,t} - X_{i,t-1}}{X_{i,lim}}\right)^n$$



- The tool has been implemented on a test system and successfully removed the overload avoiding a cascading in the

Methodology to manage inter-area oscillations with coordinated control of HVDC links

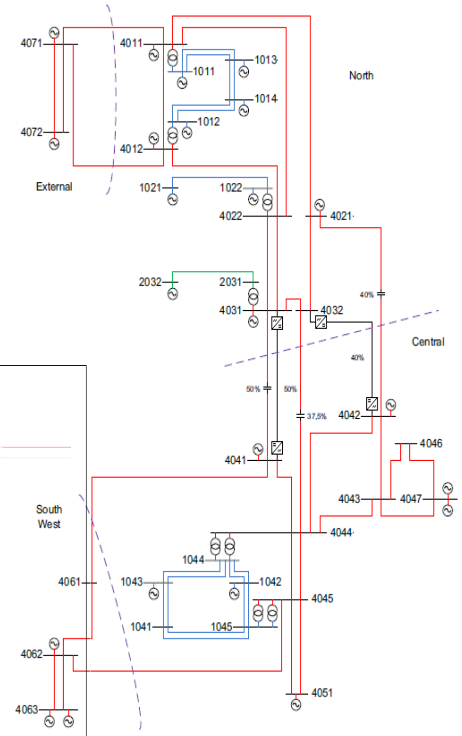
- Sequence of events and actions:

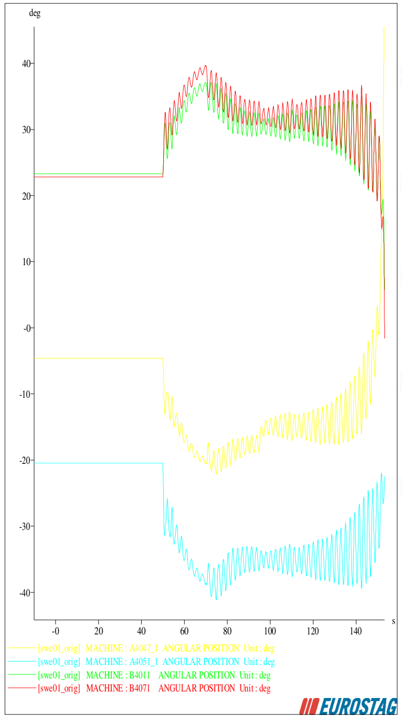


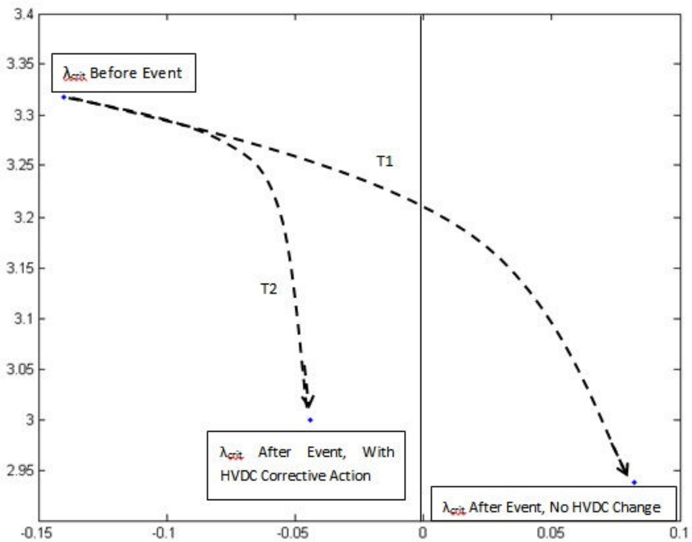
- Search the HVDC set point combination leading to the most stable operating point based on eigenvalue analysis
- Implement new set points shortly after an event when the inter-area oscillation is detected
- After stabilization move to original or more optimal set points

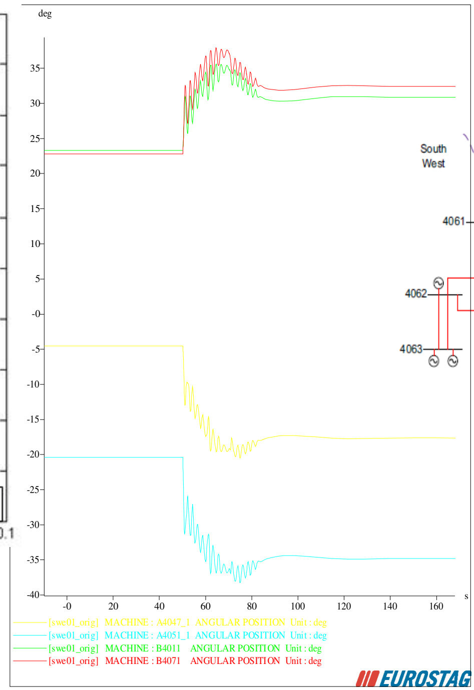
Coordinated Control of Embedded HVDC

- The methodology has been implemented on the Nordic 32 test system and successfully stabilized an inter-area oscillation









Results

- The potential of coordinated control has been shown on a test network
- A tool has been designed to inform and provide solutions to support operators managing overloads with embedded HVDC
- The tool has been implemented on a test system and successfully (automatically) removed overloads in the system
- A methodology to manage inter-area oscillations by coordinated control with embedded HVDC links has been proposed and successfully implemented on the Nordic 32 system

Conclusions & Recommendation

With the increased penetration of embedded HVDC links, coordinated control can contribute significantly to manage alert and emergency situations in the power system, specifically overloads and inter-area oscillations.

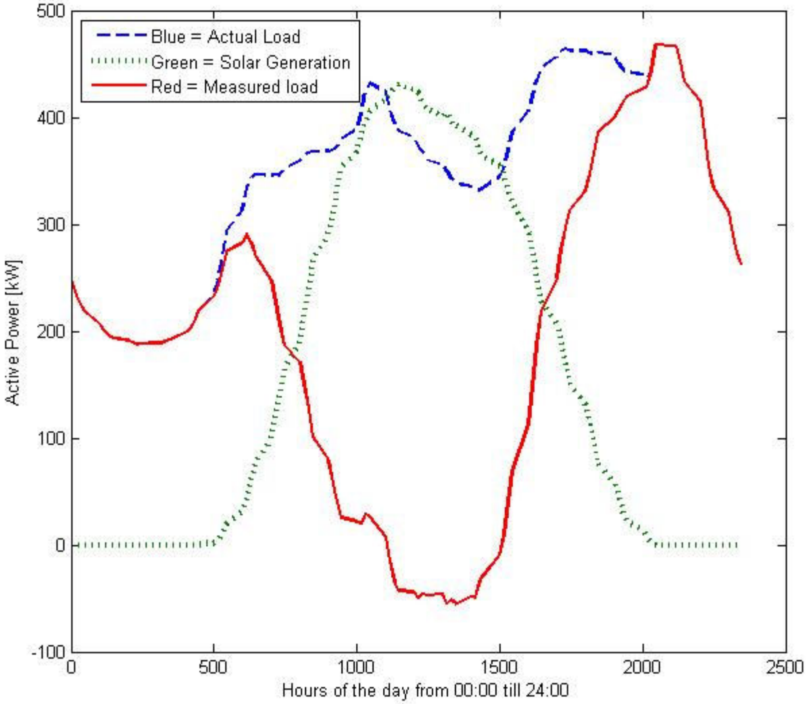
A tool for automatic control actions with HVDC links is developed and implemented on a test system. Such a tool is recommended as a support for operators and backup for failed control actions.

Impact of PV on UFLS Schemes

- EU targets: 34% of electricity production from renewables by 2020
- More PV generation installed in residential areas
- Mixed feeders behaviour:
  depending on the time of the day, feeder acts as load or generation (Example: Belgian feeder)

→ UFLS scheme becomes less adequate

→ New Emergency and Restoration Code provides more harmonized scheme design but impact of distributed generation only limited addressed



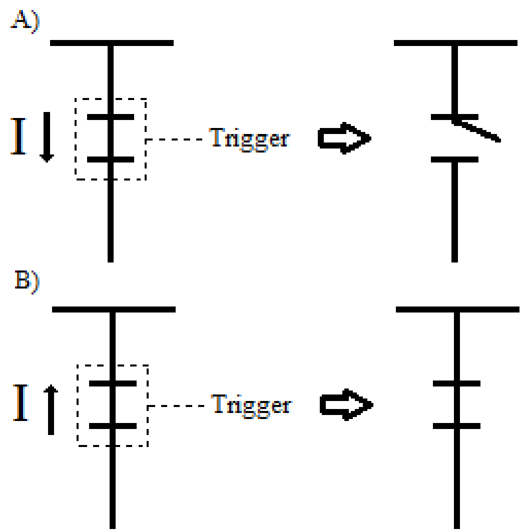
Feeder Ranking Methods

- Business as Usual: snapshots at specific days and hours every season

  → leads to under or overestimation of the amount of load available

- Direction of Current:
  Block the trip signal if the current is flowing from feeder towards the grid

  → avoid disconnection of generation
  → new measuring equipment and integration with relays needed



Feeder Ranking Methods

- Periodic Settings: Change the feeder ranking every season, month, day

Rank according to: $\text{Index} = \frac{\text{Installed PV Power}}{\text{Historical Measured Load}}$

→ Improved behaviour compared to BAU, but not optimal
→ Better performance for smaller time window
→ Hardware adjustments necessary to implement

- Smart Grid Approach: Change the feeder ranking close to real time based on measurements and estimations of PV generation

Rank according to: $LS_{eff} = \frac{System\ Contribution}{Impact_{LS\ action}} = \frac{Measured\ Load}{Measured\ Load + 2 * PV\ generation}$

→ More robust UFLS scheme (no generation disconnection, follow scheme design)
→ Minimize consumer impact

Implementation on Data ERDF

- <u>Smart Grid Approach (Equal percentage rank):</u> Implement on data ERDF
  - 1300 Feeders
  - 15% of feeders has PV

RST_load for equal percentage in each step									
%	1.1	1.2	2.1	2.2	3.1	3.2	4	5	
1.1	7.7	0	0	0	0.1	0.9	0	0	8.7
1.2	2.5	6.6	0	0	0.8	0.6	0	-0.1	10.4
2.1	0	3.5	4.9	0	0.6	0.5	0	-0.1	9.4
2.2	0	0	5.2	2.5	1	0.7	0	0	9.4
3.1	0	0	0	7.1	0.4	0.3	0	-0.1	7.7
3.2	0	0	0	0.4	7.2	1.4	0	0	9
4	0	0	0	0	0	0	18.2	-0.3	17.9
5	0	0	0	0	0	0	0	27.4	27.4
	10.2	10.1	10.1	10	10.1	4.4	18.2	26.8	

Results

- UFLS scheme becomes less adequate due to integration of DG
- Different ranking methods have been proposed and analysed
- A test on the data infrax showed the potential of the different methods
- A test on the data of ERDF of 2012 showed that the smart grid approach improves the robustness of the UFLS scheme while reducing the consumer impact

Conclusions & Recommendation

The robustness of current UFLS schemes comes under pressure from the increased penetration of distributed generation.

Different feeder ranking methods have been designed and successfully implement on power system data of different DSOs. The scheme robustness can be improved, while reducing consumer impact. Therefore it is recommended to use methods which take distributed generation into account for the feeder ranking in UFLS schemes

Thank you!

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Out-of-Step (OOS) Relay Tuning

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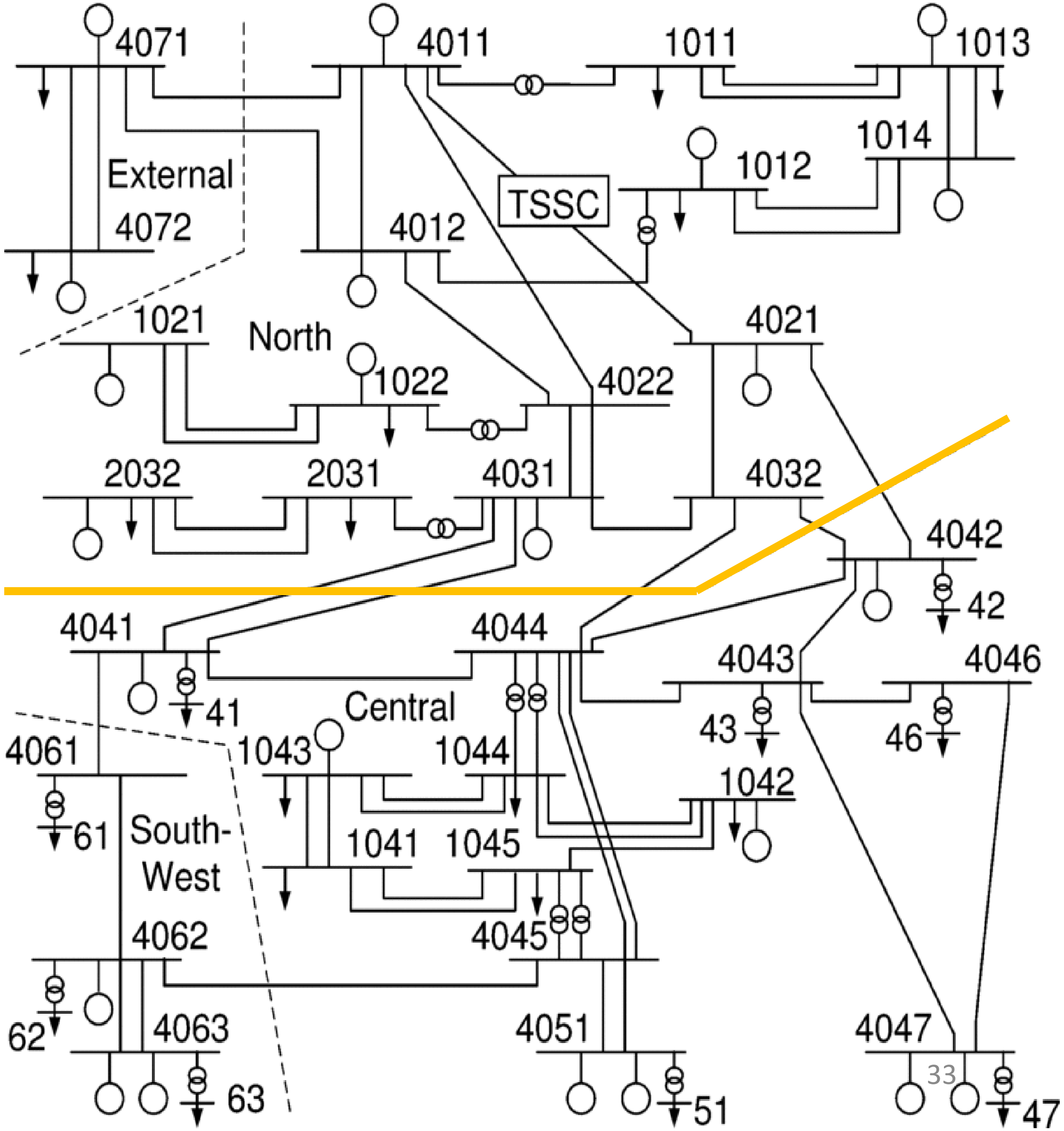
TRACTEBEL Engineering
GDF SUEZ

Out-of-step

Out-of-step relay (loss of synchronism relay)

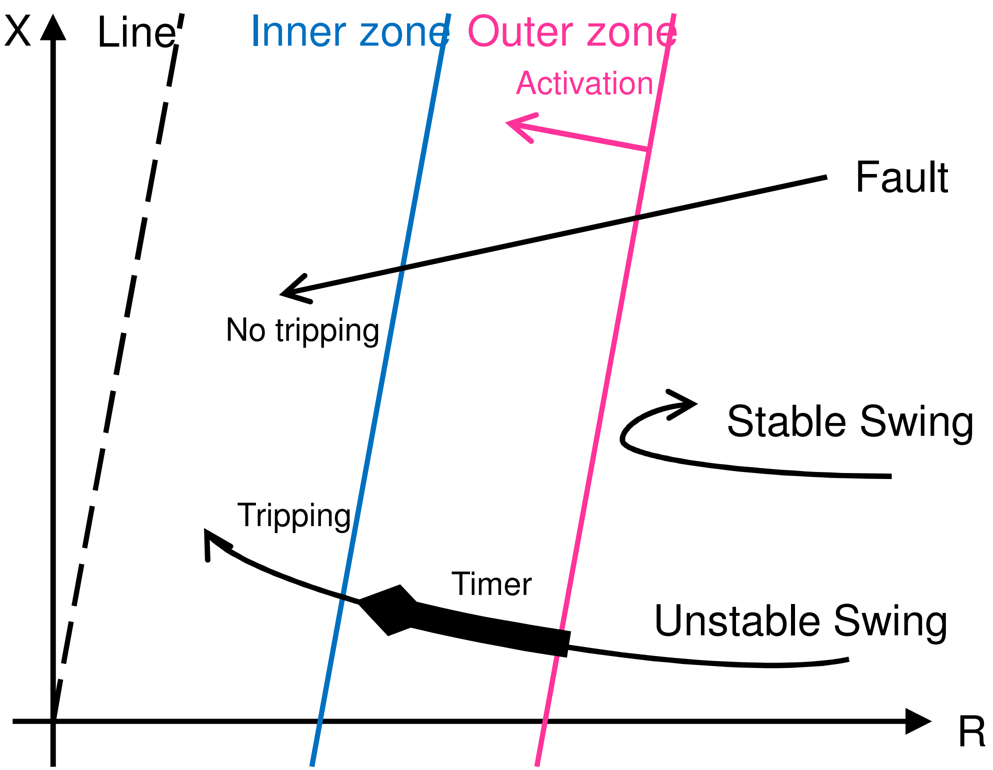
- Detects out-of-step conditions in the power system
- Sends signals to the correct breakers to split the system



OOS relay principles

Out-of-step relay (loss of synchronism relay)

- Discriminate between faults, stable swings, and unstable swings
- Based on inner and outer zone setting, and timer



Methodology

- Target trip matrix
  - Indicates the relays that are expected to trip for each of the simulated incidents
- Achieved trip matrix
  - Indicates the relays that would effectively trip for each of the simulated incidents

	Incident 1	**Incident 2**	**…**	**Incident M**
Relay 1	Not tripping	Not tripping	…	Not tripping
Relay 2	Not tripping	Not tripping	…	Tripping
…	…	…	…	…
Relay M	Tripping	Not tripping	…	Tripping

- Tune relay parameters to minimize the difference between target and achieved trip matrix
- Minimize the
  - tripping failure: OOS not activated when it should have
  - spurious tripping: OOS activated when it should not have

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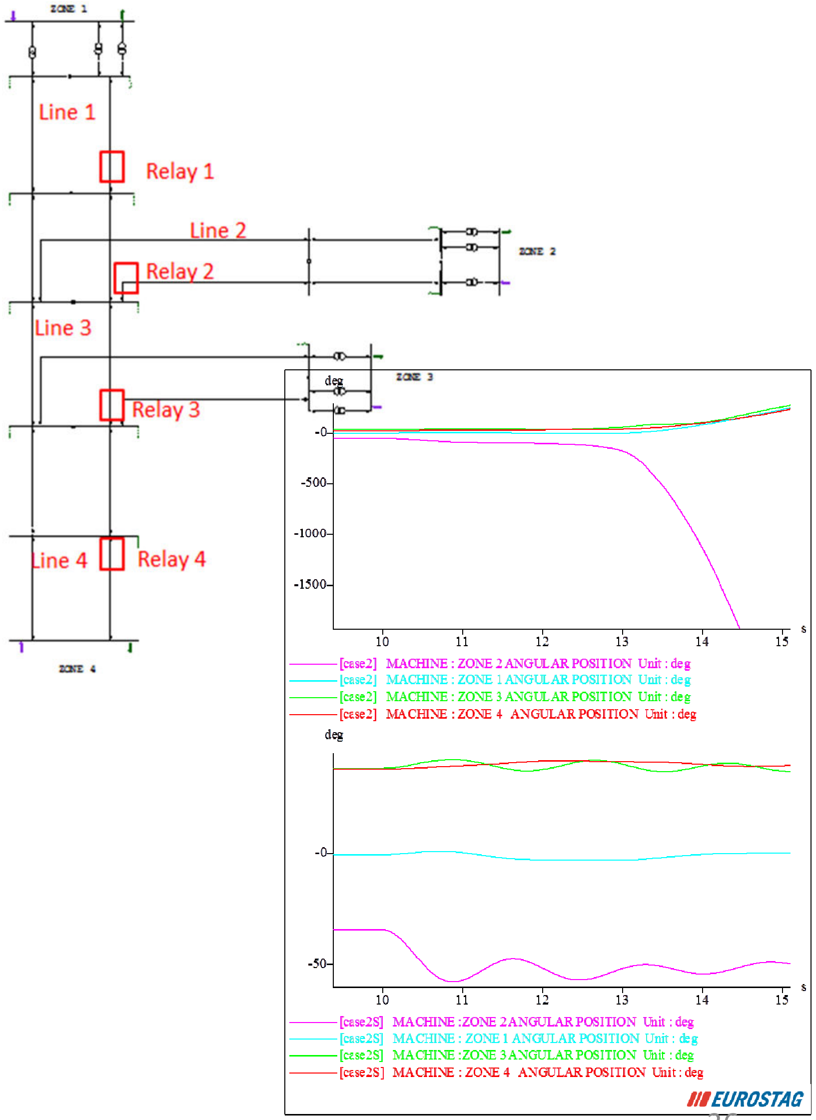
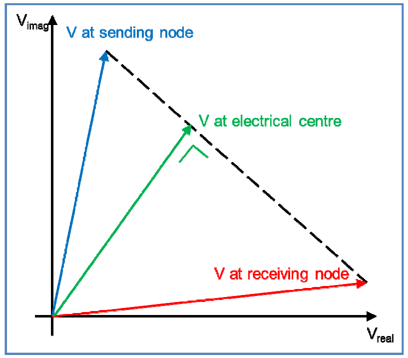
Tuning of OOS relays

- A tool for automatic tuning of OOS relay parameters was developed based on mathematical optimisation
- A test on the Nordic32 system with one relay showed that the tool found a better solution that the manual solution
- A test on a system with four relays showed the capacity of the tool to tune several relays simultaneously

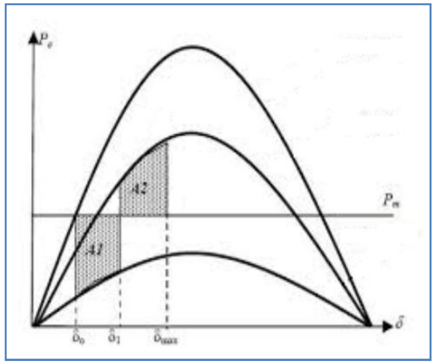


Use of PMU information

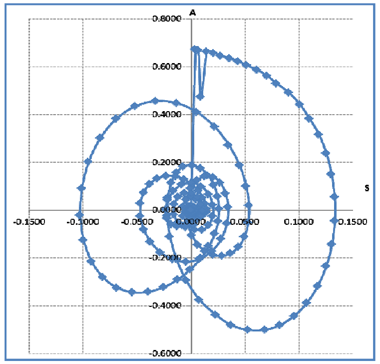
- Several ways of using PMU information have been implemented and tested
- Some of them are promising
- There are drawbacks (non-standard relay models, tuning more difficult, filter cases of spurious tripping,…)



Direct calculation of V at electrical centre



Monitoring rotor angle dynamics



Extrapolation of rotor angle curve

Conclusions & Recommendations

A tool for automatic tuning of out-of-step relay parameters is developed and successfully tested on realistic power systems. It is recommended to use such automatic tools as the results obtained are better than with manual tuning.

Use of PMU information in OOS relays is promising, but more research is needed before a recommendation on the use of PMU for OOS relays can be made.

Thank you

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