Technical University of Denmark

WP6 Defence plans and restoration

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WP6
Defence plans and restoration

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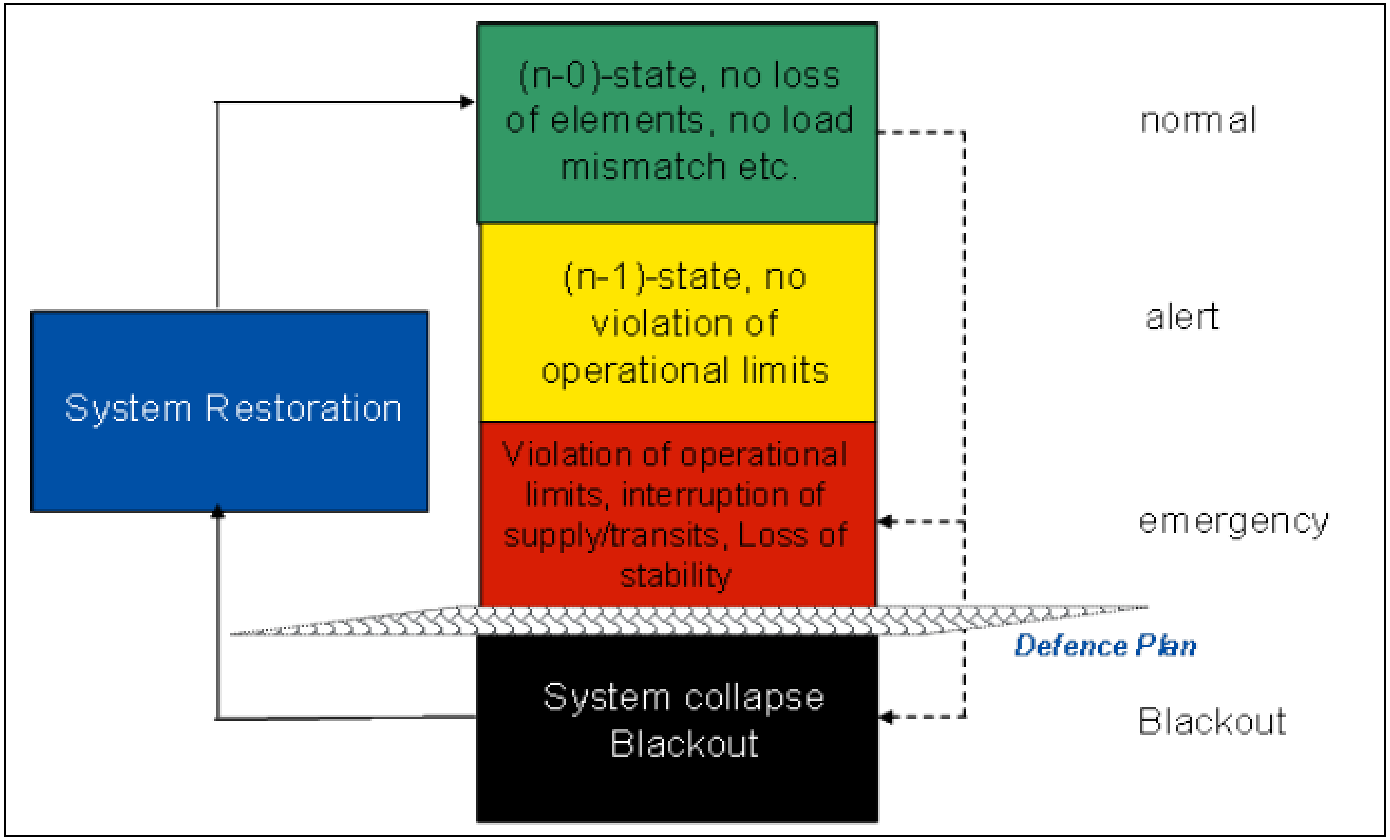
ENTSO-E definition



Workplan defense / restoration

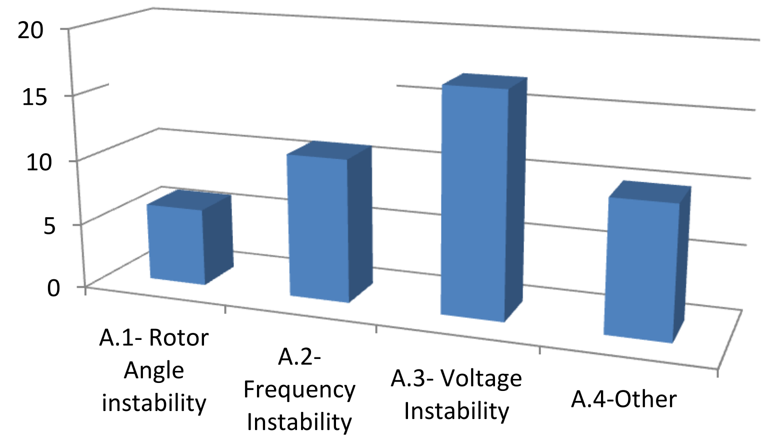
- Defense plans
  - Weak points in existing plans (AIA)
  - Role of renewable generation plants (DTU)
  - Pan-European coordination (KU Leuven)
  - Use of PMUs (Statnett / KTH)
  - Use of distributed energy resources (Imperial Col.)
- Restoration
  - Coordinated restoration (AIA)
  - Use of renewable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

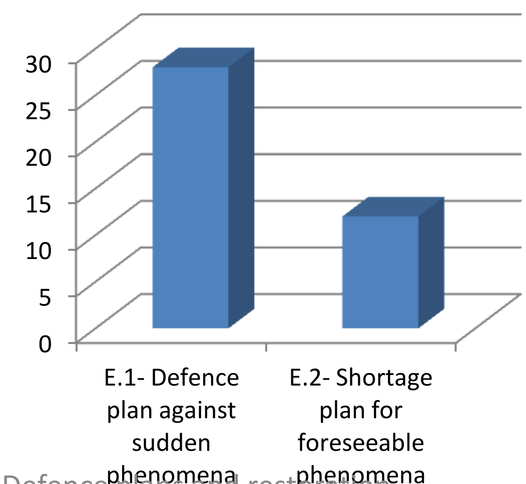
TSO survey

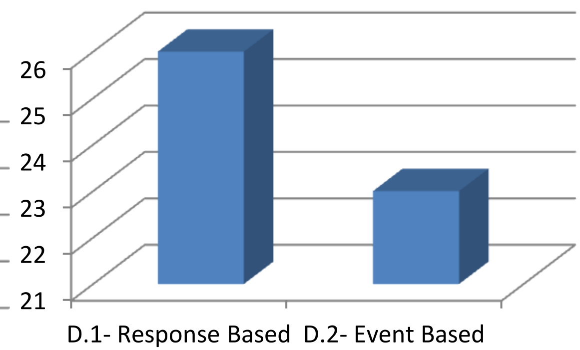
TSO	Country	Survey	Visit
ELIA	Belgium	☑	☑
IPTO	Greece	☑	
National Grid	UK	☑	☑
Statnett	Norway	☑	
REN	Portugal	☑	☑
RTE	France	☑	☑

General survey results
Numbers of Special Protection Systems

- Voltage Stability is the main concern, but there is a considerable number of “other” instabilities
- Most SPS triggering are response-based
- Defense plans are mainly oriented to face sudden phenomena







Survey conclusions

- No TSOs are currently using PMU's in defence plans, but
  - most of the TSOs have PMUs installed for detecting oscillations in the grid, and
  - some of them are planning to utilize this information more in the defence plans in the future, and
  - some of the TSOs use PMU information in post-mortem analysis of grid events.
- Switching of renewables according to the currently required grid protection settings can cause severe power imbalances.
  - This calls for coordination between TSOs and DSOs concerning protection settings.

Survey conclusions

- Under-frequency load shedding (UFLS) is a key element in the defence plans, but
  - the expected volume of load shedding is often not met in the case of a real event causing more steps of the UFLS to be activated.
  - This is primarily because the distributed generation is not taken properly into account.
- Rate of Change of Frequency (RoCoF) relays:
  - Some TSOs use RoCoF relays for islanding protection of in the network.
  - RoCoF relays are also used for unit protection of conventional thermal generators and distributed embedded generators (in DSO networks).
  - The RoCoF protection settings vary between 0.125Hz/s and 0.5Hz/s depending on the TSO.

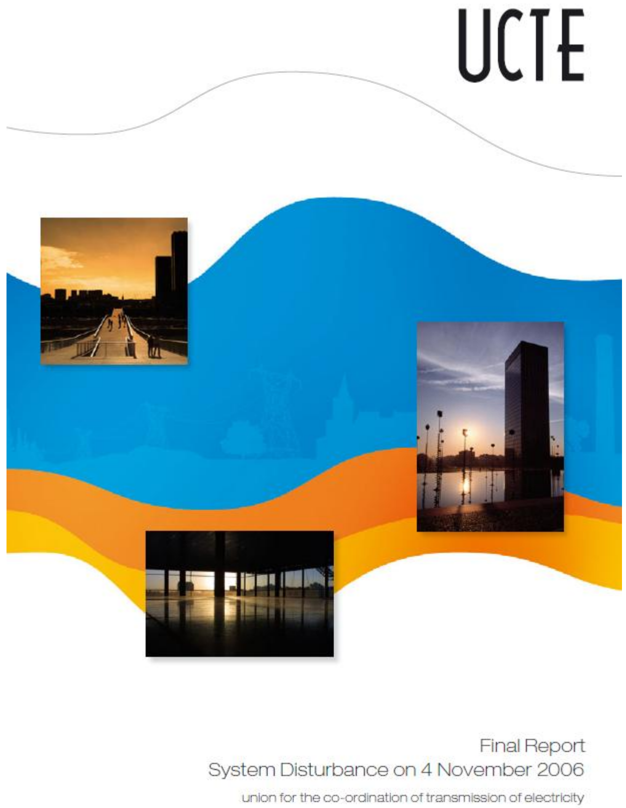
Survey conclusions

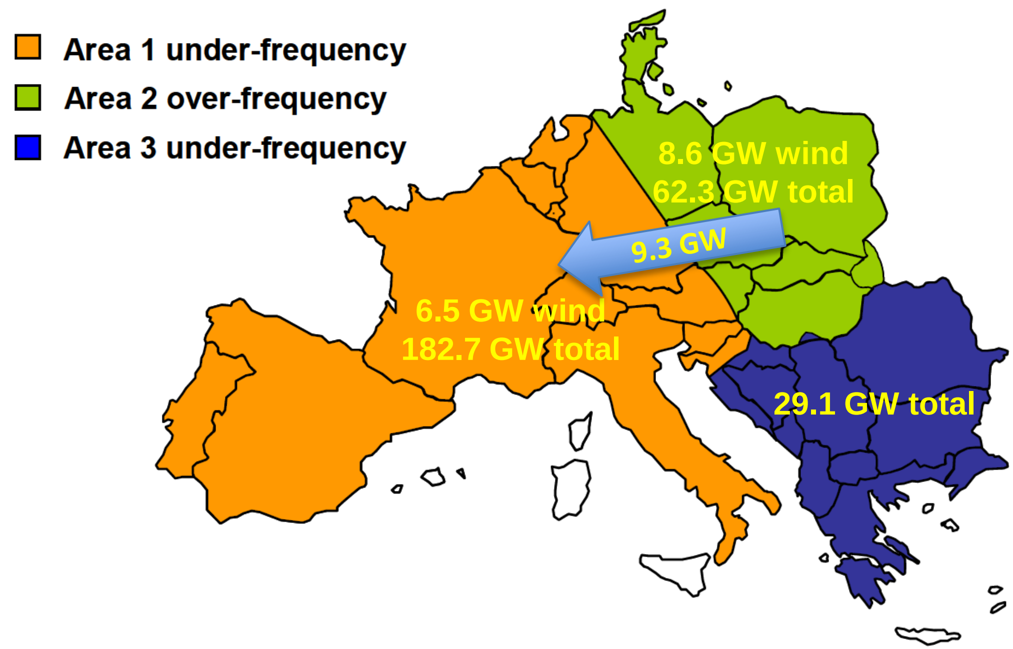
- Renewable energy is used by some TSOs in the emergency frequency control and voltage control.
- Demand side response is only used sparsely in the emergency frequency control.
  - Some TSOs are considering to use this option more.
- HVDC interconnectors are used in defence plans, but it must always be agreed in the specific situation, so the activation is manual.

Renewables in defence plans

Motivation

Example of disturbance on 4th November, 2006 at UCTE

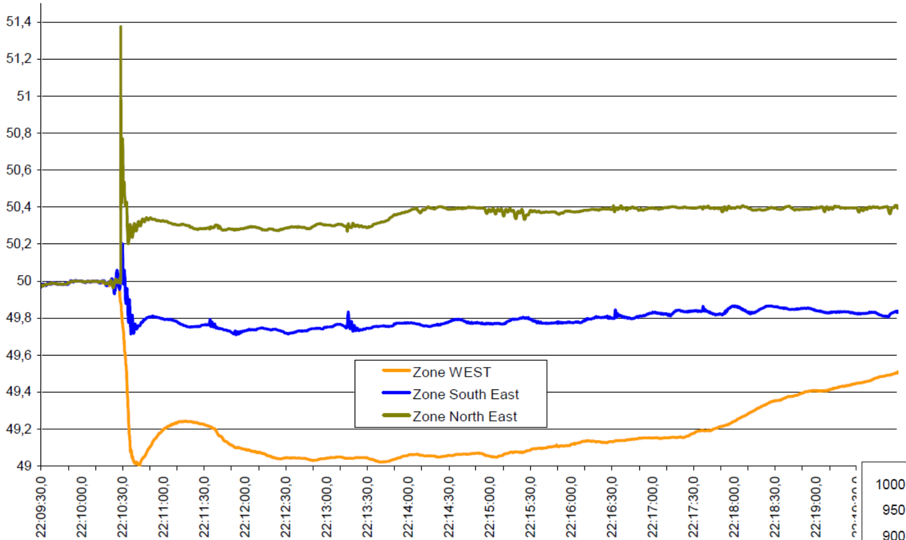




Renewables in defence plans

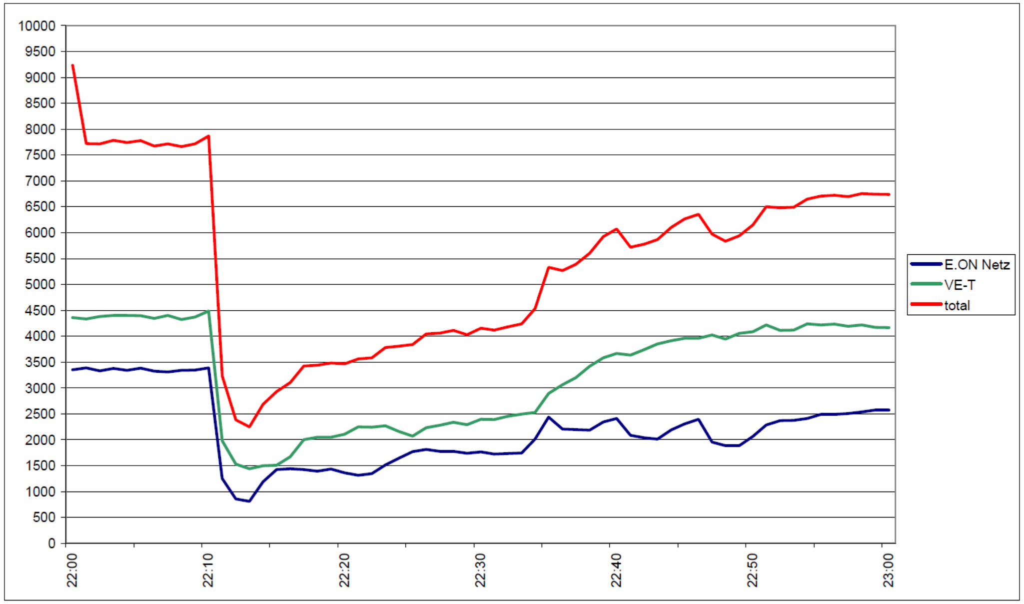
Motivation

Example of disturbance on 4th November, 2006 at UCTE



Frequency Recordings after the split

Output of wind turbines in North East Zone



iTesla
Innovative Tools for Electrical System Security within Large Areas

Renewables in defence plans

- In *Wind Integration Workshop*. London 22-24 October 2013

Aspects of Relevance of Wind Power in Power System Defense Plans

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- Wind turbine capabilities
- Defence plans
  - Frequency stability
  - Voltage stability

Wind Power during Emergency

- Overfrequency support by Wind Power Plant (WPP)
  - Relevant option since WTs can make down regulation reserves available
    - Fast active power control capability
  - Overfrequency protection not optimal
    - WTs reconnected too early 4 November
  - Low intertia: Risk of tripping of ROCOF based relays of conventional generators
- Underfrequency support by WPP
  - Conventional primary control (droop control): P ~ Δf is expensive approach because WTs usually already operate at max possible
  - Advanced control – Inertial control (P ~ df/dt) or ***temporary*** primary control possible
- Voltage support by WPP
  - Variable speed wind turbines: converters can temporarily be overloaded to provided additional reactive power

Pan-European coordination

- The transition to:
  - liberalized European electricity market
  - higher penetration of renewables

  increase the international flows and loading of the power system
  → The system is operated closer to it's limits
- At the same time: more controllable devices are (or will be) installed in the European Continental Power System (HVDC, PST,...)
- Survey results coordinated control actions:
  - Up till now PFCs (power factor correctors) only used for changing the transfer capacity for spot markets (day ahead and intra day)
  - Some TSO's have reduction schemes on the HVDC connectors
  - In real time only bilateral operation agreements (coordination between two TSO's)

Pan-European coordination

- In *IEEE Powertech.* Grenoble, 16 - 20 June 2013

Coordination of Multiple HVDC Links in Power Systems during Alert and Emergency Situations

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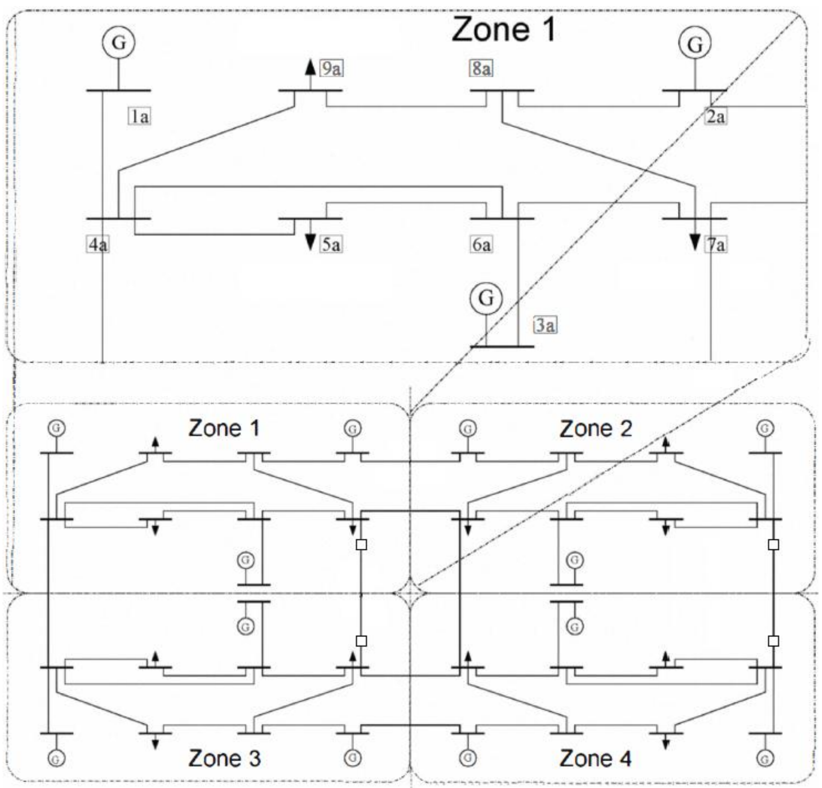
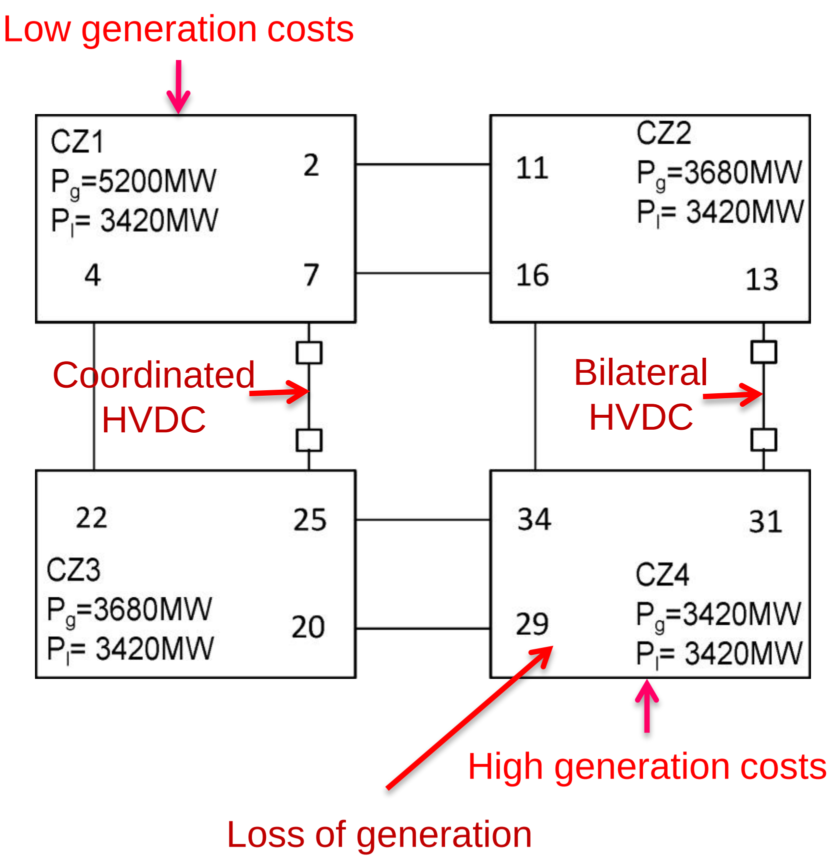
- The goal of the control methodology is to ***minimize cost*** to get the system ***back into a stable state***
- Main cost is the amount of load that needs to be shed

Pan-European coordination

The Cloverfield test system

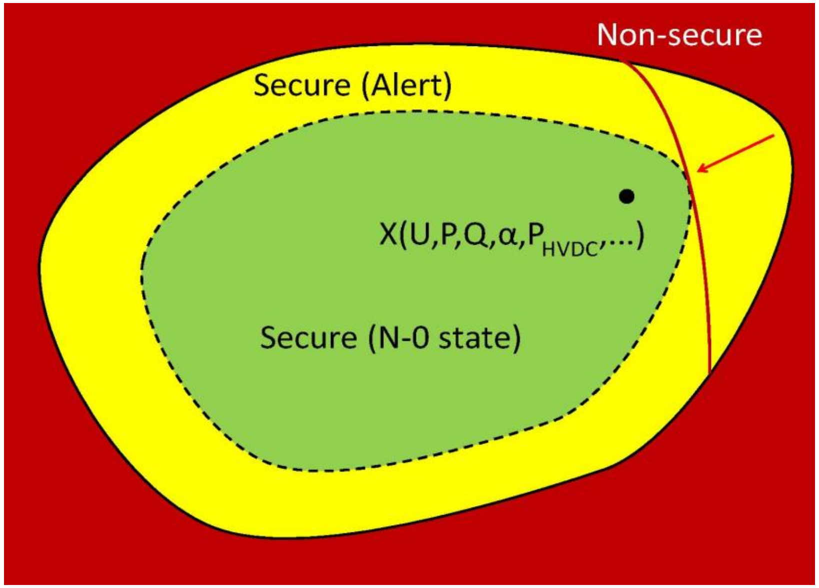


Simplified representation

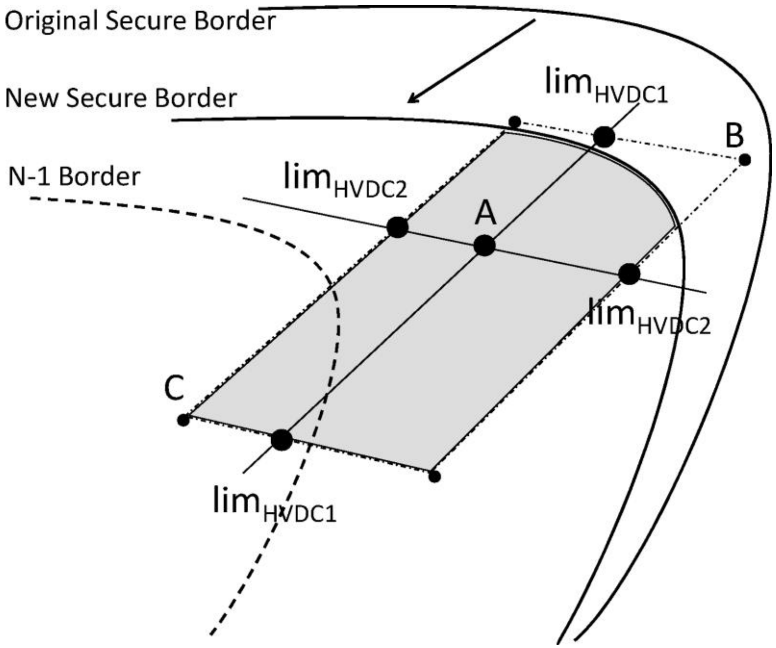


Pan-European coordination

Secure and unsecure space



HVDC setpoint influence



Pan-European coordination

- Approach:
  - Based on optimal power flow
  - Cost of lost load is higher than cost of any generation
- Results

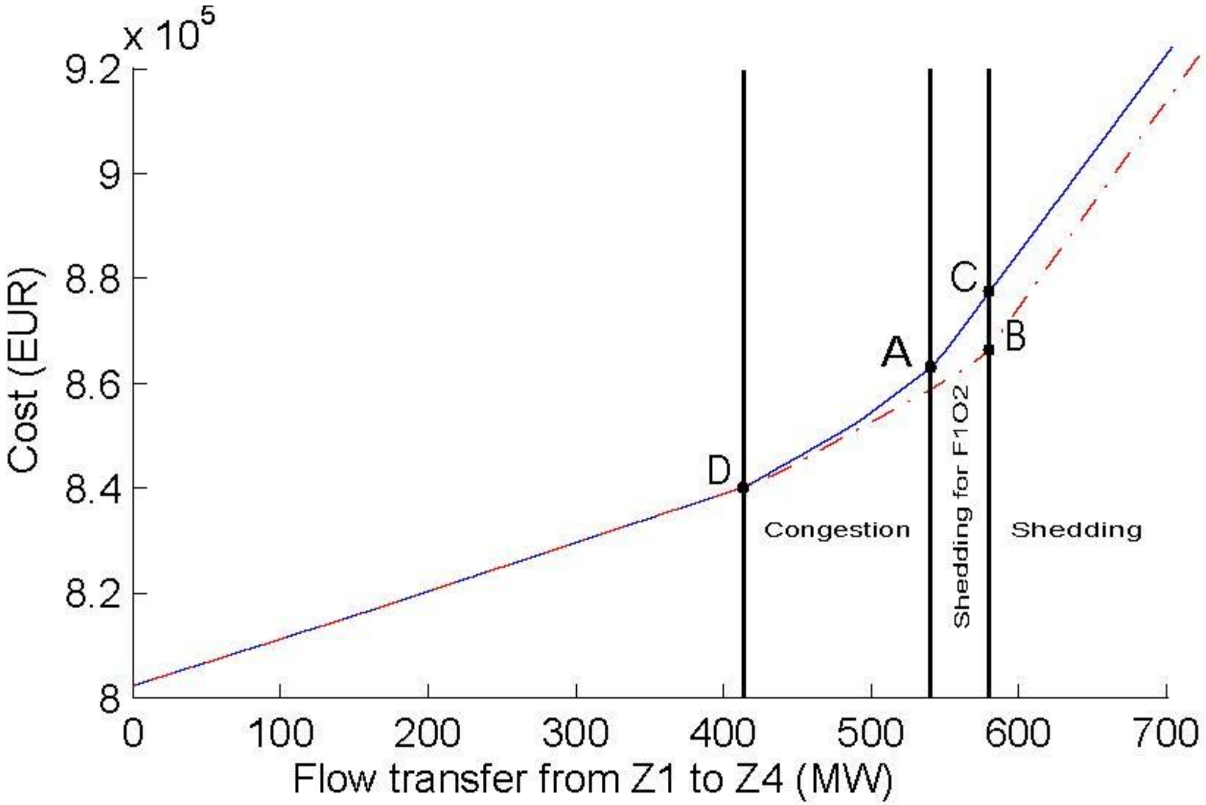
Maximum transfer possible before loadshedding (installed cross border capacity for zone 4 is 900MW)

No HVDC control → F1F2
Bilateral → F1O2
Coordinated → O1O2

	Only crossborder limits		With internal limits	
Case	MW	% of cap	MW	% of cap
F1F2	580	64.44	440	48.89
O1F2	723	80.33	552	61.34
F1O2	728	80.89	491	54.56
O1O2	760	84.44	576	64.00

Pan-European coordination

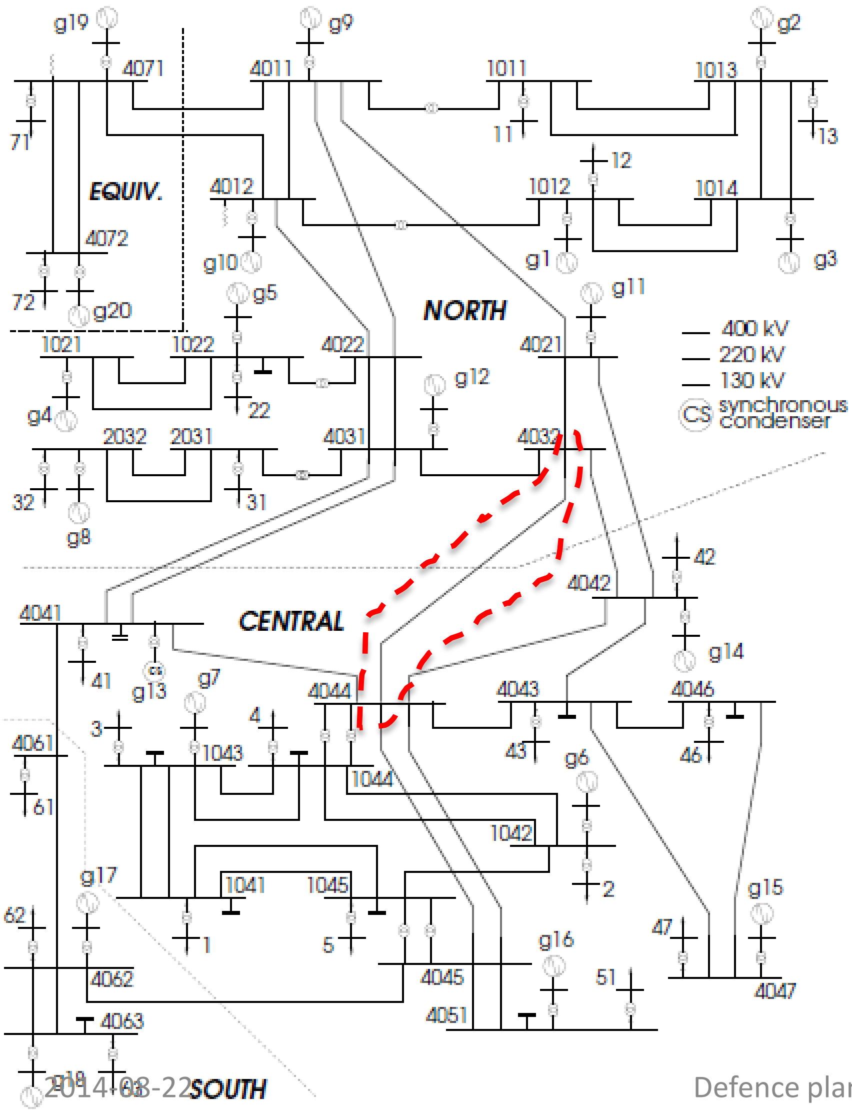
- The impact on costs



PMUs in Defence Plans

- PMUs provide high accuracy ***time-synchronized information*** of the power grid variables in different areas of the system, and can thus be used to observe oscillations, voltage levels, and frequencies at different areas
- The main goal of the WP6.4 (PMUs in defence plans) is to make advances in detection and prevention of instabilities using PMU infromation
  - The ***focus is on voltage stability*** but other types of instability phenomena are also considered

PMU – Voltage stability

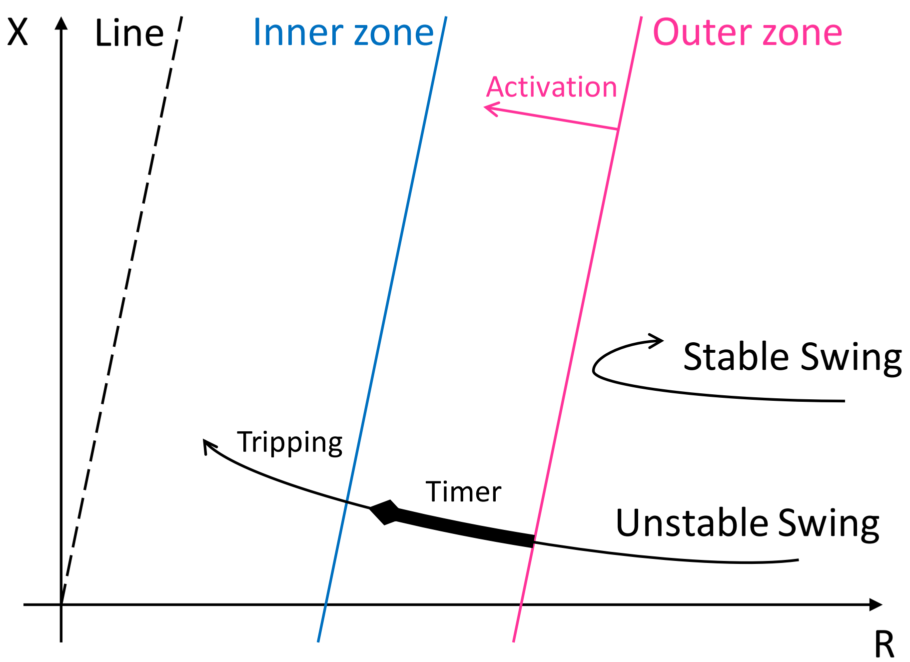


- **KTH:** The ***implementation*** of the test system (Nordic 32 system) for real-time simulation is ***completed***

- ***Voltage Instability scenario***:
  - Three-phase solid fault on Line 4032-4044, for 0.1 sec and cleared by opening the line.

PMU – Angular stability

- Goal: methodology for automated Out Of Step (OOS) relay tuning using wide-area measurements
- Approach: Minimize untimely tripping and tripping failure



Out-of-step relay tuning

- Basic idea: compare "target trip matrix" with "achieved trip matrix"

Target trip matrix

Achieved trip matrix

	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

Evaluation

	Relays trip in achieved trip matrix	Relays do not trip in achieved trip matrix
Relays trip in target trip matrix	Relays behave as expected (tripping)	Relays **do not** behave as expected (tripping failure)
Relays do not trip in target trip matrix	Relays **do not** behave as expected (unwanted tripping)	Relays behave as expected (no tripping)

Hybrid control of thermostatic loads

We propose a hybrid controller that addresses the observed shortcomings and meets the above performance criteria. Thus, we illustrate its effectiveness by using simulations in a system model.

Hybrid control strategy

1. The controller of each device identifies the frequency deviation Δf (Hz), evaluates its rate of change, and updates the temperature limits according to:

$$T_{max\,DD}(t,f) = T_{max} - K_{DD}\Delta f(t) - K_{roc}\, d(\Delta f(t))/dt$$

$$T_{min\,DD}(t,f) = T_{min} - K_{DD}\Delta f(t) - K_{roc}\, d(\Delta f(t))/dt$$

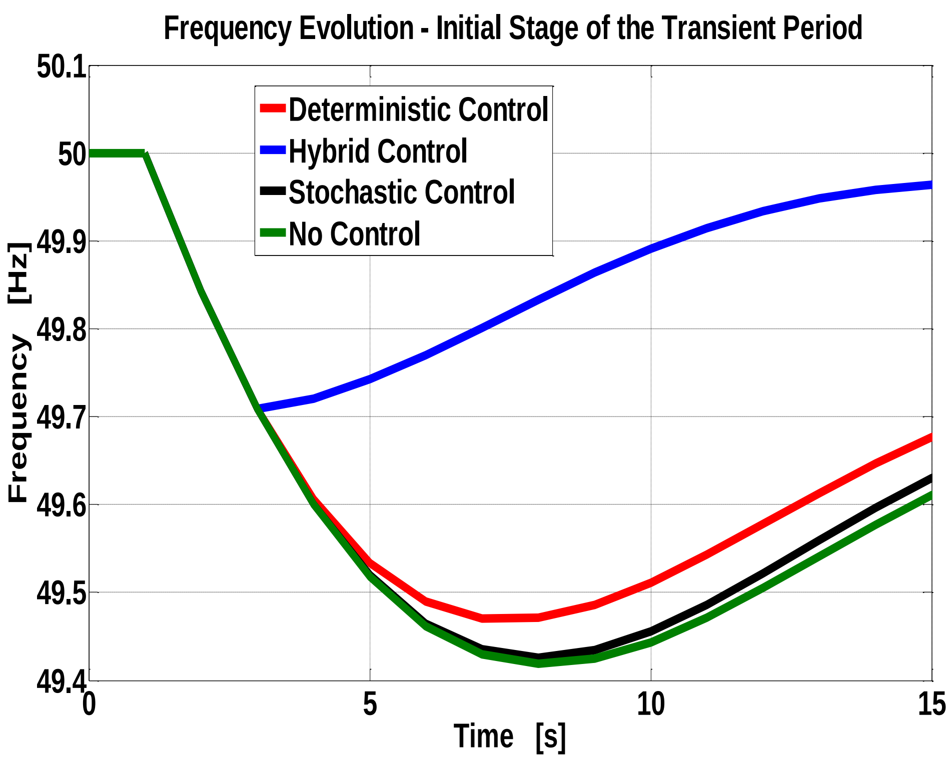
2. By increasing the threshold temperatures, the devices collectively spend more time in the off state, reducing their aggregate power consumption.

3. By monitoring the rate of change of frequency, the control enables a rapid response.

4. Moreover, a drastic reduction of the synchronization and a delayed payback is obtained due to the inclusion of a randomized disengagement strategy, which is triggered when:

$$t \geq t_r \text{ and } \Delta f(t) \leq \Delta f_{toll}$$

5. Each appliance selects a random temperature T_{rand} within the uniform distribution [T_{min}, T_{max}] and thus when the device in the on state reaches that temperature it automatically changes its status.

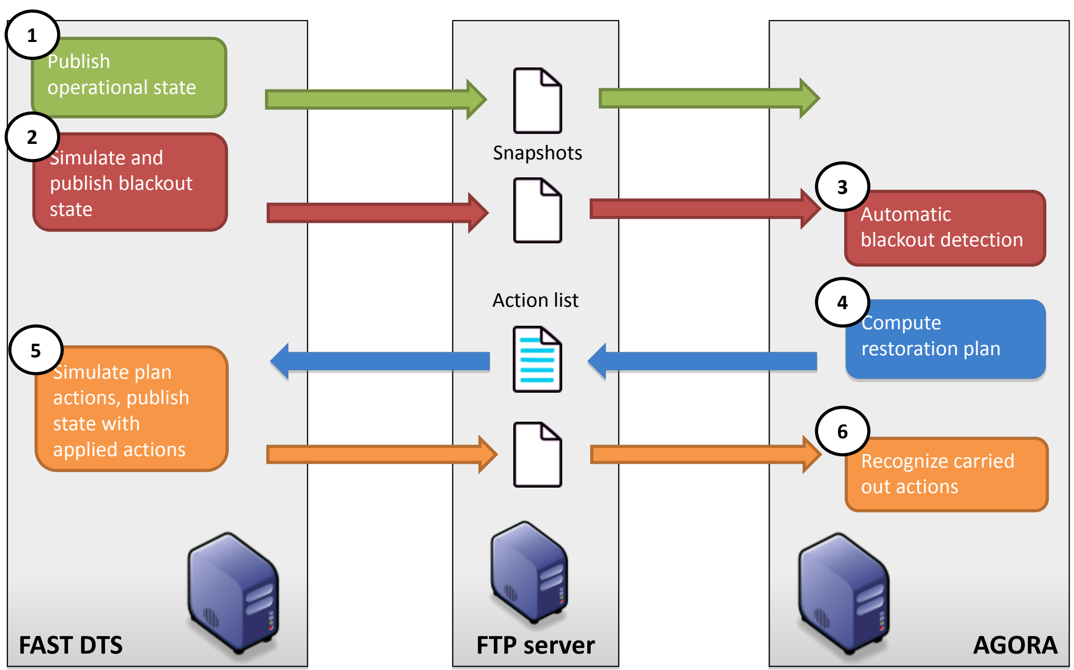


Use of renewables in restoration

- Both on-shore and offshore WF were modeled with the capability of participating in primary frequency control services, contributing to mainland primary frequency regulation
- HVDC connected offshore WF:
  - frequency changes in the mainland grid are proportionally converted into DC voltage changes, through a droop control approach implemented at the onshore HVDC station
  - these DC voltage changes are converted by the offshore HVDC station into frequency changes, exploiting another droop control approach
  - Regarding the provision of reactive power / voltage control, the HVDC-VSC is assumed to be capable to provide such functionality, behaving in a similar way to a STATCOM

Coordinated restoration

- Afternoon demo: HELM Software and simulation tools for restoration



Thank you

Questions?