2017-03-31 RAMS Seminar

Reliability of power systems of the future

Gerd Hovin Kjølle
Chief Scientist/Adjunct professor

SINTEF Energy Research/ NTNU, Department of Electric Power Engineering

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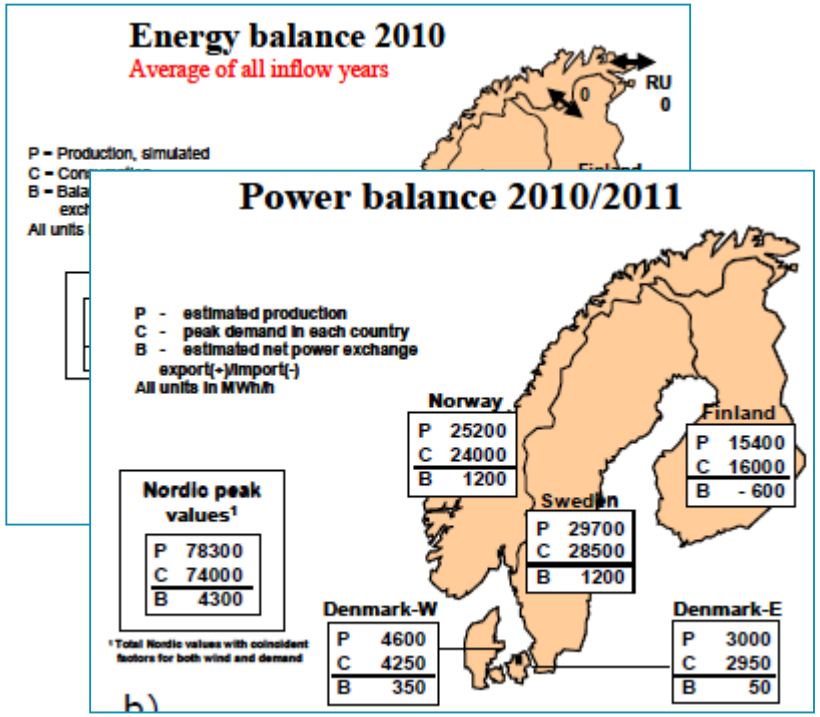
Outline

- Reliability of power systems - introduction
- Fields of expertise and areas of research interest
- Highlights from research, examples of projects, including the new centre for environment-friendly research CINELDI

Reliability is part of the Security of electricity of supply - SoS

- ”***Security of electricity supply*** *means the ability of an electricity system to supply final customers with electricity*” (EU Directive)

- Energy availability
- Power capacity
- Reliability



Power system failures

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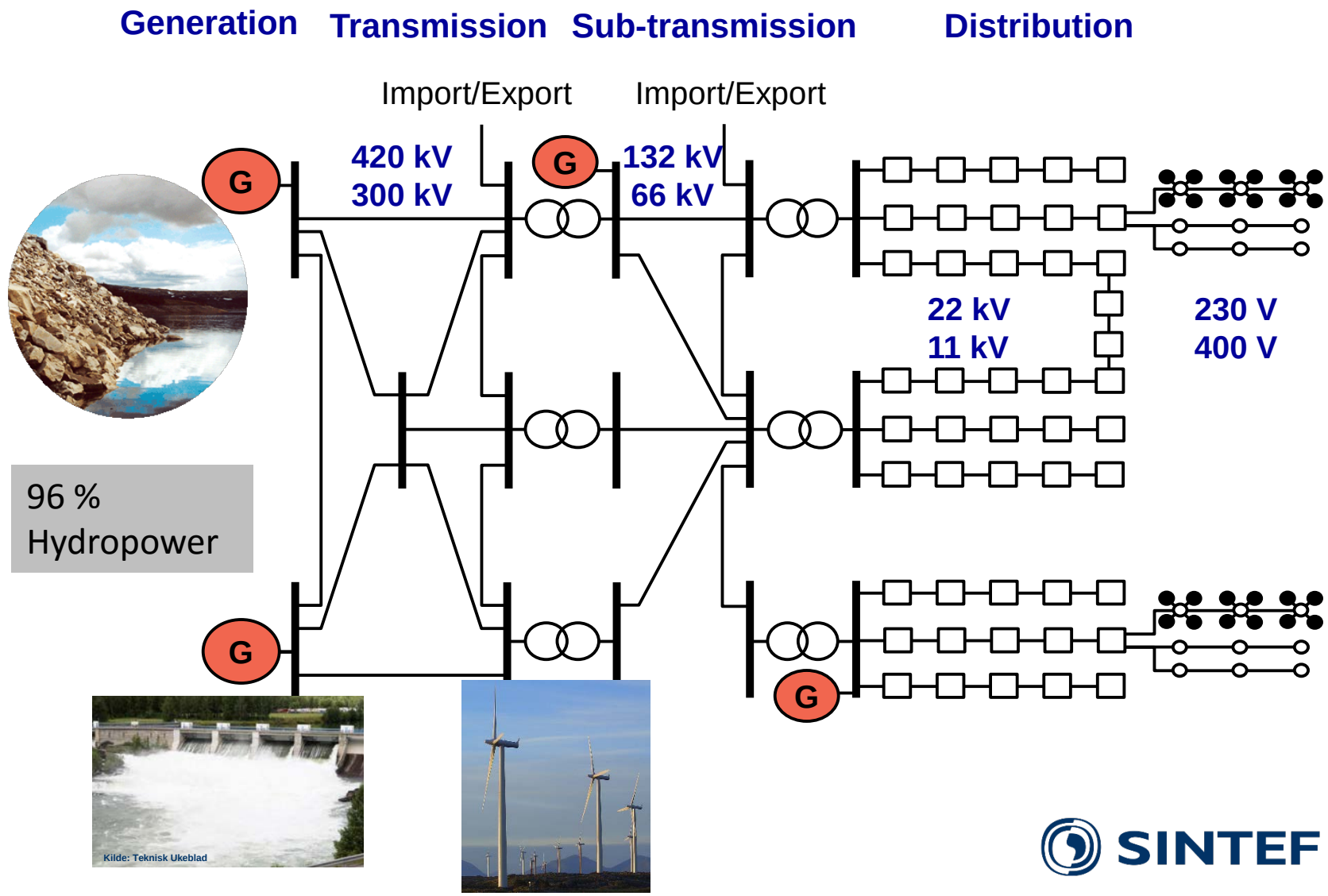
Electricity (power) system – Norway



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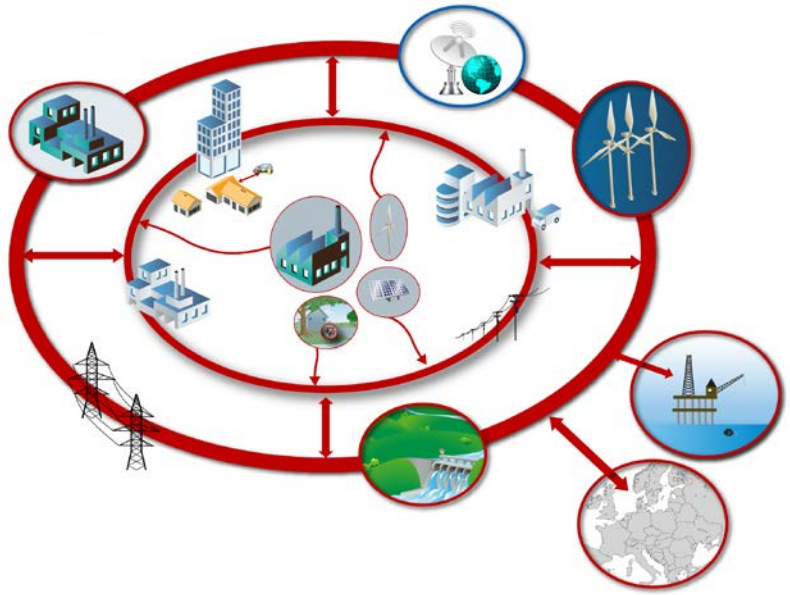
Fields of expertise

- Reliability analysis of power systems
- Fault and interruption statistics and reliability data modelling
- Interruption cost assessment
- Security of electricity supply, risk and vulnerability analysis of power systems
- Power system planning, life cycle costs, technical-economic optimization
- Smartgrids



Highlights of research through examples

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Highlights from research

- Reliability analysis of power systems
- Fault and interruption statistics, reliability data

- Security of electricity supply, risk and vulnerability analysis of power systems

- Security of supply considerations in the future power system - Smartgrids

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Reliability of power systems

- Power system adequacy

  is the ability of the system to supply the aggregate electric power and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of the system components

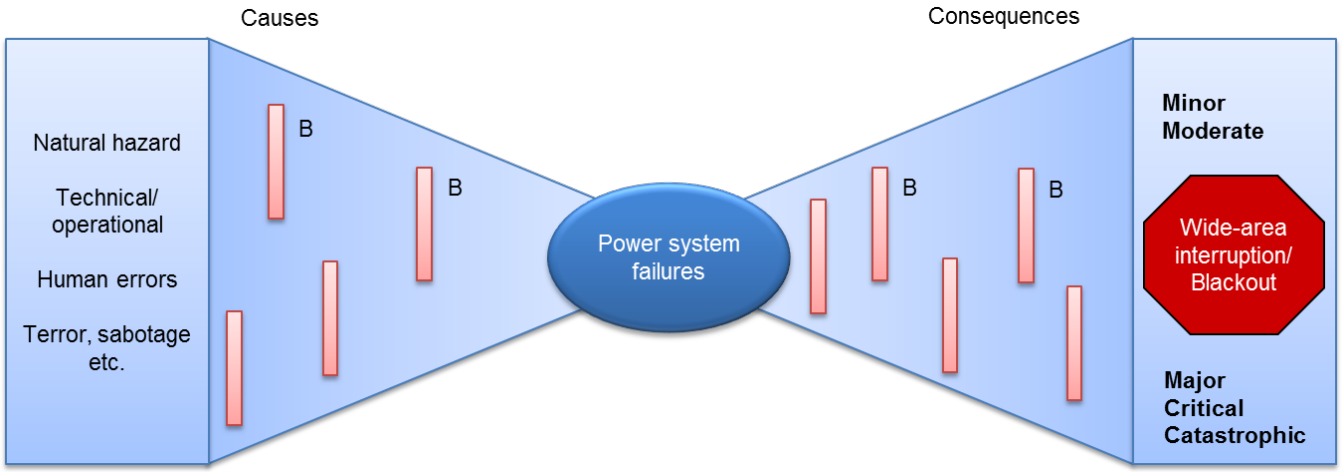
- Power system security

  is the ability of the power system to withstand sudden disturbances such as short circuits or un-anticipated loss of system components. Security refers to the degree of risk in its ability to survive imminent disturbances (contingencies) without the interruption of customer service

Power system reliability – the probability that an electric power system can perform a required function under given conditions for a given time interval (IEC)

Reliability analysis of power systems

1. What can go wrong?
2. How likely is it to happen?
3. What are the consequences?



Kjølle, G. H., Gjerde, O., Hofmann, M., Vulnerability and security in a changing power system. Executive summary. SINTEF Energy Research, 2013

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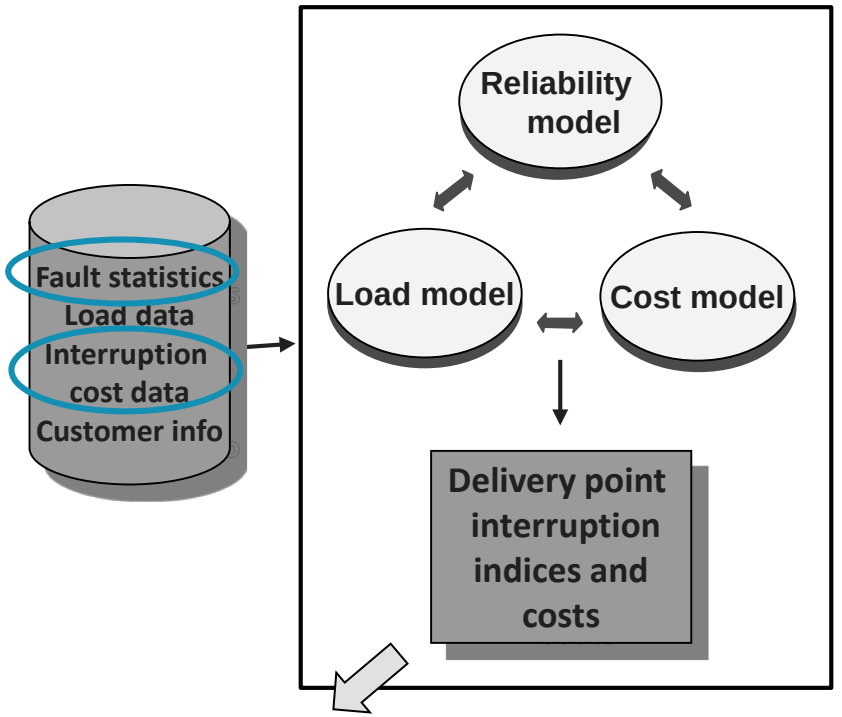
Reliability analysis of power systems

- Input data:
  - Electrical, topological data
  - Fault statistics
  - Load data
  - Customer data
- Results:
  - Reliability indices
    - Expected values
    - Probability distributions
- Methods/tools (SINTEF)
  - RELRAD (radial systems)
  - OPAL (meshed systems)



Index	Value and unit
Annual number of interruptions	λ [no./year]
Annual interruption duration	U [hours/year]
Average interruption duration	r [hours/interruption]
Annual interrupted power	Pinterr [MW/year]
Annual energy not supplied	ENS [MWh/year]
Annual interruption costs	IC [NOK/year]

Reliability of supply indices

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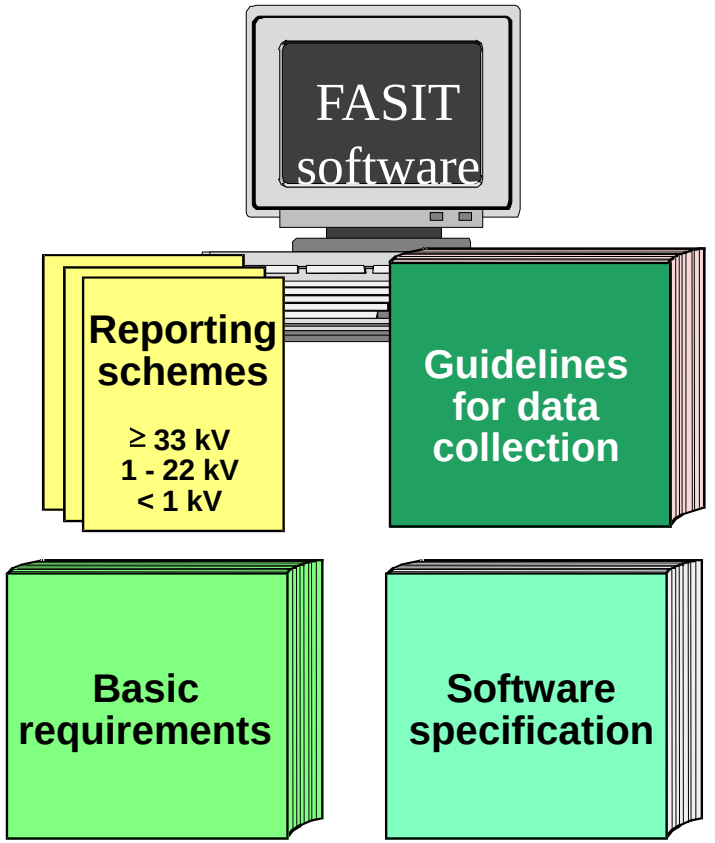
FASIT - Norwegian standard for collection, calculation and reporting of reliability data

- Developed by SINTEF Energy Research, introduced in 1995
- In use by all network companies in Norway (about 140)
- Based on international standards and terms
- 4 software vendors
- Software quality assurance (contracts and acceptance test)
- Fault and interruption statistics
- Next generation FASIT under development

www.fasit.no



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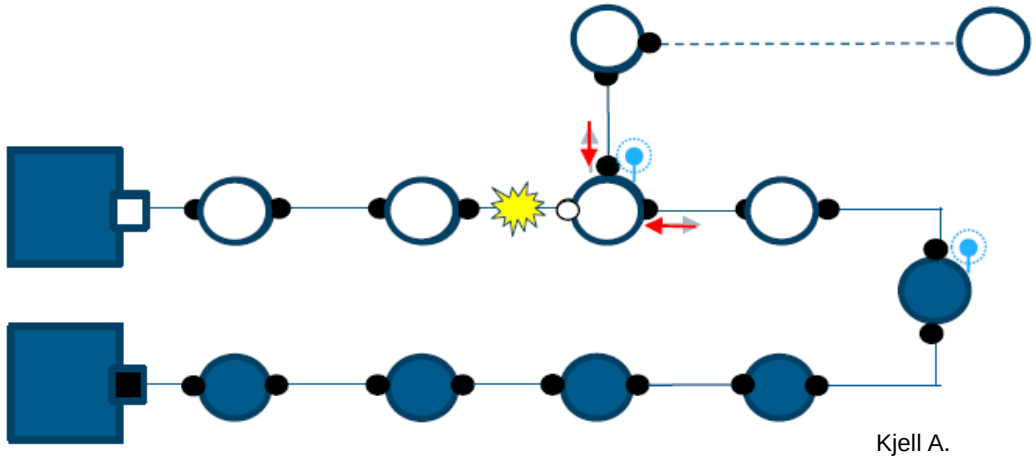
FASaD - Fault and interruption handling in smart distribution systems 2015-2017 (SINTEF)

- Fast fault location and restoration – using fault current sensors and remote controlled disconnectors
- Demo, including self-healing. Reliability and cost-benefit analysis



Kjell A. Tutvedt, Hafslund Nett

Generally Accepted Reliability Principle with Uncertainty modelling and through probabilistic Risk assessment

SEVENTH FRAMEWORK PROGRAMME

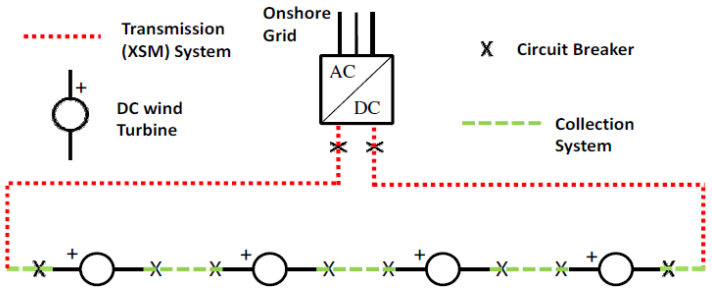
http://www.garpur-project.eu/

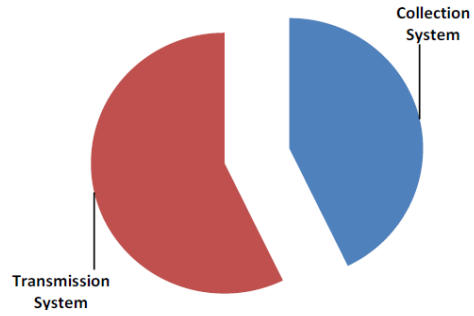
Purpose of GARPUR

- **Design and evaluate new power system reliability criteria**
  - Need for **probabilistic reliability criteria** to supplement and enhance the N-1 criterion
  - If successful, these criteria could be progressively implemented at the pan-European level, **optimally balancing reliability and costs**
  - Reliability criteria will be quantitatively evaluated in terms of their impact on social welfare: **Quantification Platform**

Reliability assessment of DC Wind farms – part of PhD study at Michigan Technological University (MTU)

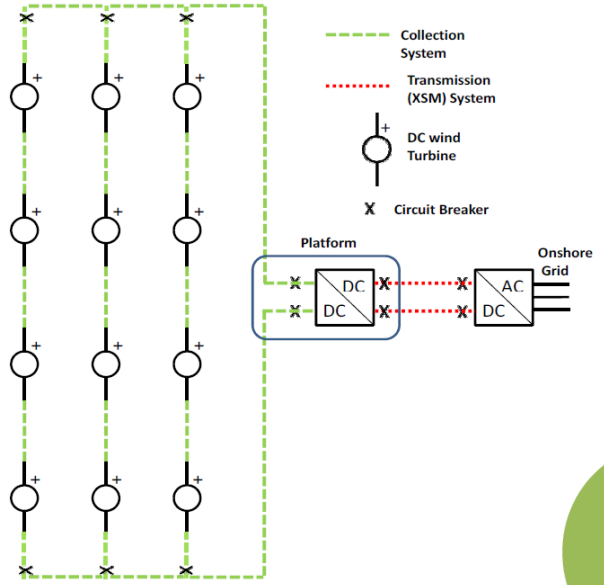
DC Series/Daisy Chain connection

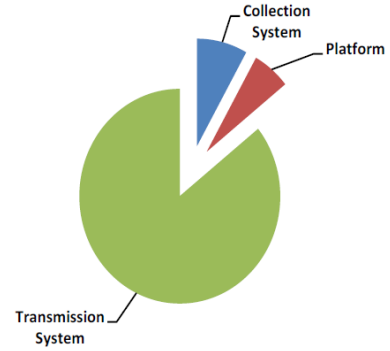




Component Contributions to EENS for DC Series farms

DC Series - Parallel design





Component Contributions to EENS for DC Series-Parallel farms

Reliability analysis using RELRAD methodology

Bahirat, H., Kjølle, G. H., Mork, B. A., Høidalen, H. K.: Reliability Assessment of DC Wind Farms, IEEE PES GM 2012, San Diego, 22-26 July 2012

Himanshu Bahirat, Collection System Design for DC Series Wind Farms, PhD, MTU 2013

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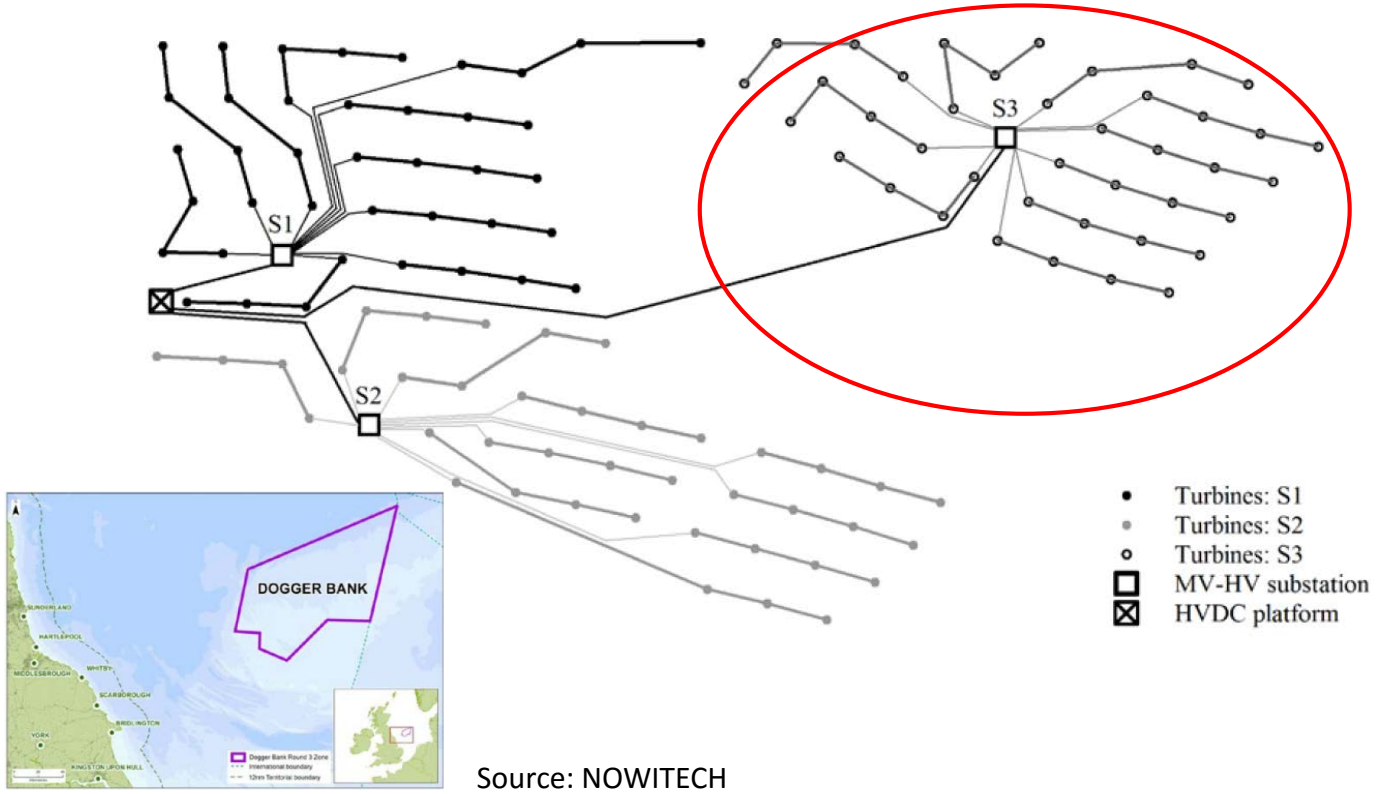
Reliability assessment offshore wind grids

Dogger Bank Reference Wind Farm (DRW) – optimal redundancy study – master projects NTNU



Source: NOWITECH

Reliability analysis using
1) DIgSILENT Power Factory
2) RELRAD

Kari Vingdal, Optimal redundancy in the NOWITECH reference wind farm, Specialization project NTNU 2014, Master thesis 2015

Vigdis A. Gustavsen: Optimum Configuration of the Dogger Bank Reference Wind Farm Grid with Consideration for Reliability, Master thesis 2016

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Highlights from research

- Reliability analysis of power systems
- Fault and interruption statistics

- Security of electricity supply, risk and vulnerability analysis of power systems

- Security of supply considerations in the future power system - Smartgrids

Two Nordic projects

- Vulnerability of the Nordic Power System, 2004, Nordic Council of Ministers
  - SINTEF Energy Research, Technical report A5962

- NordSecurEl – Risk and vulnerability assessments for contingency planning and training in the Nordic electricity system, 2009, EU/EPCIP
  - Nordic energy authorities, Nordic TSOs, 4C Strategies, SINTEF Energy Research

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Vulnerability and security in a changing power system 2009-2013 (SINTEF)

- Indicators and methods to monitor and classify vulnerabilities in electric power grids
- Methods and tools for power system risk and vulnerability analysis
- Duration 2009 - 2013
- Budget: 16,6 mill. NOK ≈ 2 mill. Euro

http://www.sintef.no/Projectweb/Vulnerability-and-security/

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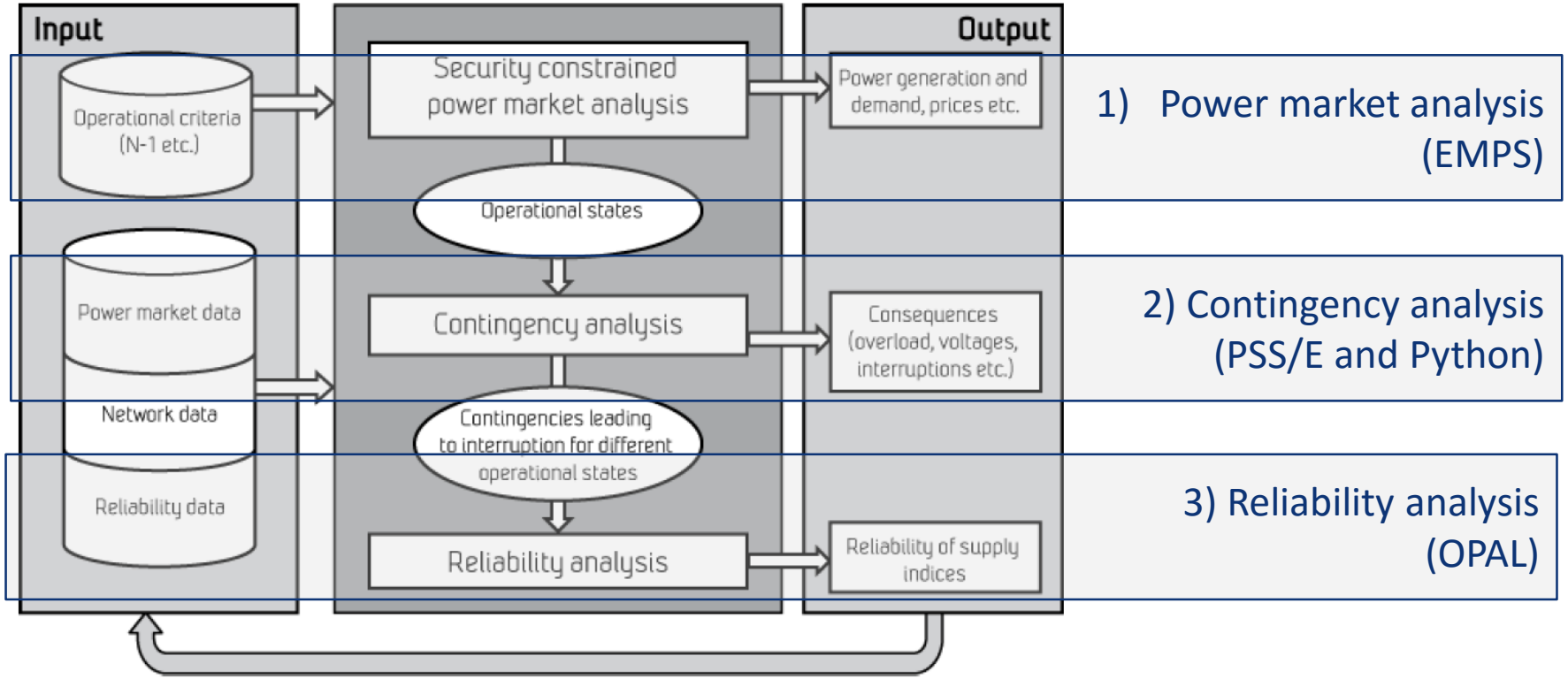
Integration of market models and reliability analysis (SAMREL) 2010-2014 (SINTEF)



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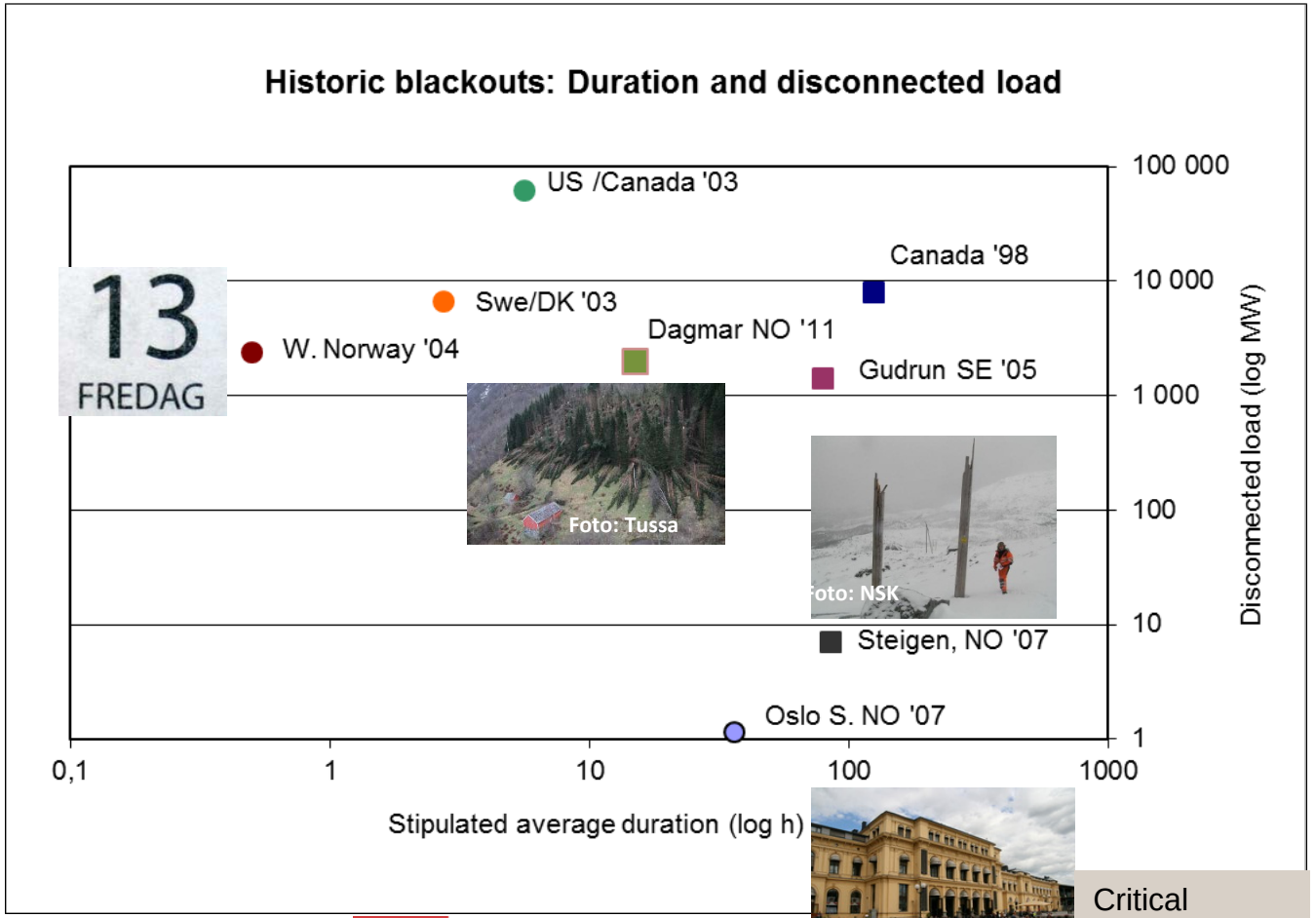
Analysis of extraordinary events

HILP – project 2016-2019 (SINTEF)



Critical infrastructures

The Research Council of Norway · Statnett · FINGRID · NVE · NTNU Det skapende universitet · SINTEF · NTNU

Highlights from research

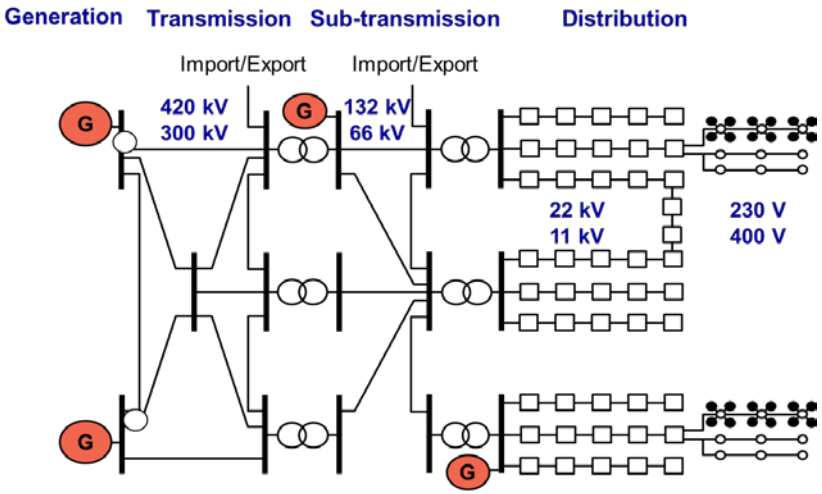
- Reliability analysis of power systems
- Fault and interruption statistics

- Security of electricity supply, risk and vulnerability analysis of power systems

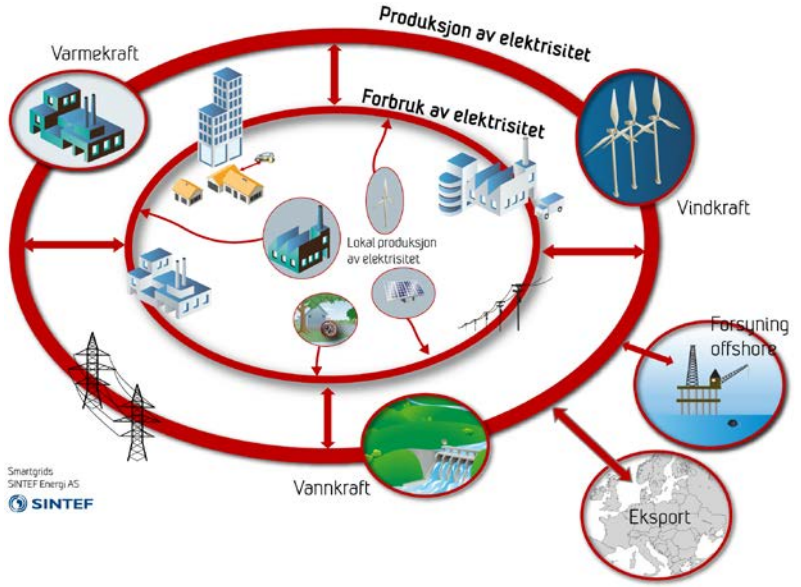
- Reliability and security of supply considerations in the future power system - Smartgrids

Smart grids – a vision for the future

Today's unidirectional electricity system:
Large scale generation → Transmission
→ Distribution → End users



Future sustainable electricity system:
Smarter, multidirectional and integrated



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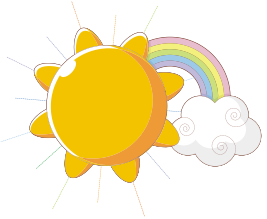
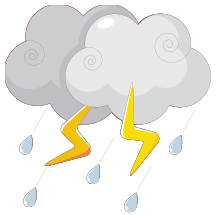
Security of supply and what can be expected for the future?

- The power system of the future – Smartgrids
  - Increasing shares of renewables (variable, intermittent)
  - New components, new loads, new operation
  - Increasing ICT dependency in the power system



- New types of threats
  - Increasing climate related stress
    (in Norway: ”wetter, warmer and wilder”)
  - Cyber attacks
  - Increasing operational stress

Increased uncertainty



First known hacker-caused power outage signals troubling escalation

Highly destructive malware creates "destructive events" at 3 Ukrainian substations.

- Society's electricity dependency increasing

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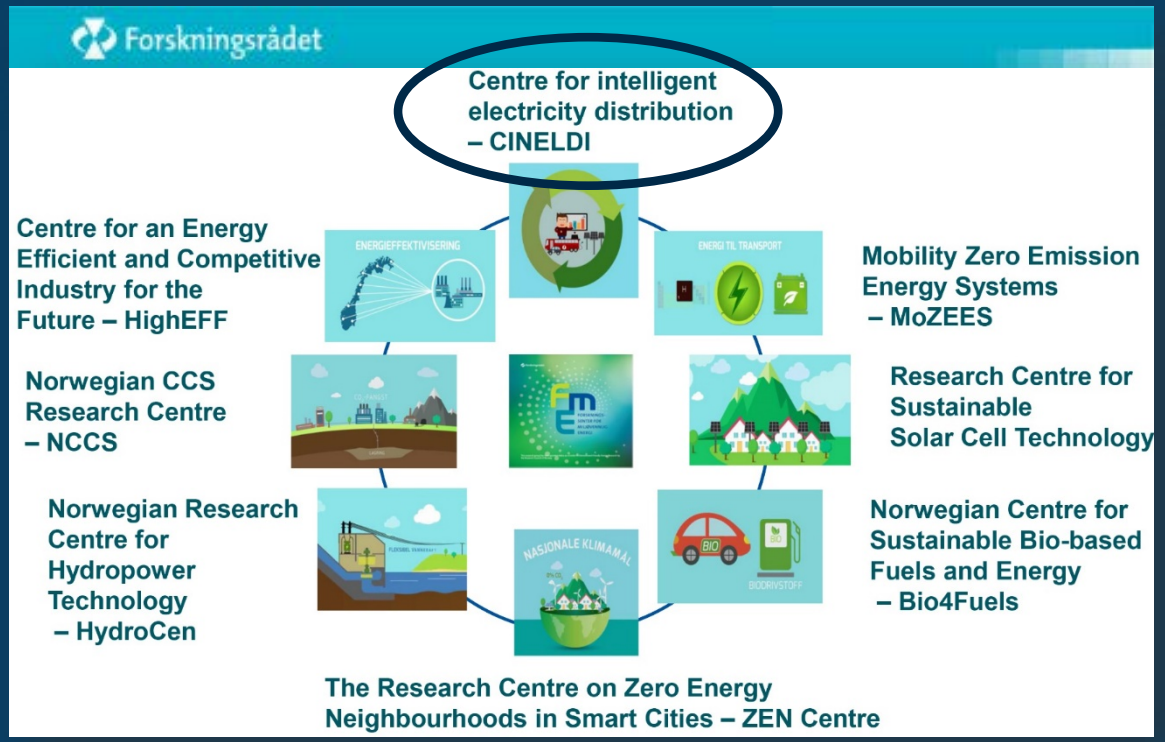
CINELDI is one of the Centres for Environment-friendly Energy Research in Norway (FME)



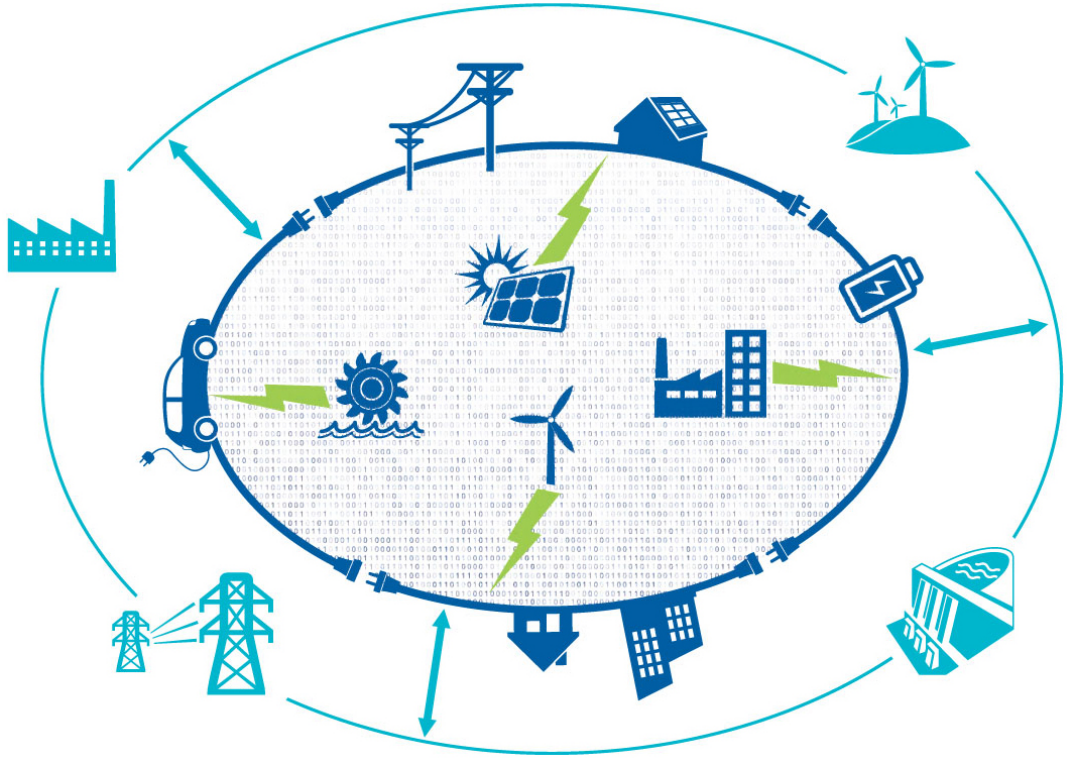
Source: Research Council of Norway

Centres for Environment-friendly Energy Research (FME)

- The scheme is the most prominent tool for long term energy research in Norway.
- The research activity is carried out in close cooperation between prominent research communities and users.
- The main objective of the Centres for Environment-friendly Energy Research is:
  - to conduct concentrated, focused research of high international calibre in order to solve specific challenges in the energy sector in Norway, and
  - to promote innovations and industrial development.
- Typical budgets: 300 – 400 mill NOK (30 – 40 mill €) over eight years with 50 % funding from the Research Council of Norway

CINELDI

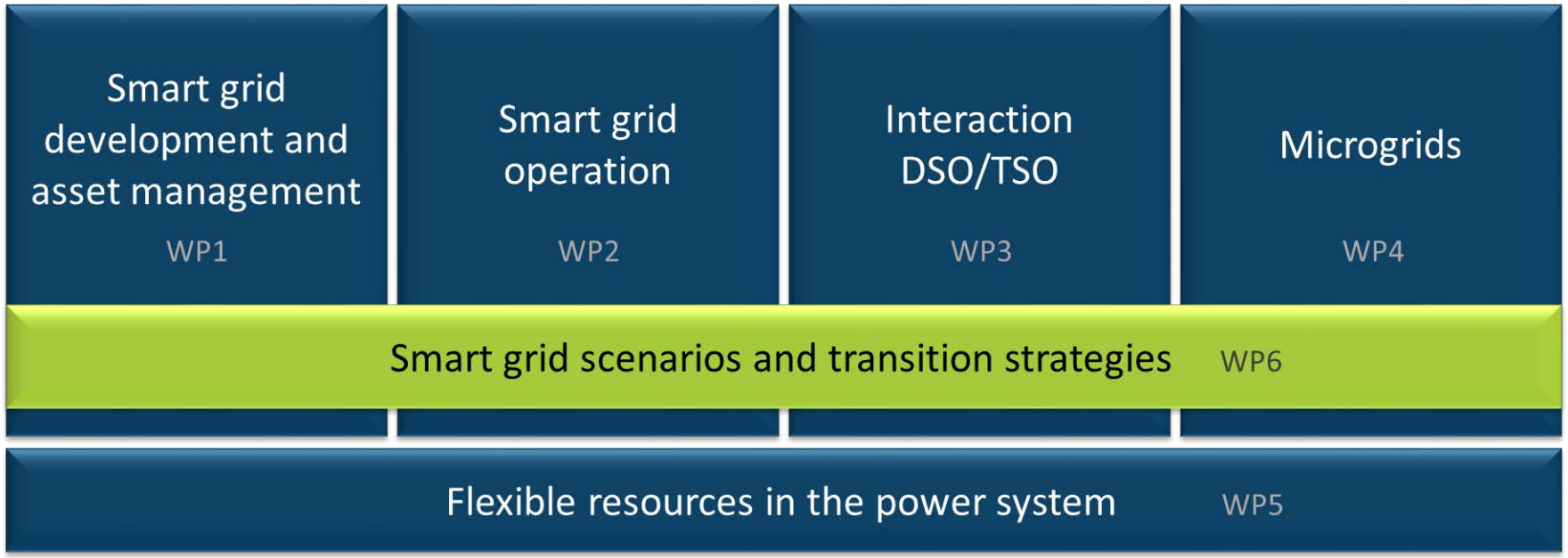
CINELDI will ensure that we are building the smart energy system of the future



CINELDI Objective

- To enable a cost-efficient realisation of the future flexible and robust electricity distribution grid
- This will pave the ground for increased distributed generation from renewable resources, electrification of transport, and more efficient energy use

CINELDI Work packages



Security of electricity supply is a cross-cutting issue

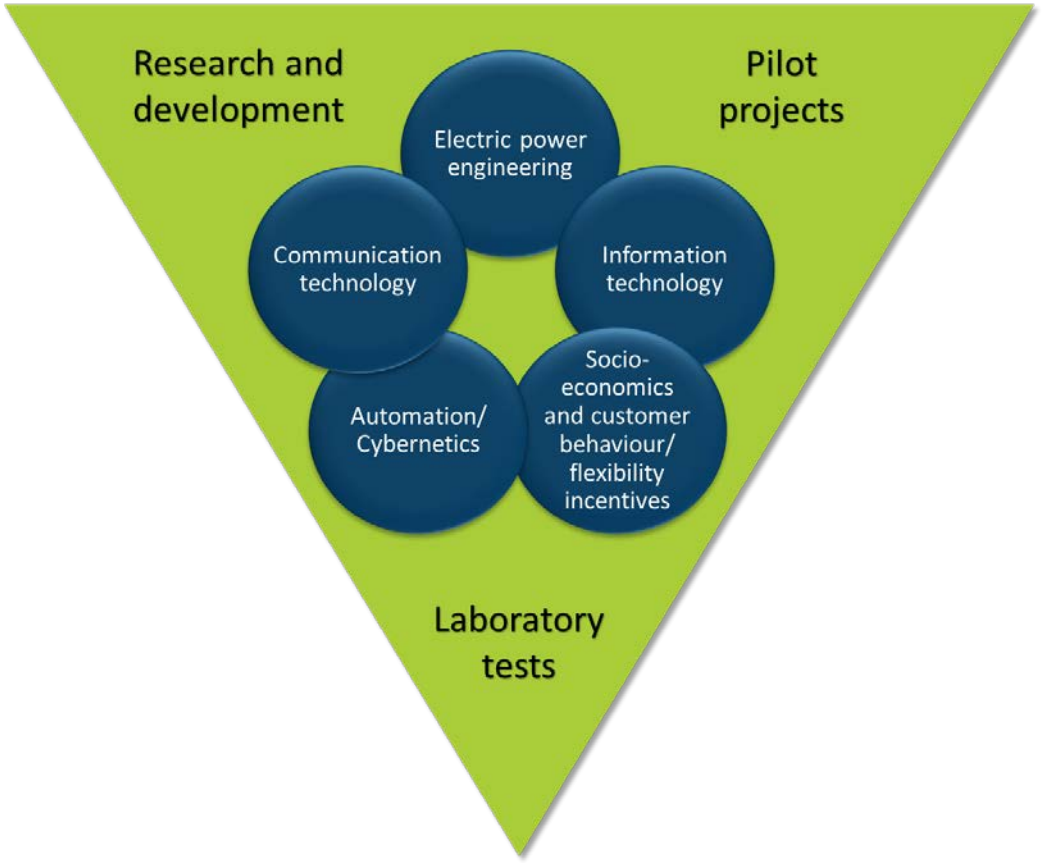
CINELDI in figures

- Budget: 360 MNOK (40 M€)
- Duration: 8 years (2016 – 2024)
- 29 partners
- Host institution/project responsible: SINTEF Energy Research
- www.cineldi.no

National partners

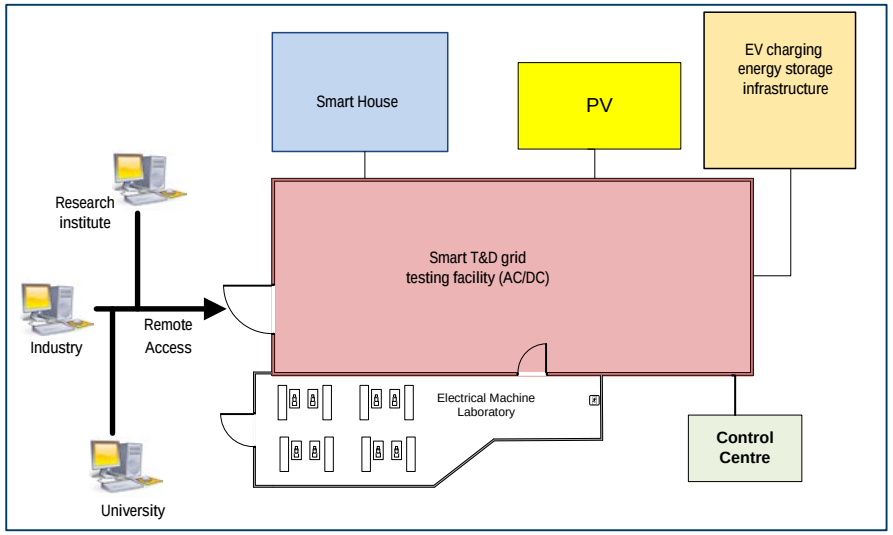
CINELDI

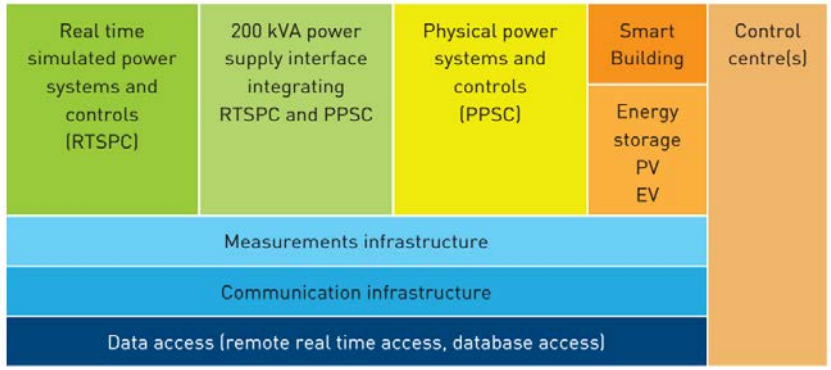
Multidisciplinary research



CINELDI targets system innovation

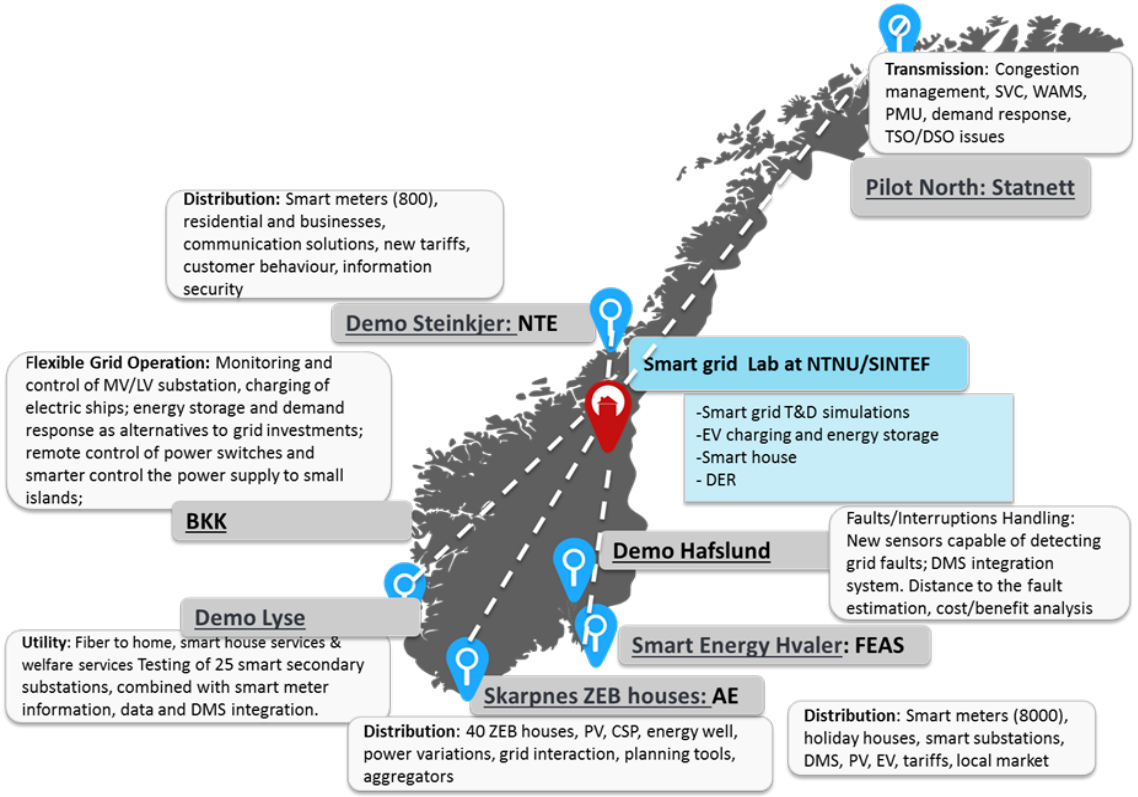
The Norwegian Smart Grid Laboratory - an important asset in CINELDI





https://www.ntnu.edu/smartgrid

…as well as smart grid pilot projects and living labs



www.smartgrids.no

Recent and ongoing research projects (SINTEF)

- Centre for intelligent electricity distribution (CINELDI) (2016-2024) – FME, Nfr, SINTEF/NTNU, 29 partners
- Analysis of **extraordinary events** in power systems (HILP) (2016-2019), Nfr, SINTEF
- **Fault and interruption handling** in smart distribution systems (2015-2017), Nfr, Hafslund Nett
- Generally Accepted Reliability Principle with Uncertainty modelling and through **probabilistic Risk assessment** (GARPUR) (2013-2017) EU 7FP ENERGY
- Next Generation **FASIT** (2014-2016), Energy Norway, Statnett, network companies
- Estimation of **costs of electricity interruptions** in Sweden (2014), Energimarknadsinspektionen
- Integration of methods and tools for **security of electricity supply analysis** (SAMREL) (2010-2014), Nfr, SINTEF
- A Framework for electrical power sysTem vulnerability identification, dEfense and Restoration (**AFTER**) (2011-2014) EU 7FP SECURITY
- **Vulnerability** and security in a changing power system (2009-2013), Nfr, SINTEF
- Optimal infrastructure for seamless **integration of distributed generation** (2009-2013), Nfr, SINTEF
- Socio-economic **costs of interruptions**, voltage disturbances… (2009-2012), Nfr, Energy Norway, NVE, Statoil, Statnett, Norsk Hydro, BKK Nett
- Study on estimation of **costs due to electricity interruptions** and voltage disturbances (2010), Council of European Energy Regulators (CEER)
- Risk based **distribution system asset management** (RiskDSAM) (2006-2010), Nfr, SINTEF
- NordSecurEl – **Risk and vulnerability assessments** for contingency planning and training in the Nordic electricity system, 2009, EU/EPCIP
- Risk and Decision Systems for **Critical Infrastructures** (DECRIS) (2007-2009), Nfr, SINTEF
- **Critical infrastructures**, public sector reorganization and societal safety (CISS) (2007-2009), Nfr, NTNU Samf. Forskn.
- Sustainable energy distribution systems: **Planning methods** and models (2003-2007), Nfr, SINTEF
- GRID – A coordination action on **ICT vulnerabilities** of power systems and the relevant defence methodologies (2006-2007), EU FP6 IST Programme
- **Vulnerability** of the Nordic Power System, 2004, Nordic Council of Ministers

Contact information

Gerd Hovin Kjølle

Chief Scientist/ Professor II

Centre Director CINELDI
SINTEF Energy Research/ NTNU
P. Box 4761 Sluppen, NO-7465 Trondheim, Norway
Mobile phone: +4790672035
email: gerd.kjolle@sintef.no
http://www.sintef.no/energy

http://www.ntnu.edu/employees/gkj

Responsible for the PhD course ET8207 Power system reliability

ROSS Gemini centre, www.ntnu.edu/ross

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