Smart and Flexible Energy Systems

«Controlling the grid»

Challenges in power system operation

Prof. Kjetil Uhlen

Electric Power Engineering

NTNU

Source: Statnett

Outline

- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

Outline

- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

INSTITUTT FOR ELKRAFTTEKNIKK

Mon Jan 22 2018

16:01:19

Administrasjon


Midtgård, Ole-Morten
Instituttleder
E417


Vadlamudi, Vijay Venu
Nestleder
F365


Wold, Bodil
Kontorsjef
F465


Meistad, Åshild U.
Førstekonsulent
E352


Berg, Silje
Førstekonsulent
E351


Lien, Siri Wæhre
Førstekonsulent
E357


Christensen, Fredrik
Energikontakten / Rådgiver
E351


Aastebøl, Halsten
Studieveileder
E355

Elkraftteknologi (ET)


Høidalen, Hans Kristian
Professor / Faggruppeleder
F411


Ildstad, Erling
Professor
F468


Nilsen, Roy
Professor
E455


Nilssen, Robert
Professor
E418


Nysveen, Arne
Professor
F412


Niayesh, Kaveh
Professor
F465


Undeland, Tore
Professor Emeritus
E323


Hansen, Eilif Hugo
Førsteamanuensis
E317


Mauseth, Frank
Førsteamanuensis
F467


Peftitsis, Dimosthenis
Førsteamanuensis
E464


Glimen, Pål
Førstelektor
Kalvskinnet


Olsen, Pål Keim
Universitetslektor
Kalvskinnet


Furuhaug, Ola
Høgskolelærer
Kavlskinnet


Solvang, Eivind
Førsteam. II
SINTEF 223

Kraftsystemer (KS)


Uhlen, Kjetil
Professor / Faggruppeleder
F364


Norum, Lars
Professor
E467


Fosso, Olav Bjarte
Professor
E318


Korpås, Magnus
Professor
E463


Tedeschi, Elisabetta
Professor
F363


Toftevaag, Trond
Dosent
F366


Vadlamudi, Vijay Venu
Førsteamanuensis
F365


Farahmand, Hossein
Førsteamanuensis
E465


Norheim, Ian
Førsteamanuensis
Gjøvik


Folkestad, Tor Arne
Universitetslektor
Gjøvik


Kjølle, Gerd Hovin
Professor II
SINTEF 221


Sand, Kjell
Professor II
F353


Doorman, Gerard
Professor II
F361


Anaya Lara, Olimpo
Professor II
E328


Lindberg, Karen Byskov
Førsteam. II


Haugan, Thomas S.
Forsker

Teknisk stab


Aastebøl, Halsten
Leder teknisk stab / Senioring.
E355


Klubicka, Vladimir
Overingeniør
E361

Salmi, Kurt
Overingeniør
E367

Wiggen, John Arild
Overingeniør
Kalvskinnet

Gytri, Anders
Amanuensis
E365

Flå, Morten
Avd.ing.
F0052

Almås, Bård
Avd.ing.
E363

Norum, Svein Erling
Avd.ing.
E361

Hanssen, Aksel A. Reitan
Avd.ing.
E360

Häger, Dominik
Ingeniør
F0052

PhD-studenter og forskere v/ET

Abid, Fahim
PhD student
F463

Engevik, Erlend L.
PhD student
E425

Giannakis, Andreas
PhD student

Grebla, Maciej
PhD student
F414

Göthner, Fredrik T. B. W
PhD student
E420

Håkonseth, Gunnar
PhD student
F455

Jabs, Philipp
PhD student

Kantar, Emre
PhD student
F464

Meyer, Hans Kristian H.
PhD student
F463

Pandakov, Konstantin
PhD student
F461

Ranaweera, Iromi U.
PhD student
E420

Spro, Ole Christian
PhD student
E455

Taxt, Henning
PhD student
F464

Tiwari, Raghbendra
PhD student

Tiwari, Subhadra
PhD student
E455

Wang, Wei
PhD student
E420

Aakre, Torstein Grav
PhD student
F455

Chen, Anyuan
Post doc
E421

Valavi, Mostafa
Post doc
E419

PhD-studenter og forskere v/KS

Völler, Steve
Forsker

Acharya, Anirudh Budnar
PhD student
E453

Bødal, Espen Flo
PhD student
E427

Elahidoost, Atousa
PhD student
F352

Graabak, Ingeborg
PhD student
SINTEF 456

Haugdal, Hallvar
PhD student
E451

Hjelmeland, Martin N.
PhD student
F352

Håberg, Martin
PhD student
E427

Jakobsen, Sigurd Hofsmo
PhD student
F367

Kiel, Erlend Sandø
PhD student
E327

Kristiansen, Martin
PhD student
F352

Löschenbrand, Markus
PhD student
E425

Naversen, Christian Ø.
PhD student

Nejati Fard, Razieh
PhD student
F352

Pinel, Dimitri
PhD student
E451

Reigstad, Tor Inge
PhD student

Taffese, Abel Assegid
PhD student
F368

Zaferanlouei, Salman
PhD student
E423

Aghaei, Jamshid
Post doc

Bergna-Diaz, Gilbert
Post doc
F351

Cheng, Xiaomei
Post doc
E423

Duong, Dinh Thuc
Post doc
F355

Ghadikolaei, Jalal K.
Post doc

Lakshmanan, Venkatachalam
Post doc
E461

Sanchez A., Santiago
Post doc

Bjarghov, Sigurd
Vitenskapelig assistent

Department of Electric Power Engineering

(One of 8 institutes at the Faculty of Information Technology and Electrical Engineering, IE)

Permanent staff

- 22 academic staff (11 profs., 6 assoc.profs., 5 lecturers)
- 10 technicians (laboratories og workshops)
- 6 in admin.

Temporary staff

- 8 adjunct profs. (part time positions)
- 2 teaching assistants (full time)
- Approx. 8 postdocs and researchers
- Approx. 30 PhD candidates

Department of Electric Power Engineering

Students:

- Approx. 80 master degrees per year
  - 60 from 5 year «Energy and Environment» master programme, spesializing in electric power
  - 20 from 2 year international master degree programmes within Electric Power Engineering.

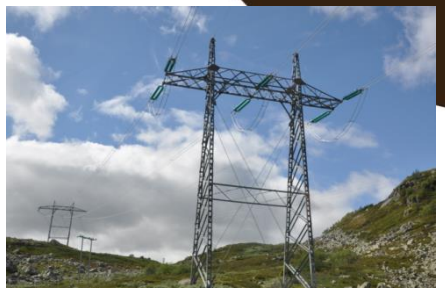
- Approx. 60-70 bachelor candidates per year

- Approx. 6-8 PhD’s per year

Electric power engineering in 2 main sectors

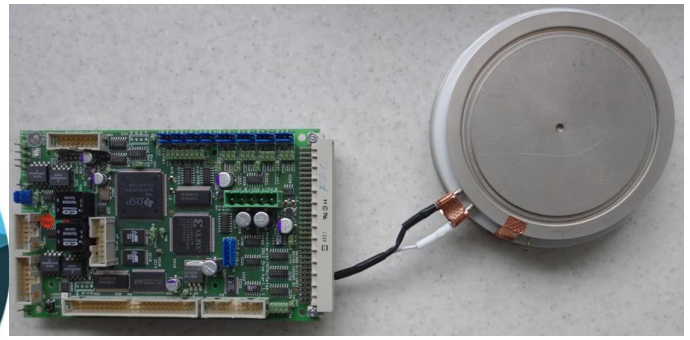
The electricity supply system

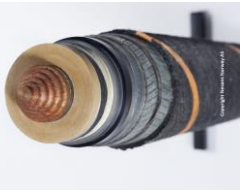
(Power Systems Research Group)



Electrotechnical industry

(Power Technology Research Group)





Power Technology

- High voltage equipment
- Insulation materials and cables
- High current interruption
- Electrical installations

Power Systems

- Power system modelling and analysis (operational security, stability, planning)
- Wide area monitoring & control
- Power markets and mathematical optimization
- HVDC power grids and marine power systems

Energy conversion

- Power electronics
- Electrical machines
- Digital control and electric motor drives

New: Digital electric power

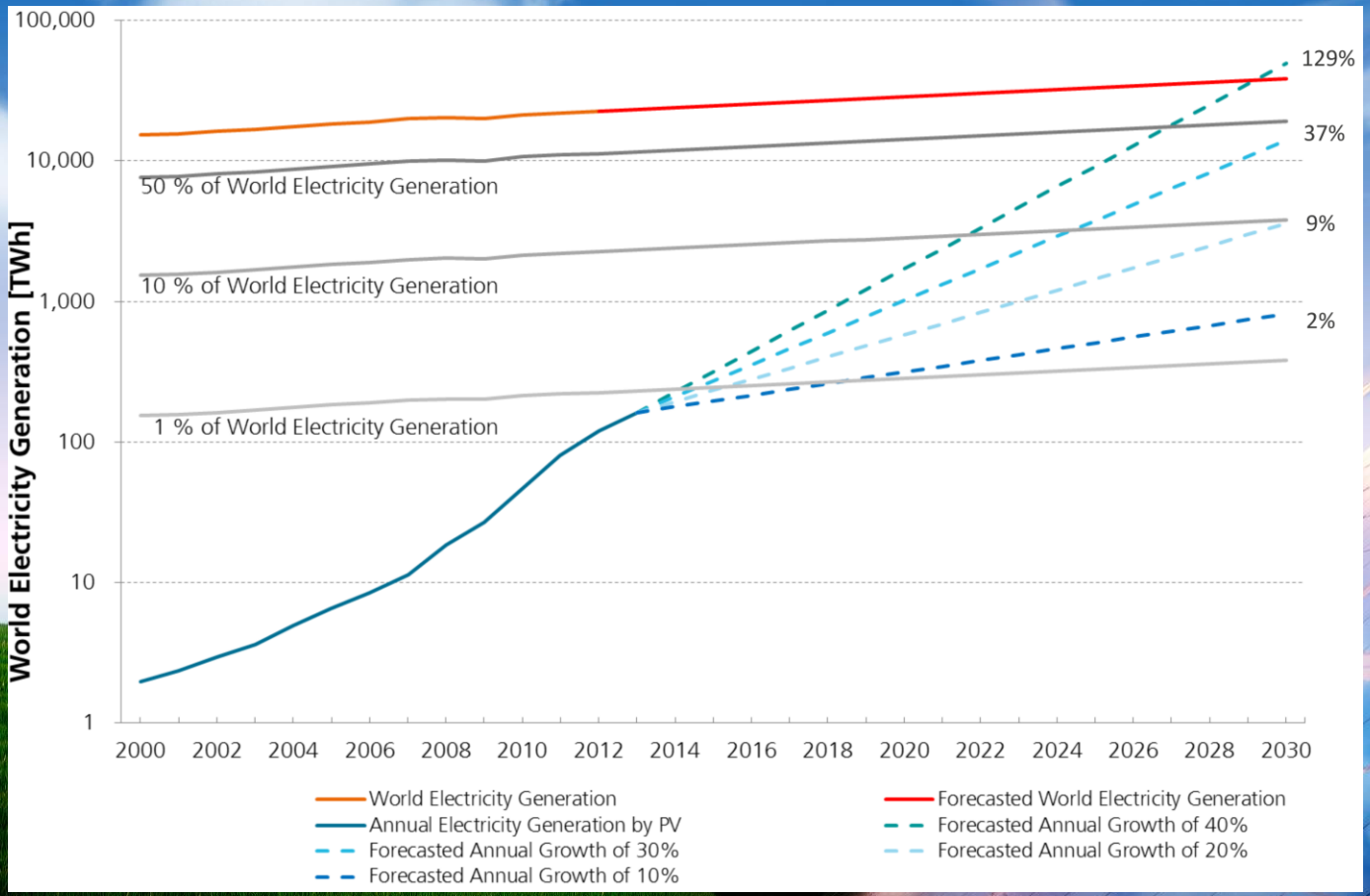
- The new digital energy landscape: smart grid, microgrids, merger of ICT and power
- New renewables (solar, wind)
- New business models and blockchain
- …

Outline

- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

The green shift…

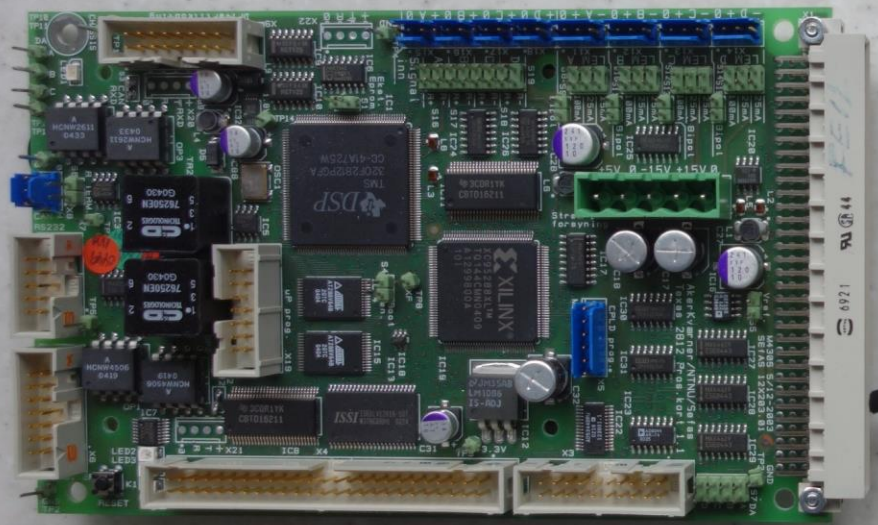
Solar takeover – Vision or reality?

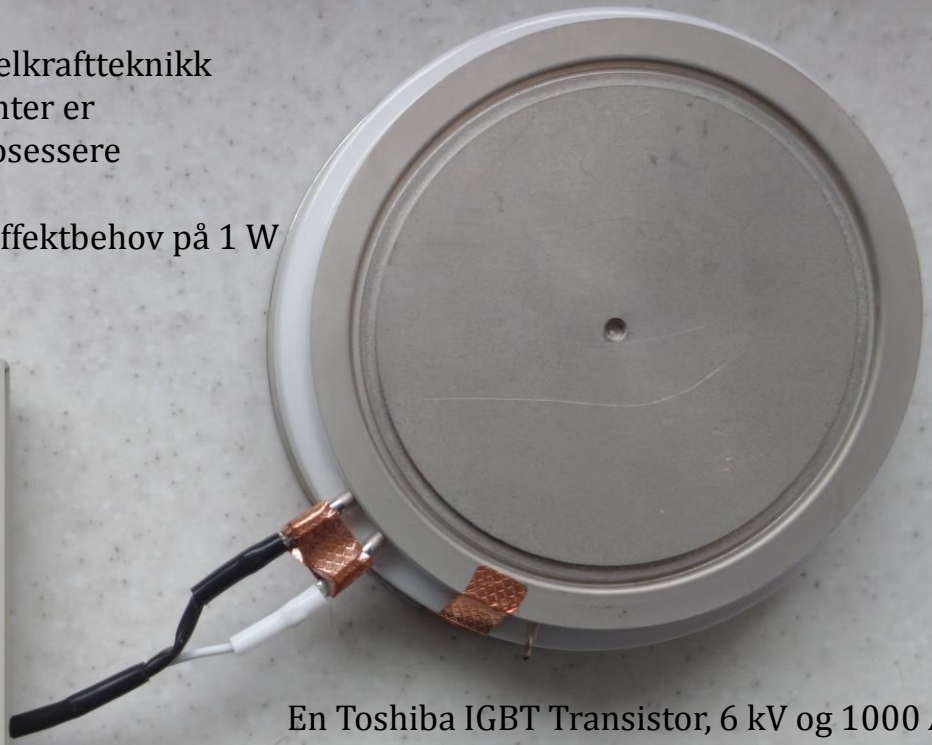


Electrification of transport

From digital electric power components to…

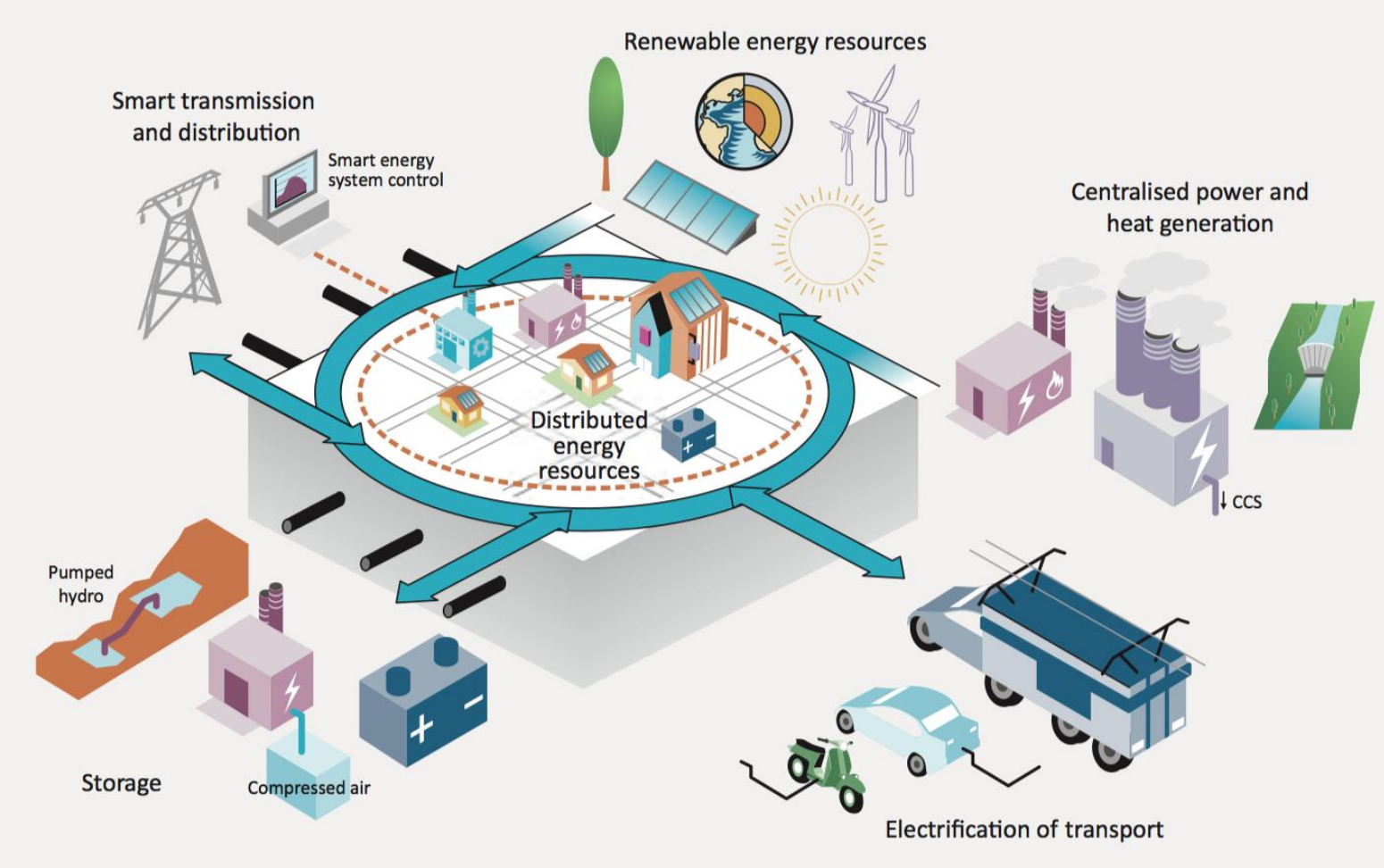
En integert prosessdatamaskin utviklet av Institutt for elkraftteknikk i samarbeid med SINTEF Energi. De store brikkene i senter er en digital signal prosessor DSP, og en FPGA som kan prosessere data så hurtig som det kreves av kraftelektronikken.
DSP har integrert millioner av transistorer, med totalt effektbehov på 1 W

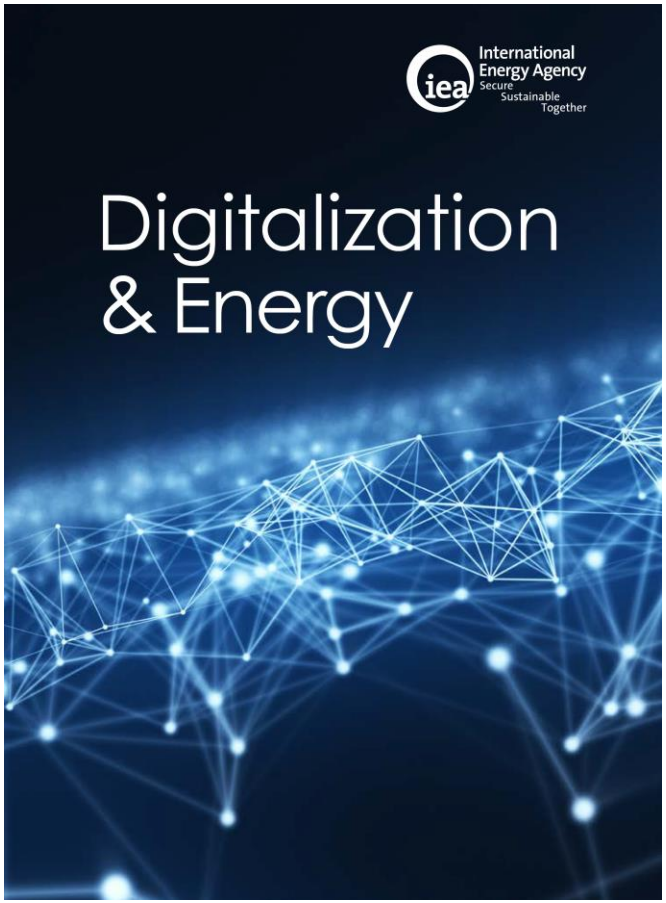




En Toshiba IGBT Transistor, 6 kV og 1000 A
6 slike kan styre en 10 MW motor for Dynamisk posisjonering av offshore skip, vindturbiner, elektriske ferger osv

… Smart Grid – the new, digital energy landscape





– Det grønne skiftet er umulig uten NTNU

Electric power…

Norge skal bli et lavutslippssamfunn, men ikke et lavinntektssamfunn. Derfor vil miljøministeren tjene penger på grønn teknologi.

Sjefen intervjuer statsråden: Miljøvernminister Vidar Helgesen forteller at forskning og høyere utdanning er viktig når han blir intervjuet av NTNU-rektor Gunnar Bovim. FOTO: VEGARD EGGEN, ADRESSEAVISEN

Outline

- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

Smart Grids vision

Grafik: M. SANCHEZ, 2006, Kilde: European Technology Platform SmartGrids

CINELDI

Various definitions of Smart Grid depending on perspective:

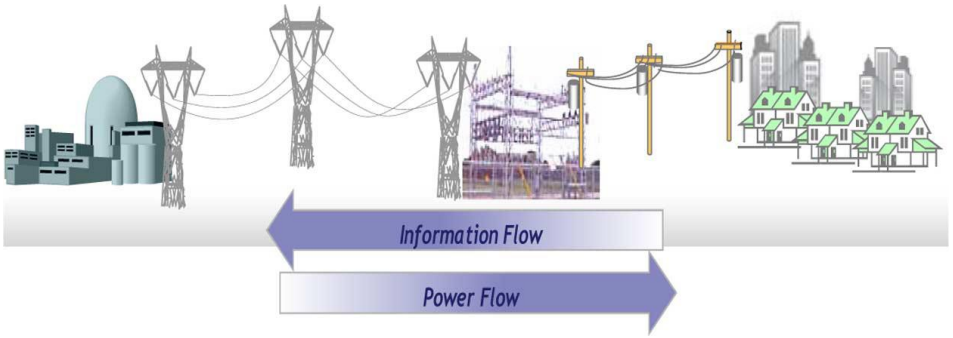
- From electric power engineering, perhaps: A flexible electricity grid where new applications* can be integrated «plug and play» with existing infrastructure.

*Applications are e.g. integration of renewable, stochastic and distributed sources of electricity, small and large; electric energy storage; demand side management; control of active and reactive power; integration of electric vehicles; monitoring and control of the flow of electric energy to ensure stability and reliability of the grid.

- From ICT, perhaps: An electricity grid where all components have an IP-address and can communicate two-way with one another, a part of «Internet of things».
- From economy, perhaps: An electricity grid which secures a free, transparent market for electricity to optimize the use of the society's total resources.
- From social science, perhaps: A means to realize a vision of a sustainable future.

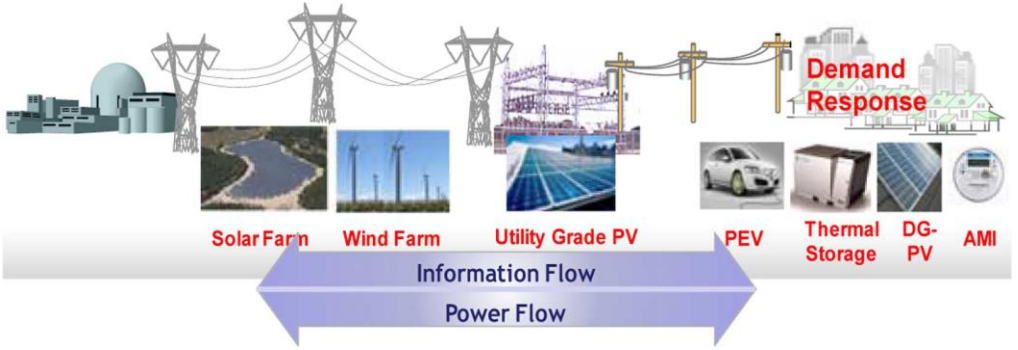
CINELDI

Traditional Grids vs. Smart Grid



Traditional Grid

Smart Grid Scenario



F. Rahimi, A. Ipakchi, "Demand Response as a Market Resource Under the Smart Grid Paradigm," in *IEEE Transactions on Smart Grid*, Vol. 1, No. 1, June 2010, pp. 82-88

The power system operation challenges

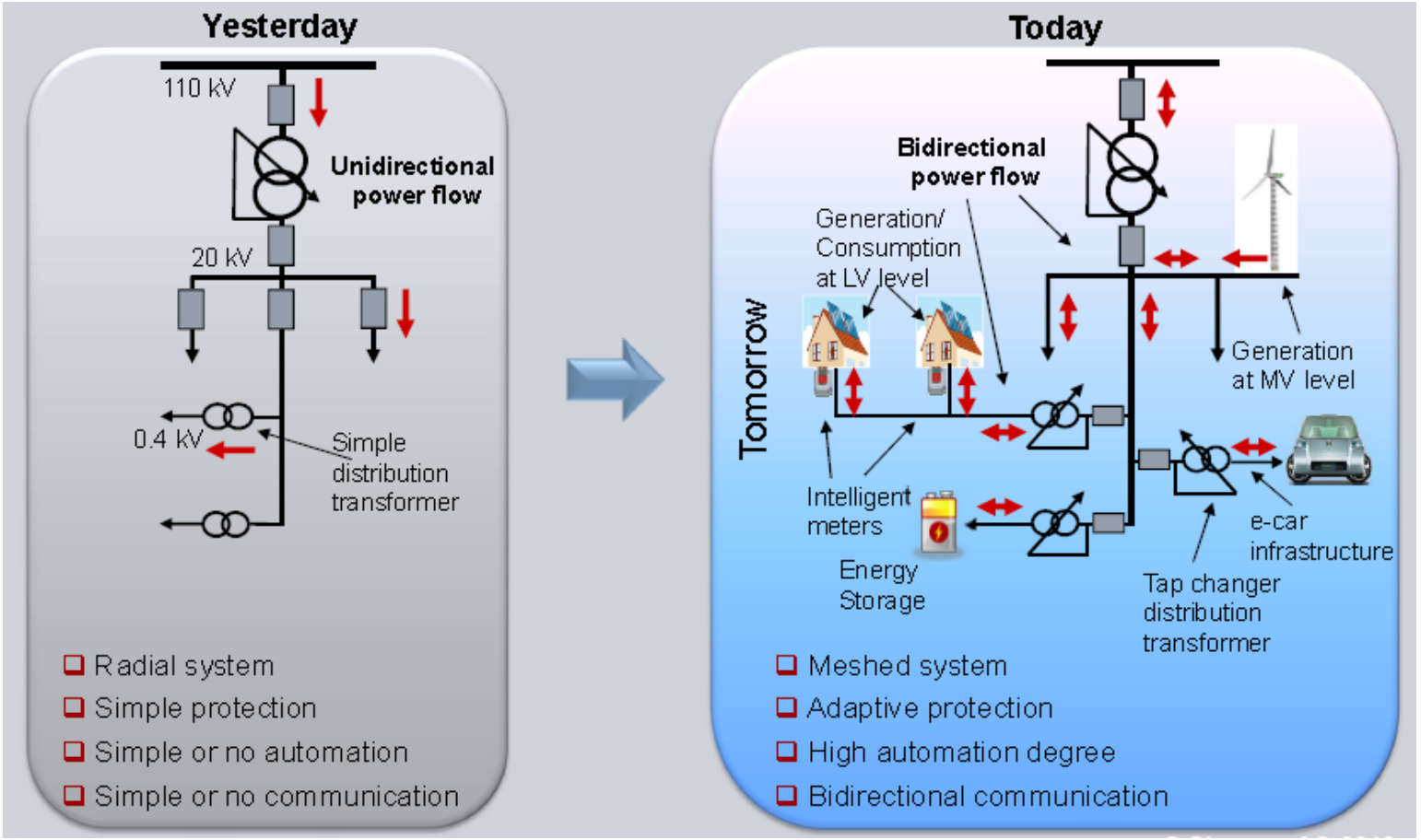
- 99.9% uptime is no longer good enough (black-outs have huge economic consequences)
- New renewable energy and distributed generation on a large scale
- Active customers who produce electricity themselves
- Electric vehicles that have to be charged and must play together with the grid
- Creates a mismatch between time of maximum power generation and maximum consumption → The balancing challenge!
- Better utilization of the society's total resources
- The electrification of the rest of the world
- Climate challenges

→ **Smart Grid**

CINELDI

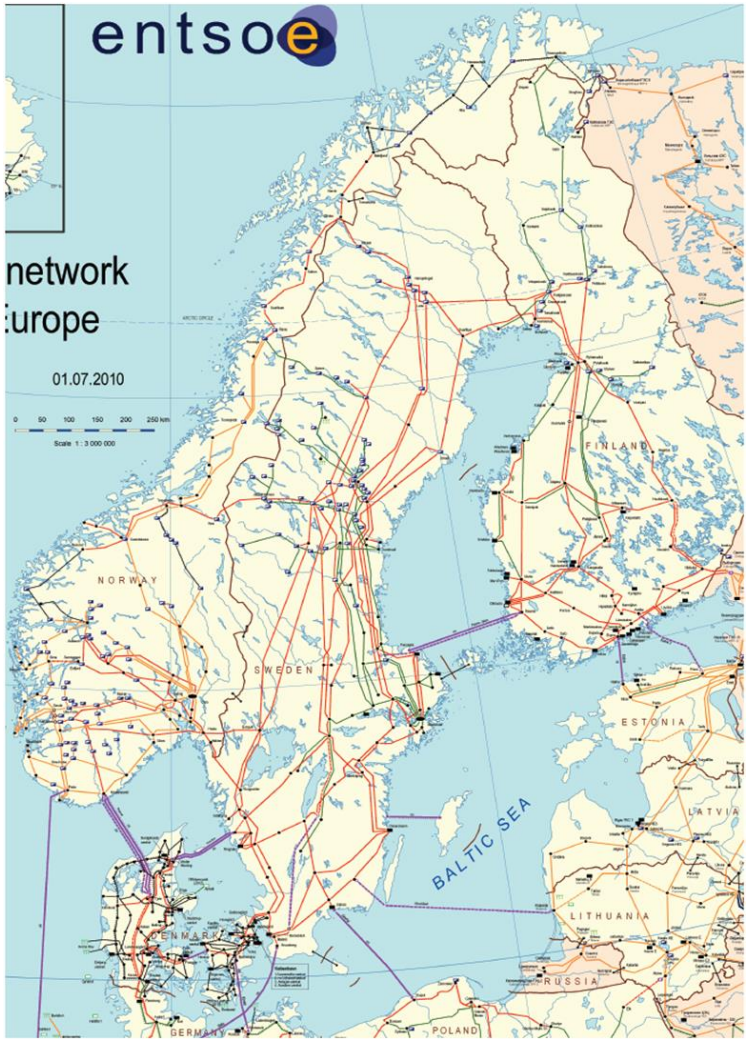
Smart grids→ flexibility

From passive to active networks



Power systems

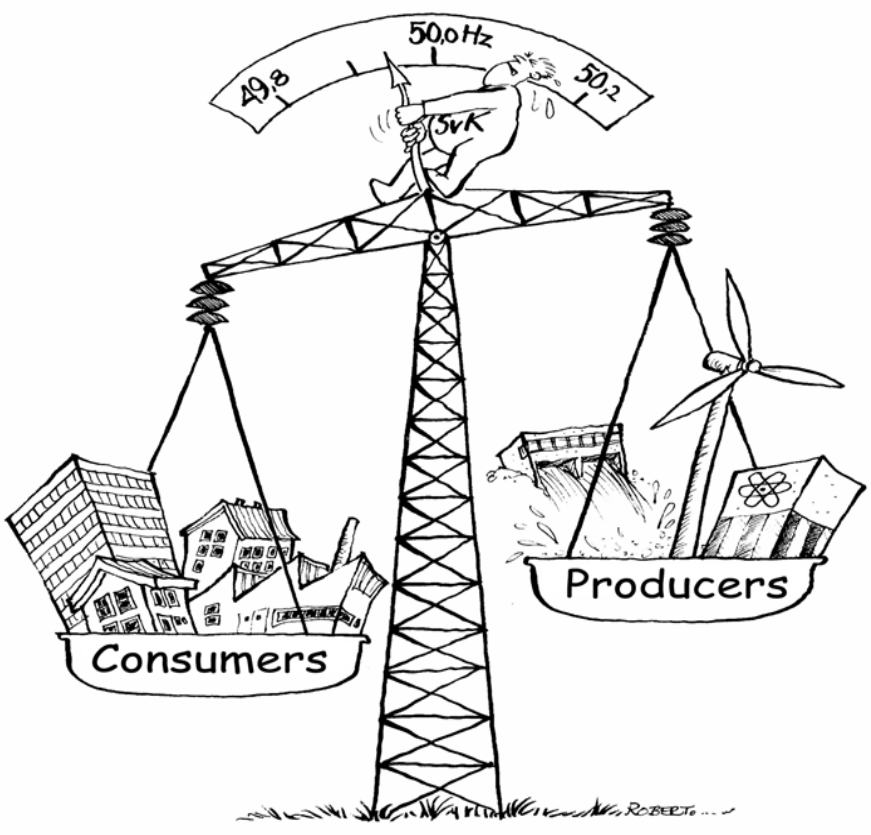
- **Large interconnected system**
  - **pros**
  - **cons**
- Balancing challenge!



Kilde: entso-e

Power systems

- Large interconnected system
  - pros
  - cons
- **Balancing challenge!**

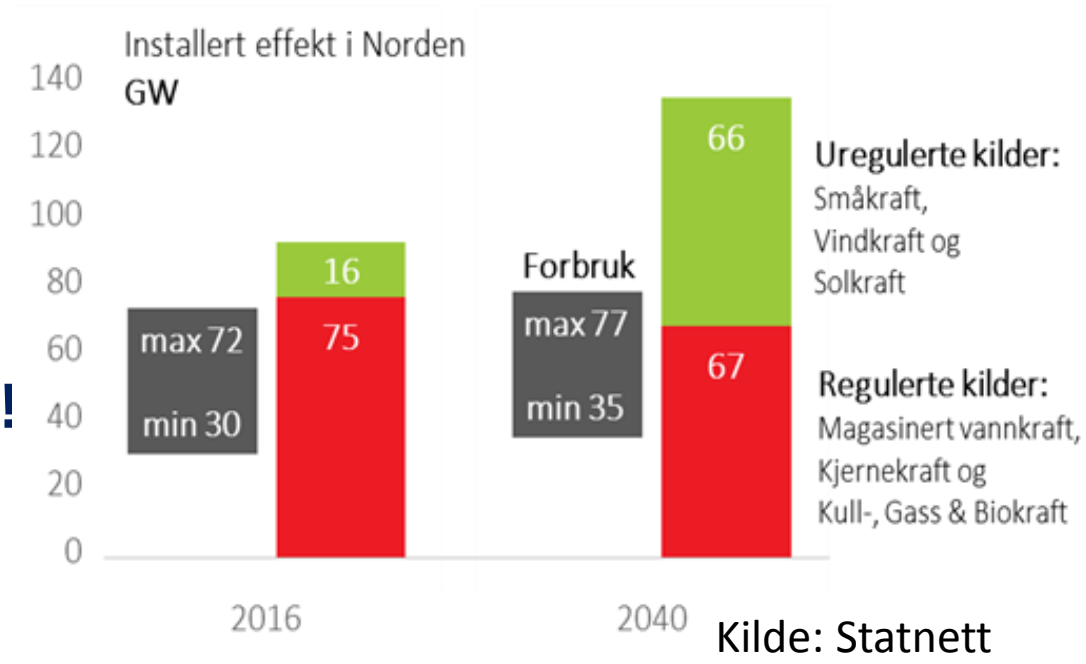


Kilde: Statnett

- Society increasingly dependent on security of power supply

Major challenges in operation

- Towards **100 % renewable electricity** generation
  - Larger variability
  - More uncertainty
  - Increasing complexity



Kilde: Statnett

- **More dynamics!**
- **Less time for actions!**
- **Resilience and predictability equally important**

Controlling the grid:

Increased complexity requires better control centres, more automation and improved situational awareness!

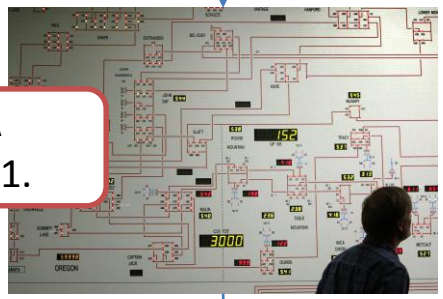
- We need:
  - «full» awareness of the process
  - "full» control of the process
    - In all states…
    - From normal operation to extreme disturbances
    - At all times....

Developement of control centres

Analog Tech.

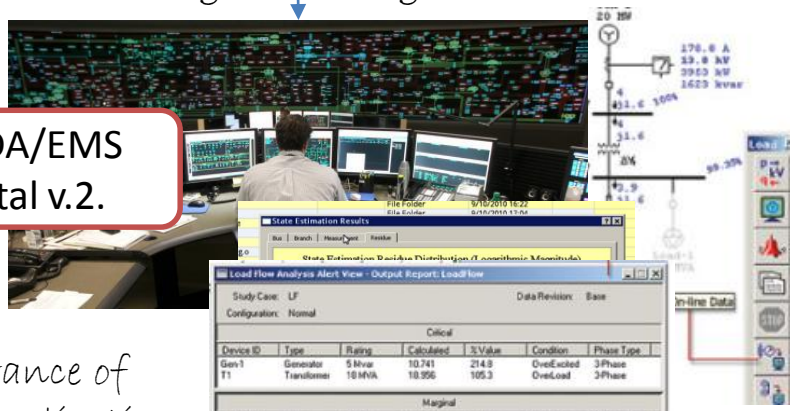
From analog to digital

SCADA
Digital v.1.



From digital to digital "+"

SCADA/EMS
Digital v.2.

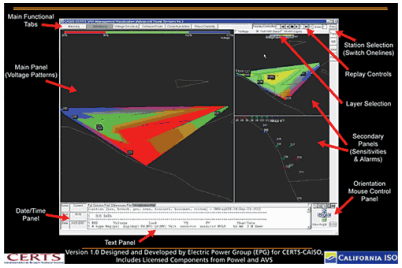


Appearance of
EMS applications

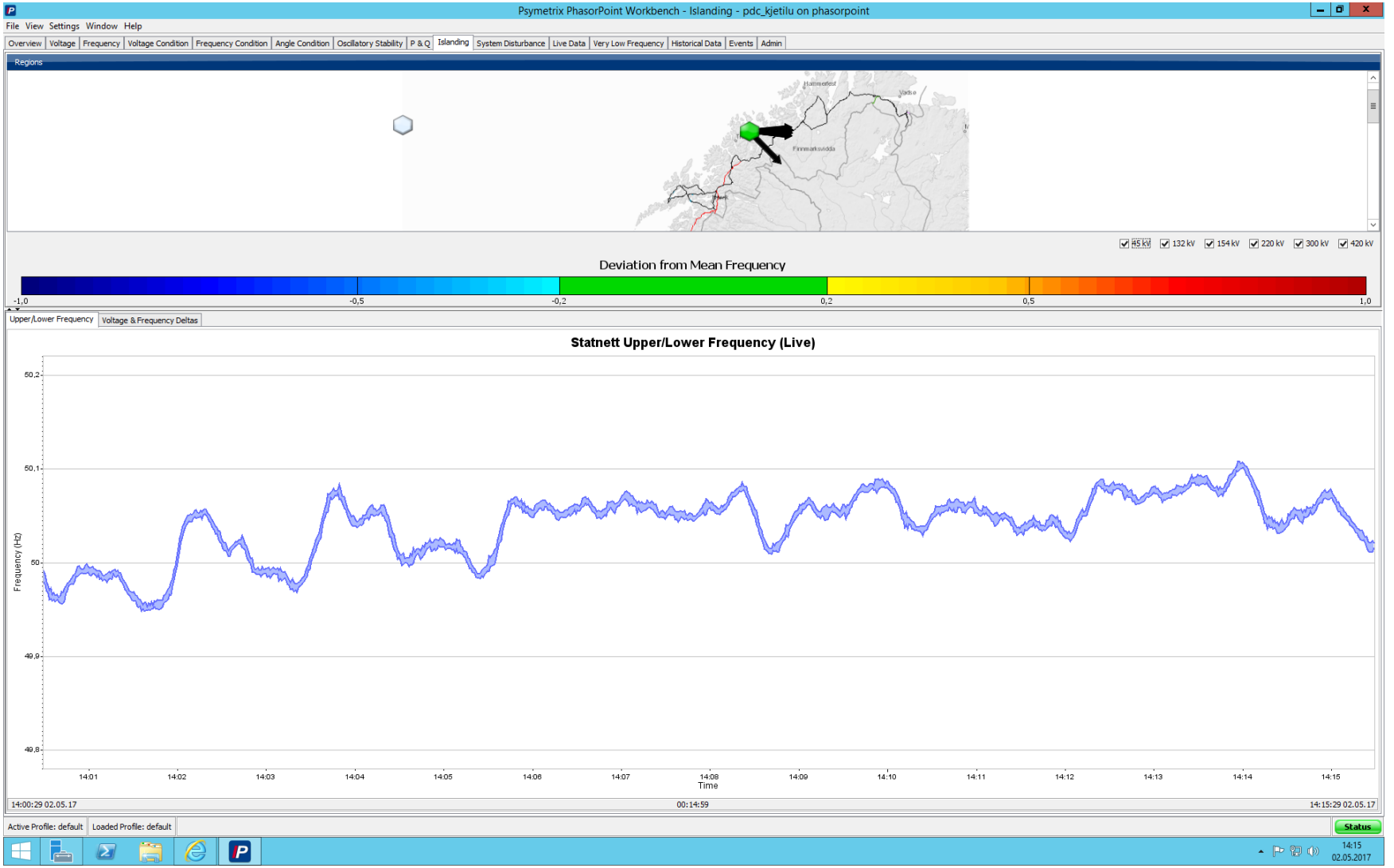
SCADA/EMS+ PMU

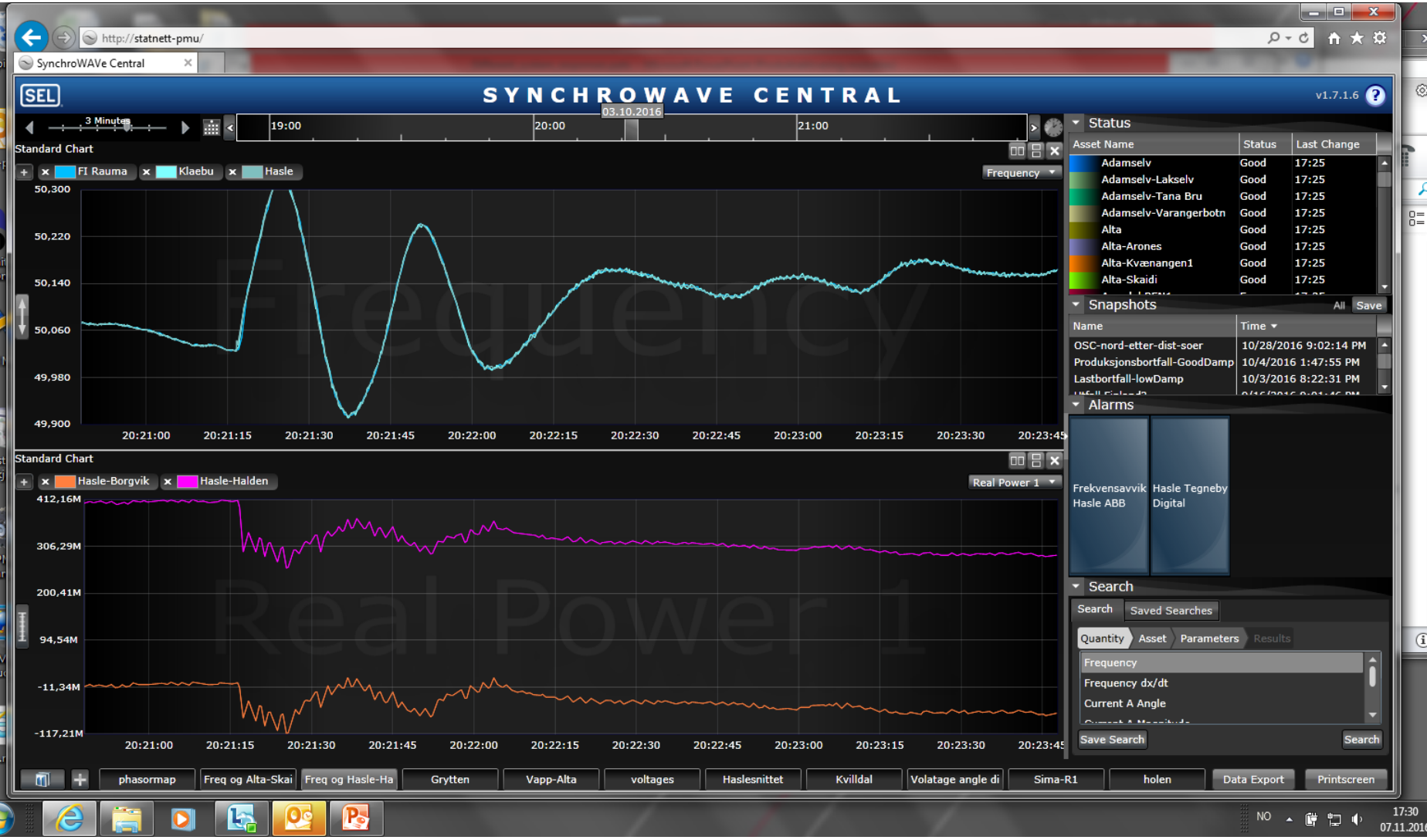
PMU data starts being used in control rooms for monitoring displays & alarming (2002 – 2014)

Today: SCADA/EMS+ PMU + *PMU Applications for Monitoring a few Specific Conditions*



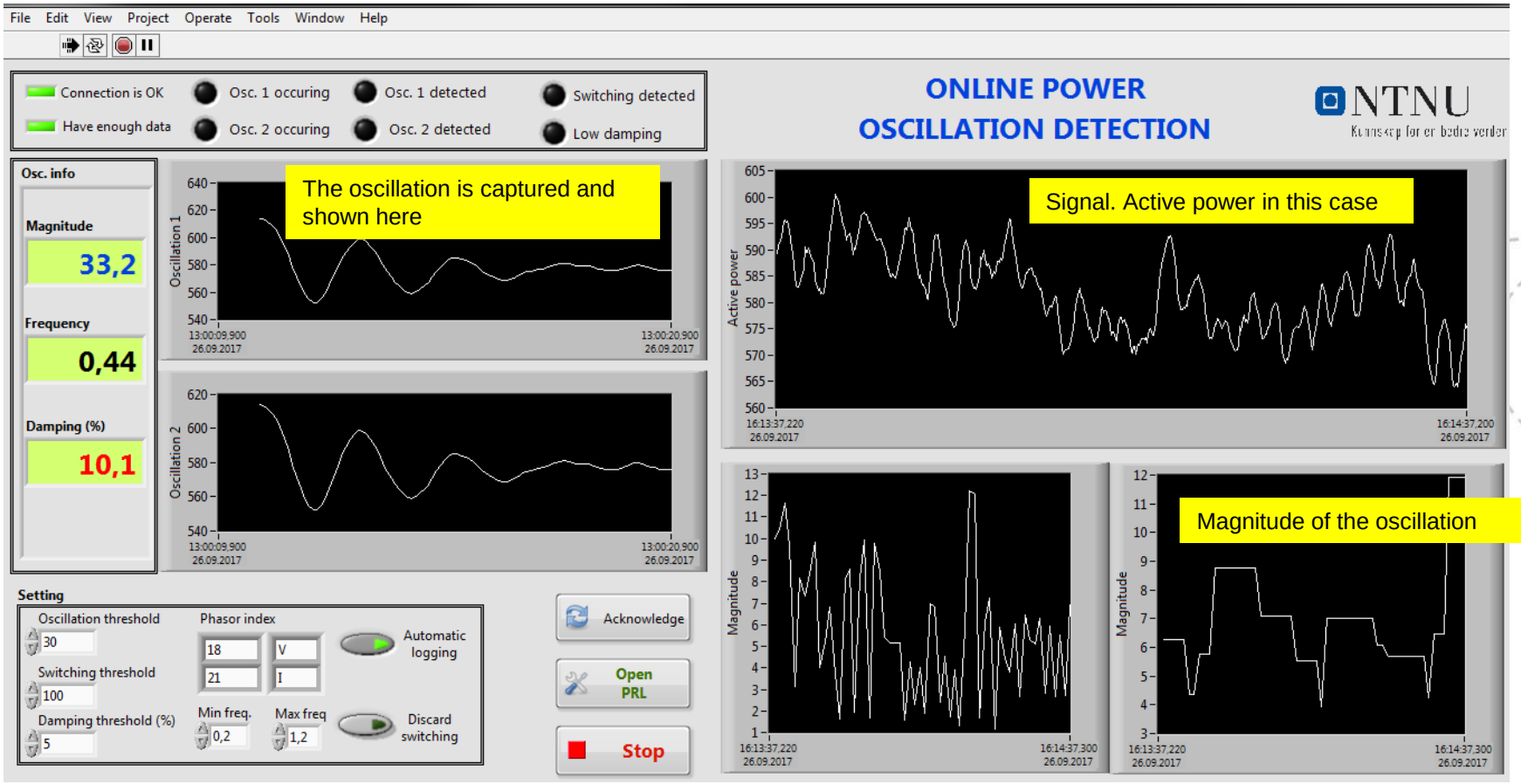
The Future?


Psymetrix PhasorPoint Workbench - Islanding - pdc_kjetilu on phasorpoint
File View Settings Window Help
Overview Voltage Frequency Voltage Condition Frequency Condition Angle Condition Oscillatory Stability P & Q Islanding System Disturbance Live Data Very Low Frequency Historical Data Events Admin
Regions
Hammerfest
Vadsø
Finnmarksvidda
Alta
45 kV
132 kV
154 kV
220 kV
300 kV
420 kV
Deviation from Mean Frequency
-1,0
-0,5
-0,2
0,2
0,5
1,0
Upper/Lower Frequency
Voltage & Frequency Deltas
Statnett Upper/Lower Frequency (Live)
50,2
50,1
50
49,9
49,8
Frequency (Hz)
14:01
14:02
14:03
14:04
14:05
14:06
14:07
14:08
14:09
14:10
14:11
14:12
14:13
14:14
14:15
Time
14:00:29 02.05.17
00:14:59
14:15:29 02.05.17
Active Profile: default
Loaded Profile: default
Status
14:15
02.05.2017


http://statnett-pmu/
SynchroWAVe Central
SYNCHROWAVE CENTRAL
v1.7.1.6
3 Minutes
03.10.2016
19:00
20:00
21:00
Standard Chart
FI Rauma
Klaebu
Hasle
Frequency
50,300
50,220
50,140
50,060
49,980
49,900
20:21:00
20:21:15
20:21:30
20:21:45
20:22:00
20:22:15
20:22:30
20:22:45
20:23:00
20:23:15
20:23:30
20:23:45
Standard Chart
Hasle-Borgvik
Hasle-Halden
Real Power 1
412,16M
306,29M
200,41M
94,54M
-11,34M
-117,21M
Status
Asset Name
Status
Last Change
Adamselv
Adamselv-Lakselv
Adamselv-Tana Bru
Adamselv-Varangerbotn
Alta
Alta-Arones
Alta-Kvænangen1
Alta-Skaidi
Good
17:25
Snapshots
All
Save
Name
Time
OSC-nord-etter-dist-soer
10/28/2016 9:02:14 PM
Produksjonsbortfall-GoodDamp
10/4/2016 1:47:55 PM
Lastbortfall-lowDamp
10/3/2016 8:22:31 PM
Alarms
Frekvensavvik Hasle ABB
Hasle Tegneby Digital
Search
Search
Saved Searches
Quantity
Asset
Parameters
Results
Frequency
Frequency dx/dt
Current A Angle
Save Search
Search
phasormap
Freq og Alta-Skai
Freq og Hasle-Ha
Grytten
Vapp-Alta
voltages
Haslesnittet
Kvilldal
Volatage angle di
Sima-R1
holen
Data Export
Printscreen
NO
17:30
07.11.2016

Prototype application for power oscillation monitoring

From ambient data and ringdown analysis after disturbances



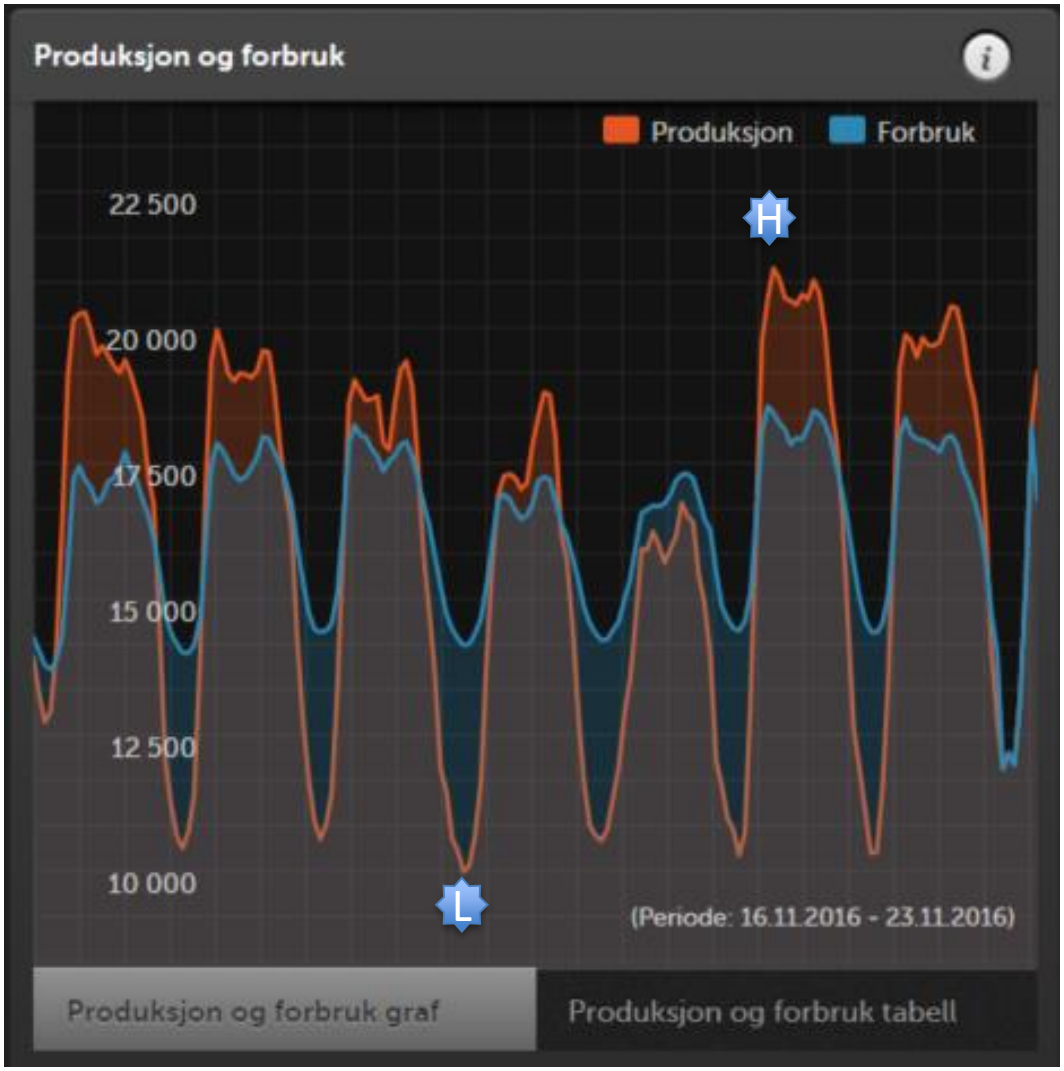
We have proposed 2 methods to estimate the oscillation magnitude. That is why there are figures for the captured oscillation and the magnitude

NTNU – Trondheim
Norwegian University of Science and Technology

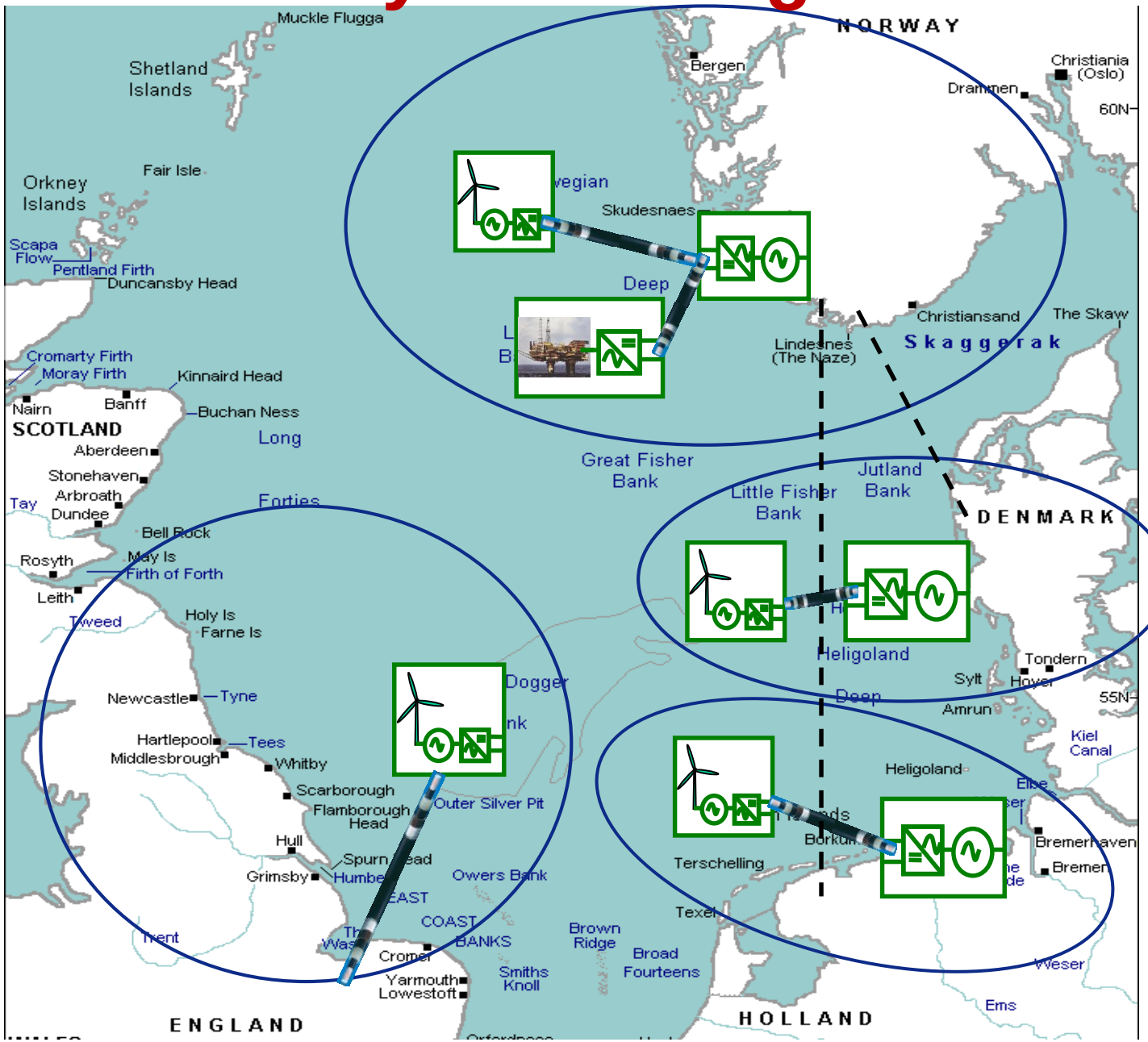
Outline

- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

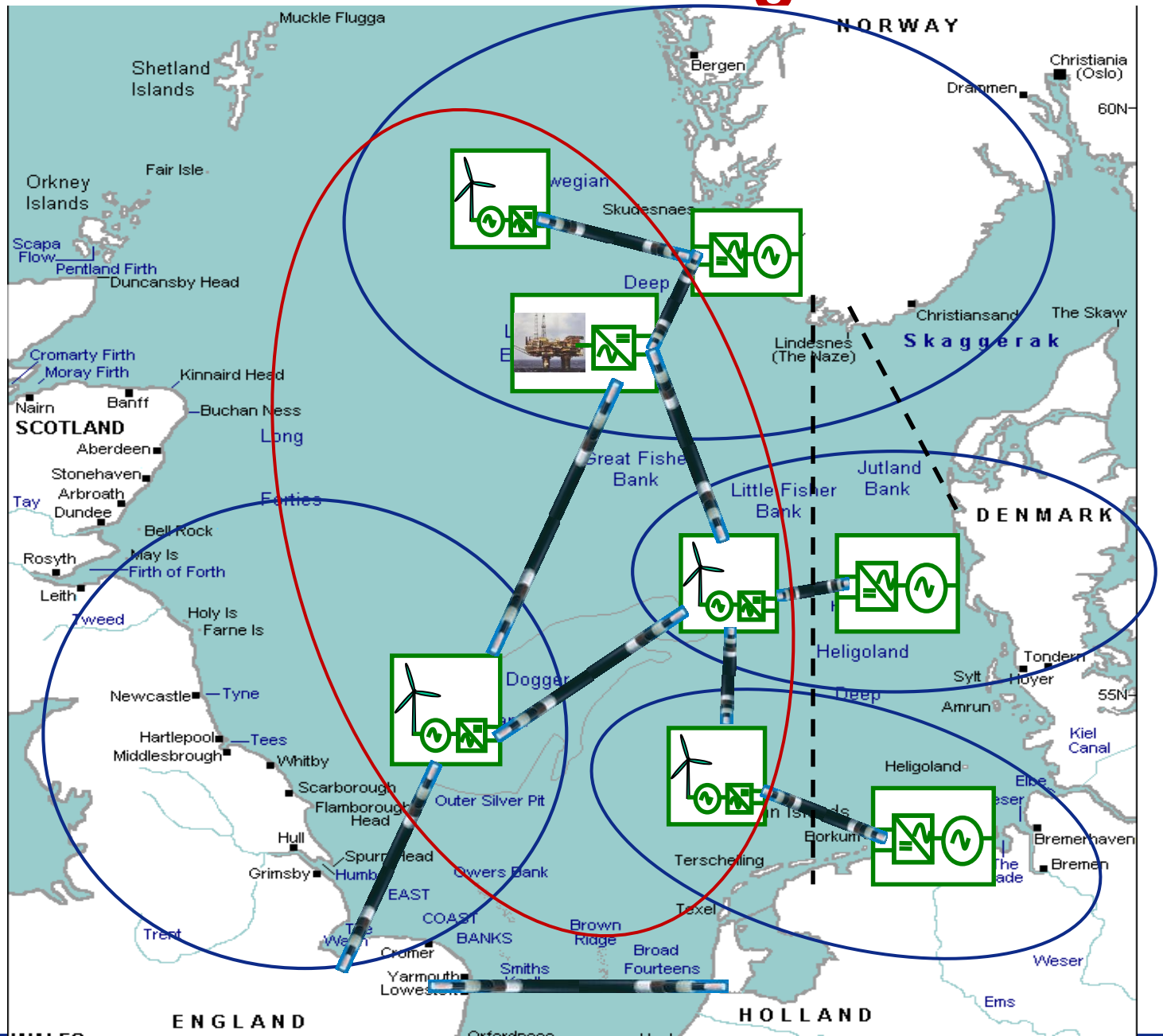
Power should be produced where it is cheap and sustainable!



Power system integration..



Power market integration..



Power Electronic Converters for Hybrid Marine Systems

Converters:

- Motor Inverters
- DC/DC converters
- Active Front End : Virtual Generators creating AC-grid (hotel/auxillary loads)

Topologies:

- **2-level (690 V) 500-6000 kW**
- 3-level (Medium Voltage)

Devices:

- Si IGBTs and diodes
- ***Si IGBT and SiC diodes***
- ***SiC MOSFETs and diodes*** gives reduced losses

Reduced volume & size

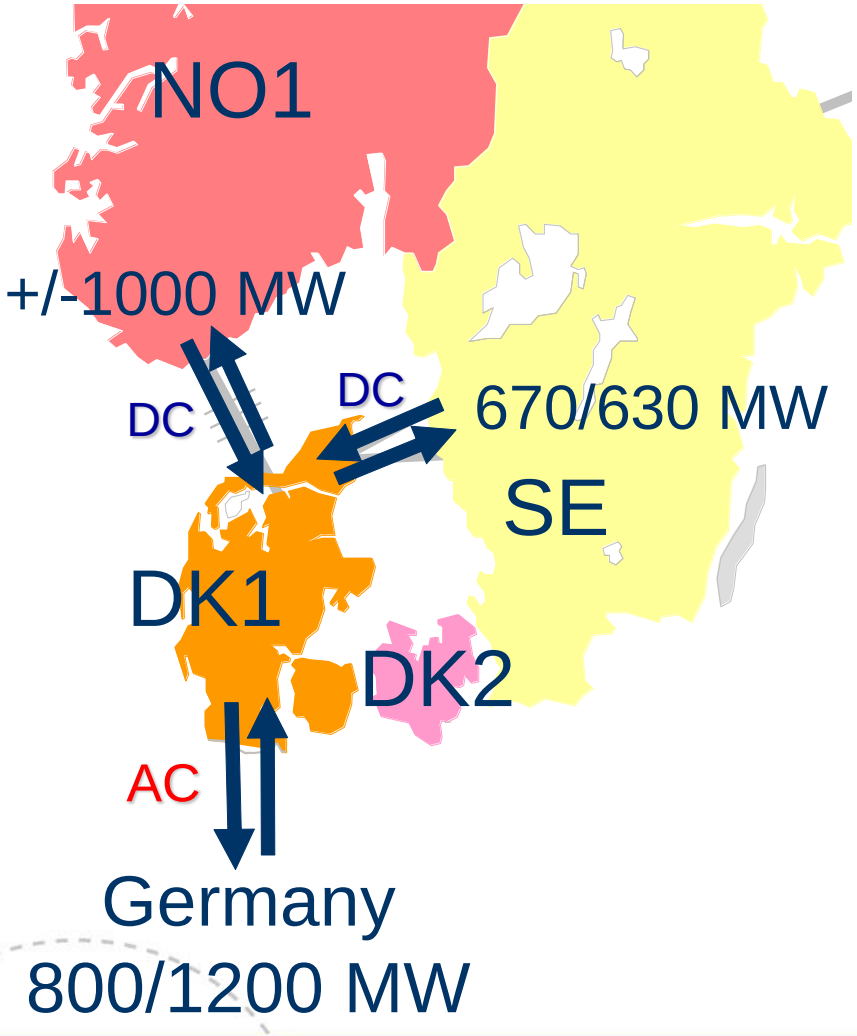
IGBT 1700V/1400 A Si/Si
IGBT 1700V/1000 A
Si/SiC, Infineon

SiC MOSFET 1200V/800 A
under development
Mitshubishi

Outline

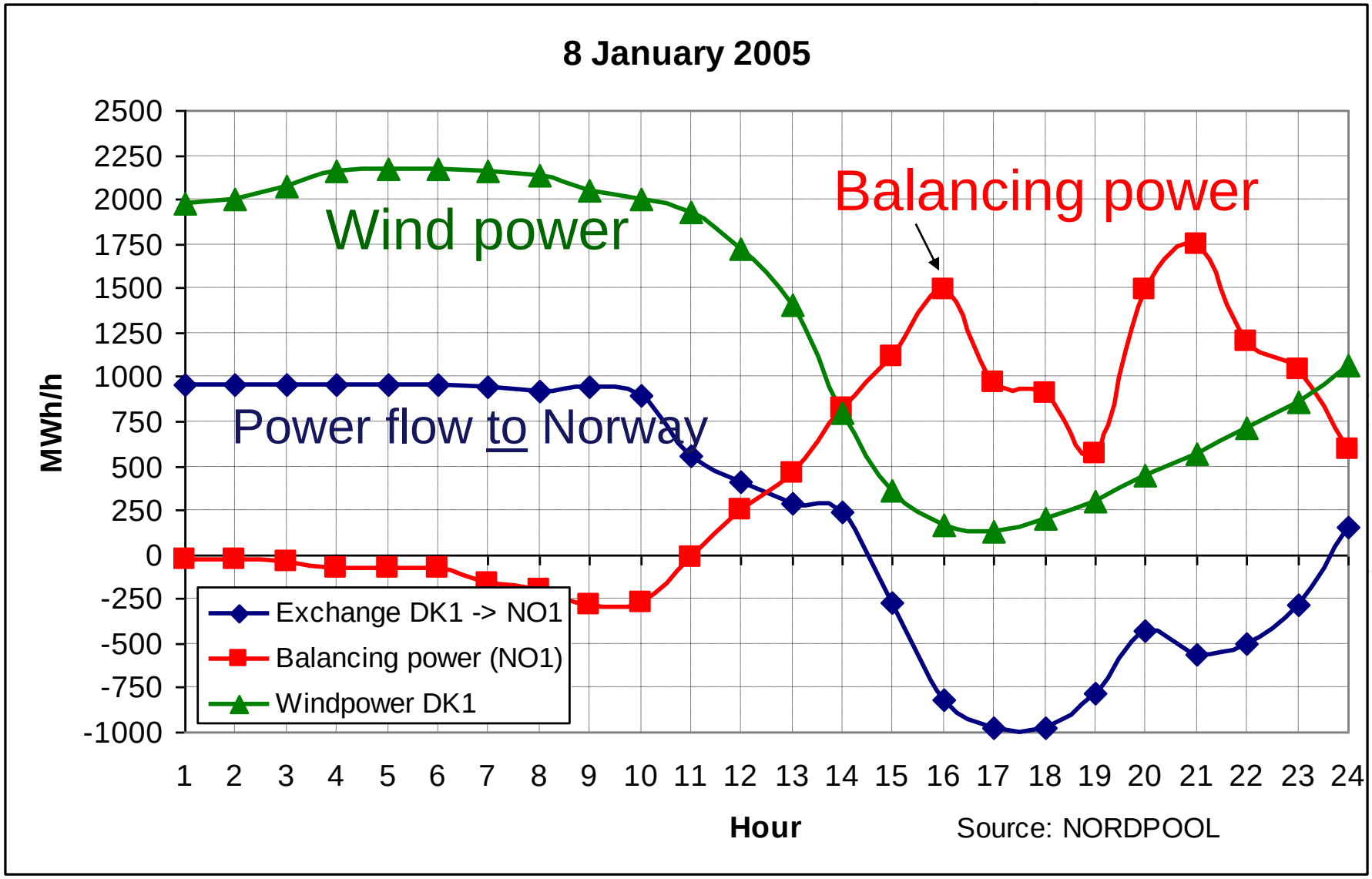
- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

Eksample:
Collaboration on balance management



- January 8, 2005 a strong storm crossed over Denmark
- The wind farms of western Denmark at first produced close to rated power, but then started to cut out due to the excessive wind speed (+ 25 m/s) – the wind production were reduced from about 2200 MW to 200 MW in a matter of 10 hours

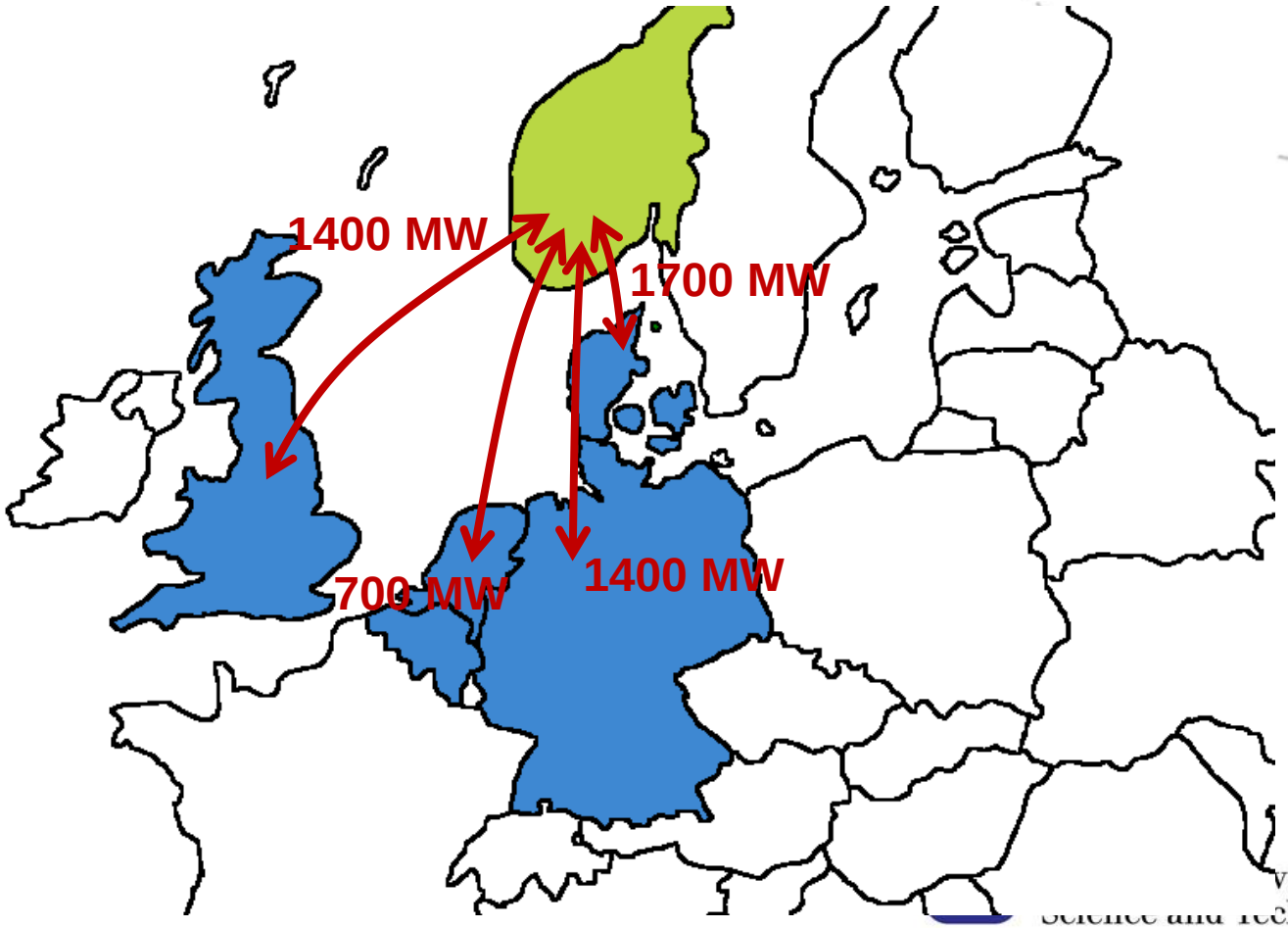
Data for DK1, west Denmark 2003	MW
Central power plants	3,516
Decentralised CHP units	1,567
Decentralised wind turbines	2,374
Offshore wind farm Horns Rev A	160
Maximum load	3,780
Minimum load	1,246



The common Nordic balancing market is able to manage large variations in (wind power) generation and loads

NTNU
Norwegian University of Science and Technology

Norwegian hydropower as Europe's green battery → possibilities and challenges



HydroCen

NORWEGIAN RESEARCH CENTRE
FOR HYDROPOWER TECHNOLOGY

Tot. 384 mill. NOK	
Forskningsrådet	192 mill.
Bransjen	96 mill.
Forskningsinstitusjonene	96 mill.
41 partnere	**8 år**

Outline

- About us (NTNU, Electric Power Engineering dept.)
- Development trends, challenges and possibilities
- Key research topics
  - Smart Grids / digitalization
  - Offshore grids / power electronics
  - Hydropower, electricity markets and energy system analysis
- About our study programmes
  - BSc, MSc, PhD
  - Future demand

Electric Power Engineering (Bachelor, Master and PhD)

Key topics in education and research:

- Power generation, transmission and distribution
- Power system planning
- Power system operation, protection and control
- Energy system analysis and optimization
- Power markets
- Electrical machines
- Power electronics
- High voltage engineering

Energi og miljø – 5 yr MSc
(*Energy and Environment*)

is a successful cooperation between two faculties, with Electric Power Engineering as one specialization. **Common ground: ENERGY**

Two-year international master programmes

- Energy Use and Energy Planning (MIENERG)
- Electric Power Engineering (MSELPOWER)
- European Wind Energy Master EWEM – Erasmus Mundus (MSWIND)
- Renewable Energy in The Marine Environment REM – Erasmus Mundus (new)
- Innovative Sustainable Energy Engineering – Nordic Five Tech – (MSISEE)

Quo vadis Electric power engineering?

A new era calls for **innovation in study programmes**:

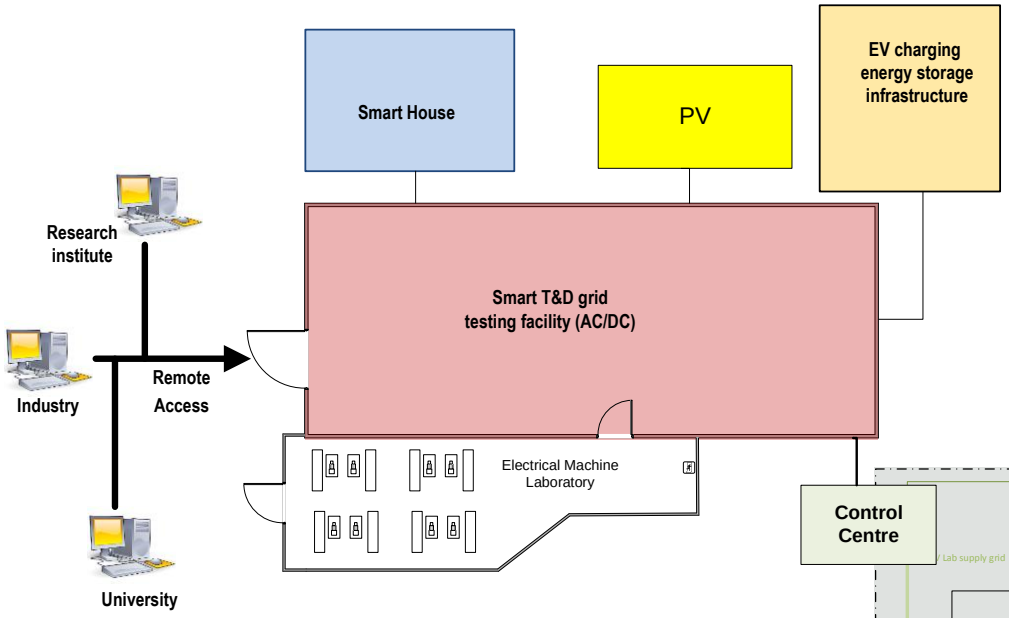
- Green Energy Shift – Solar takeover
- Automation, cybernetics
- Smart Grid – the new, digital energy landscape (merger of ICT and Electric Power)
- Digitalization, new business models (e.g., blockchains)
- World class engineers who can
  - Describe – Analyse – and **Design and Innovate** for the as yet **unborn** industry!

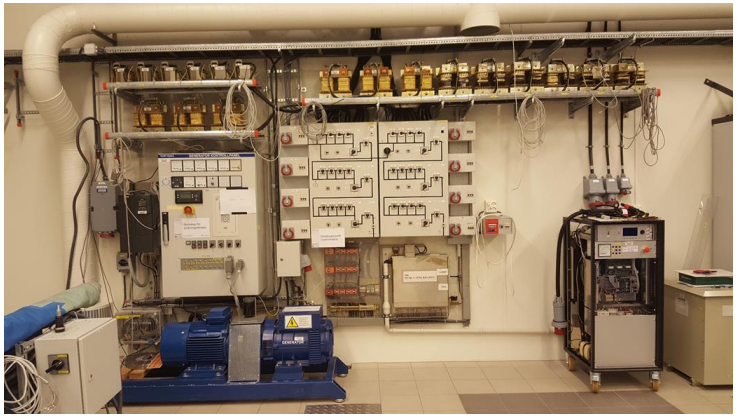
The Norwegian Smart Grid Laboratory

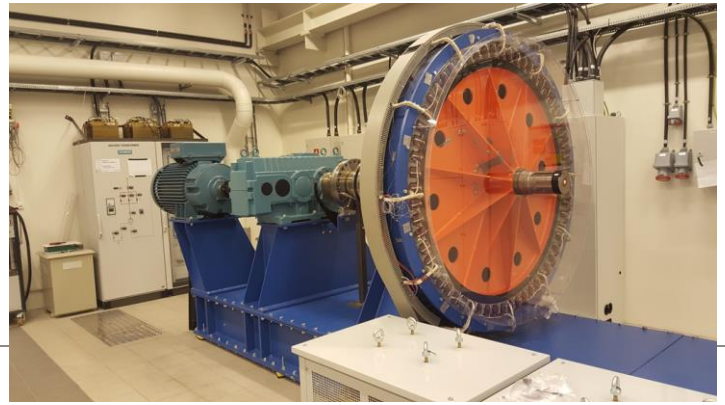
https://www.ntnu.edu/smartgrid

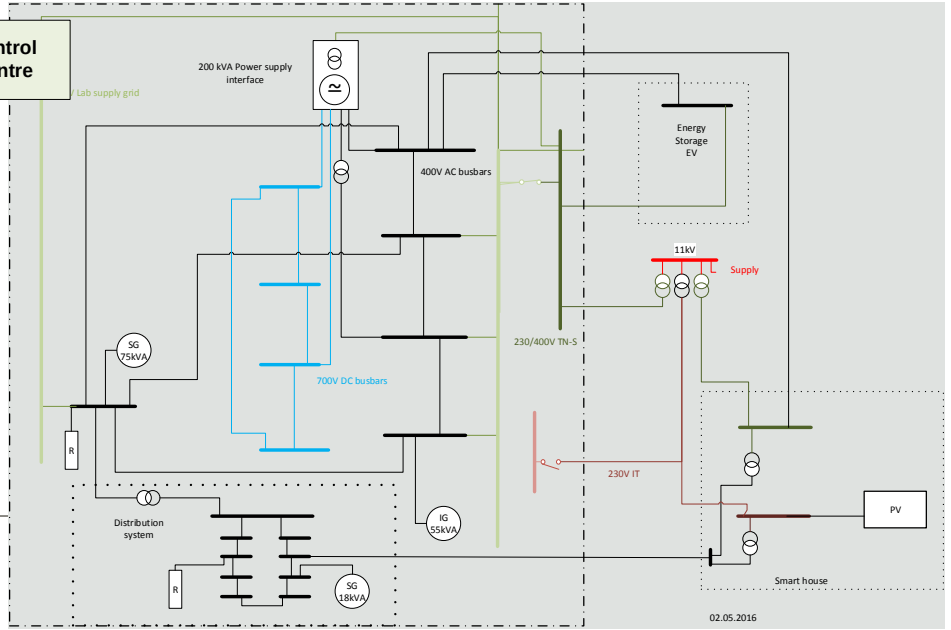
The National Smart Grid laboratory

(NSGL)

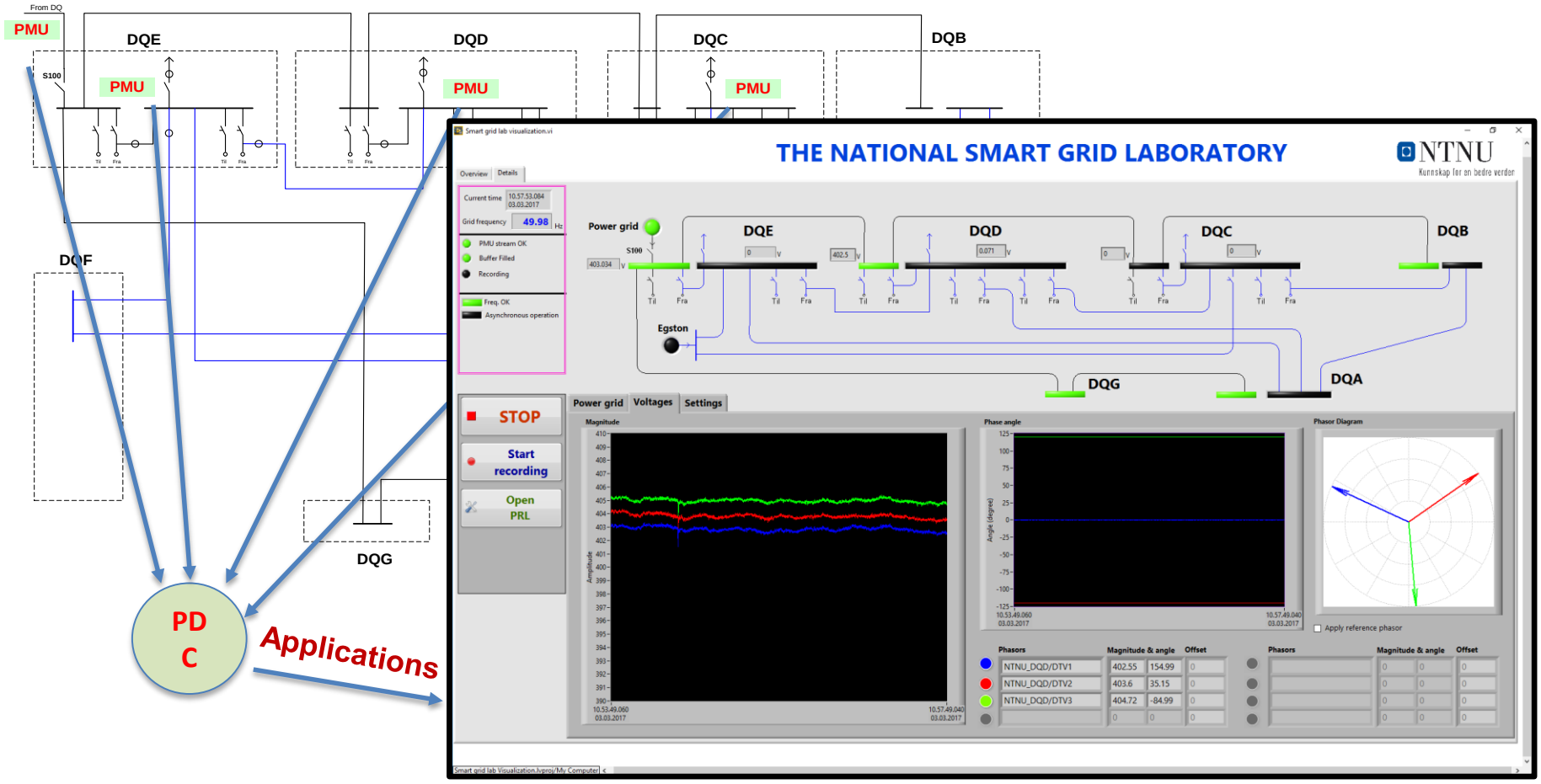




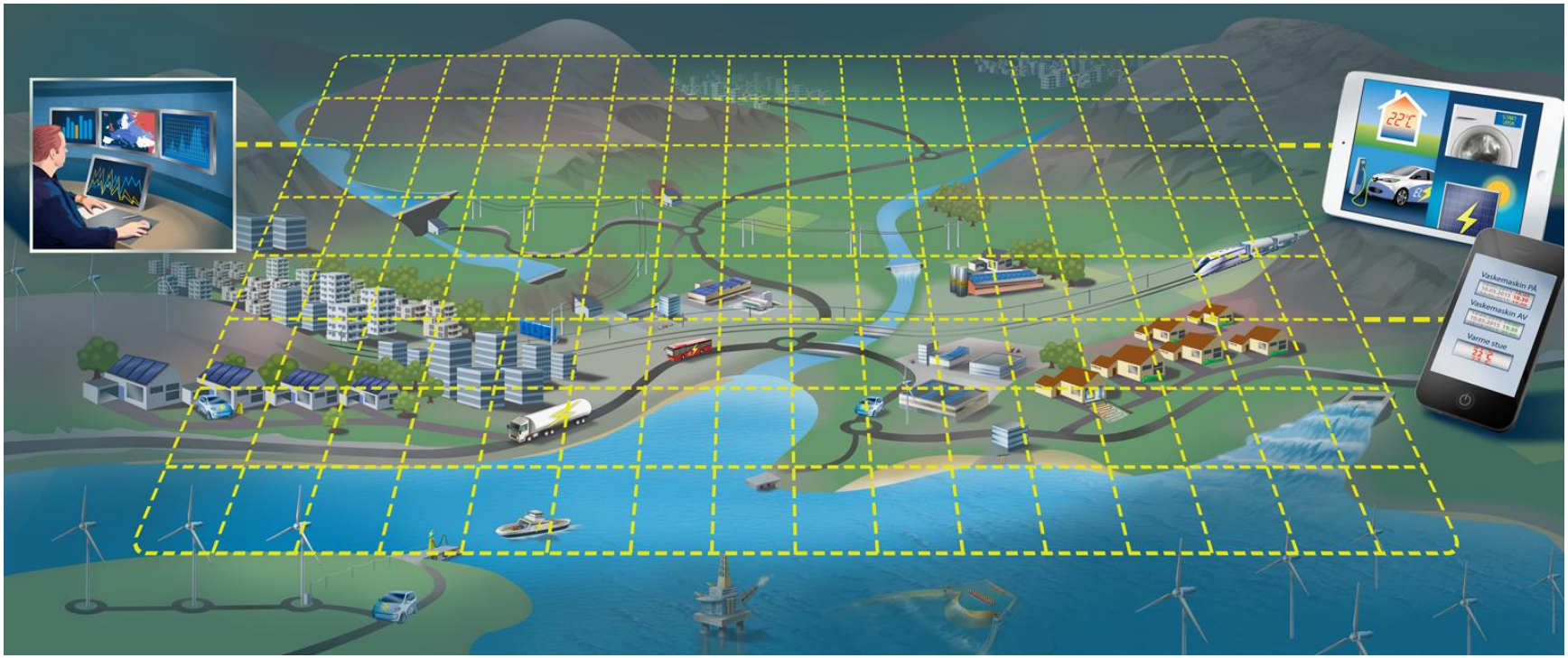




PMUs / WAMS in the smart grid lab



«The future is digital, renewable and runs on electricity!»



- Thank you☺