CMU Electricity Conference, 9th March 2011

Operation Challenges in Power Systems with Renewable Energy Sources

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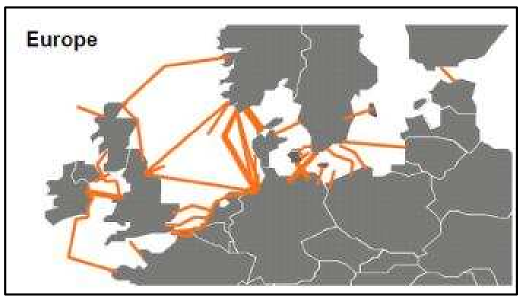
ABB US Corporate Research

Main Points

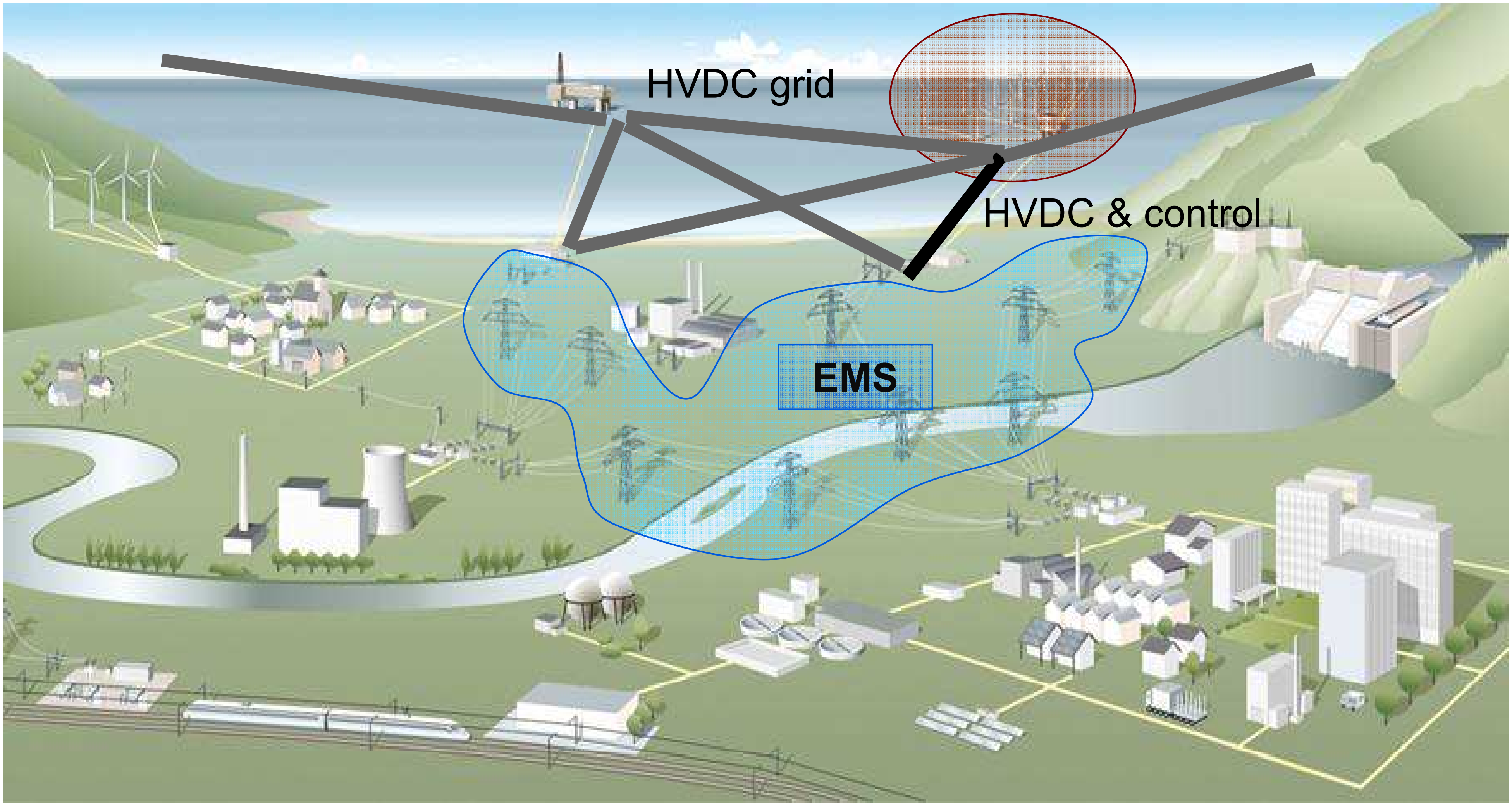


- Technologies allowing for the Integration of Renewables (Transmission)
  - Hardware
    - HVDC Light
    - DC Grids?
  - Software
    - EMS/SCADA

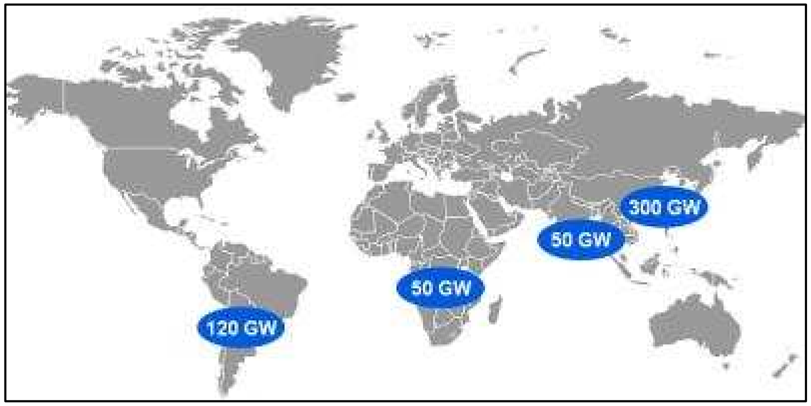
- Technologies allowing for the Integration of Renewables (Distribution)

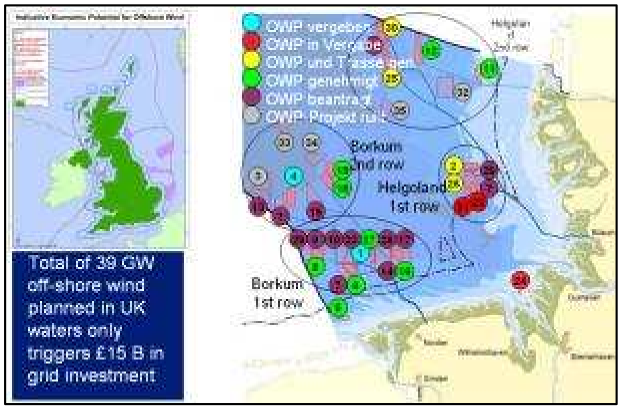
Integration of the Renewables
Transmission

Large-scale and lumped energy sources

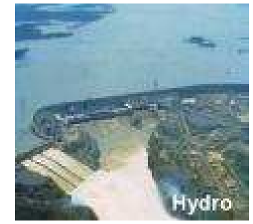


Key Renewable Energy Alternatives



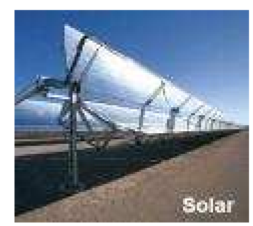


- Hydropower resources of about 500GW available. Transmission distance 2000-3000 km



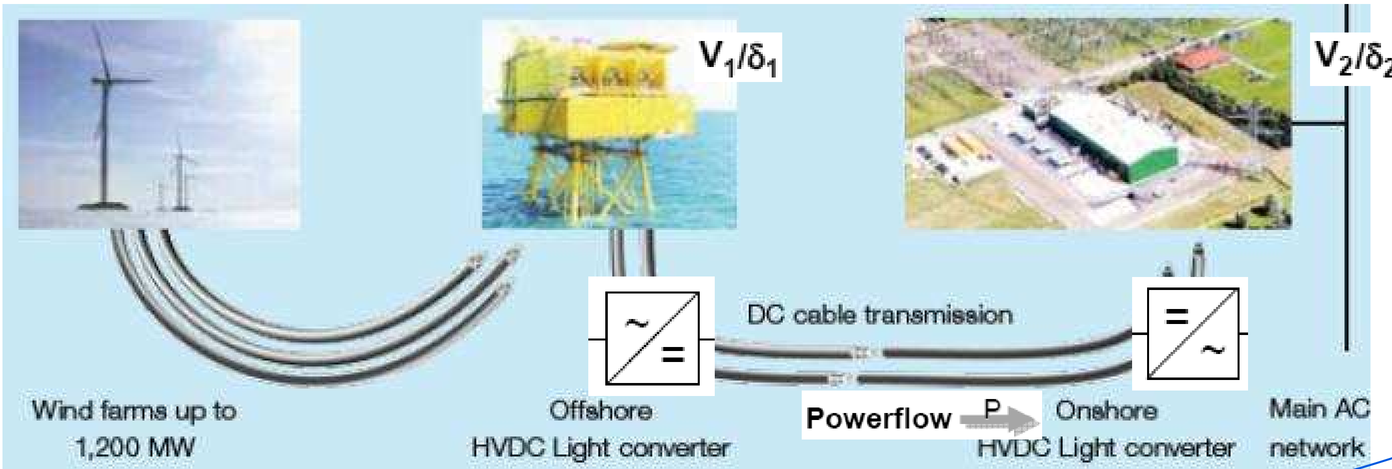
- Wind power projects in the north sea for connection in Germany

- Solar energy from deserts. 90 percent of people live within 2,700 km of a desert



Major bulk renewables located remotely: need for new transmission

Why HVDC for Large-scale Renewables



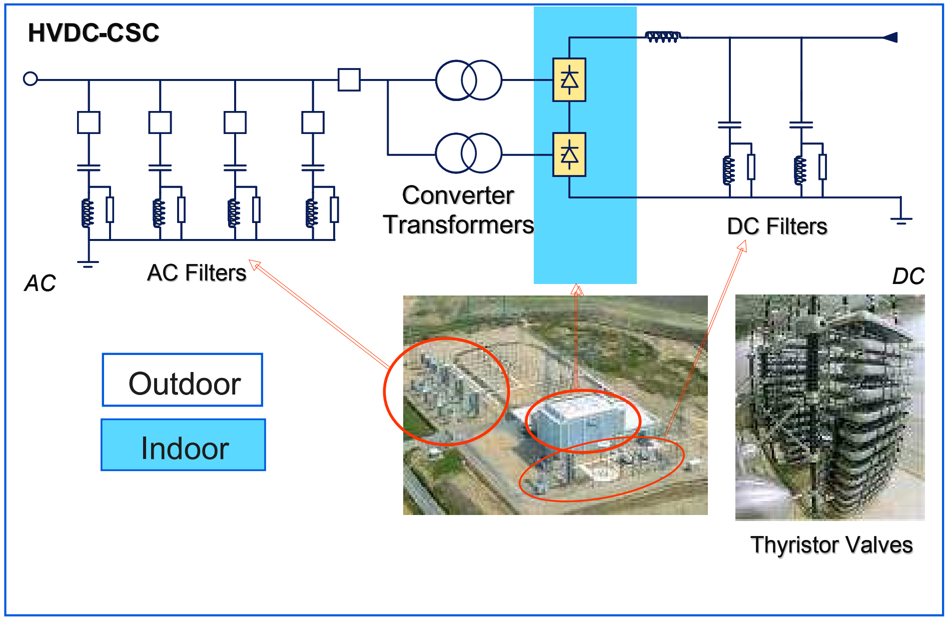
HVDC converters

$$P = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2) + P_{HVDC}$$

- HVAC cables not attractive due to charging current for long distances
- Contingency in on-shore grid doesn't affect the off-shore voltage
- Can operate wind farm at different/varying frequency for optimal use
- Dynamic reactive power support with HVDC Light
- Flexibility of control, lower losses

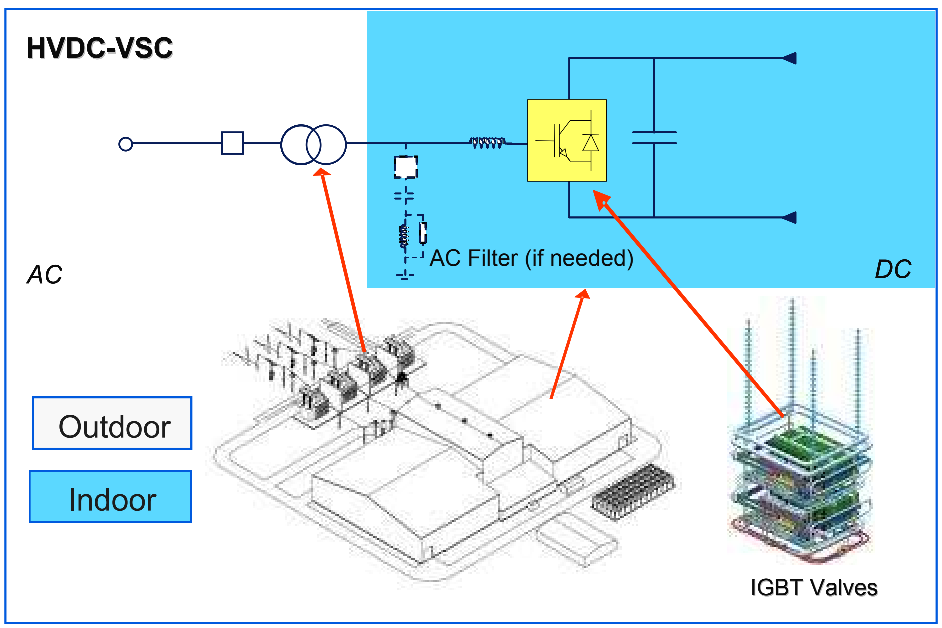
HVDC Tutorial at ABB:
http://www.abb.com/cawp/GAD02181/C1256D71001E0037C1256D08002E7282.aspx

Core HVDC Technologies from ABB



HVDC Classic

- Current source converters
- Line-commutated thyristor valves
- Experience since 1954
- Requires additional "Q" control
- Requires min short circuit capacity for connection
- Over 100 projects around the world, many in 1000-3000MW, max power is 6400MW
- ±500kV, ±800kV



HVDC Light

- Voltage source converters (VSC)
- Self-commutated IGBT valves
- Experience since 1997
- PWM accommodates the "Q" control
- Virtual generator at receiving end: P,Q
- Weak system, black start capability
- Compact footprint, low losses (~ 1% per converter)
- Dozen projects around the word, quite few in 300-400MW
- ±150kV, ±320kV

Large-scale Wind Connection by HVDC Light

- ABB + Transpower
- Robust grid connection, significant reduction in CO_2 emissions and losses
- Supports German wind power development

- **BorWin1, Offshore Wind, Germany**
- HVDC Light, 400 MW, ±150 kV DC, commissioned 2010
- The world's largest offshore wind park in operation
- 125 km subsea + 75 km underground cable, operational in 24 mo.

- **DolWin1, Offshore Wind, Germany**
- HVDC Light, 800 MW, ±320 kV DC, to commission 2013
- 165 km long subsea & underground cable. Invisible, sustainable transmission
- 14th HVDC Light project, 4th with wind, 4th offshore, proven black start

Remote off-shore large wind farms requires a strong transmission connection to the grid – provided by HVDC Light

Customer: transpower
Year of commissioning: 2013

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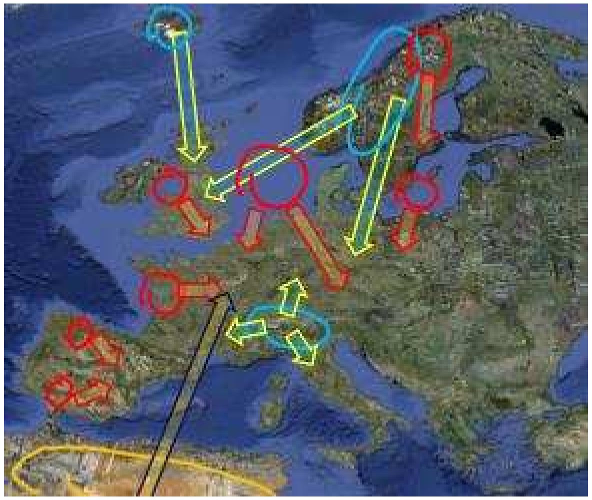
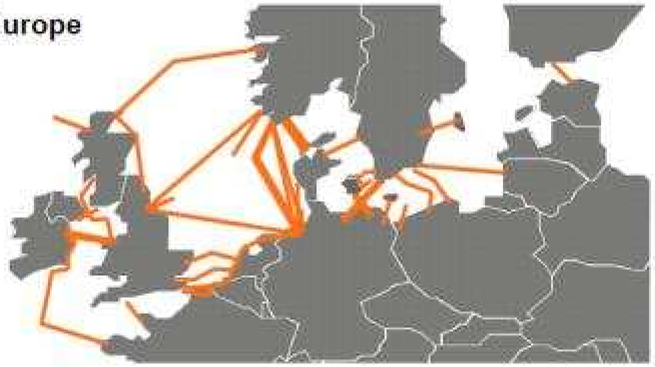
Options for Strengthening Grids
DC Grids Vision



Europe



Desertec

China

Need stronger grid to support bulk renewables and demand-side participation

DC vs AC

- Significant loss reduction when compared to AC
- Increased power capacity per line/cable vs. AC
- Less visual impact and lower electromagnetic fields
- DC = only solution for subsea connections > 60 km
- Connection of asynchronous AC Networks
- Circumvent right of way limitations

DC Evolution

- Number of DC connections increases
- Point-point → Grids for grid reliability and economics

Technology required for visions like Desertec & North Sea Offshore Grid

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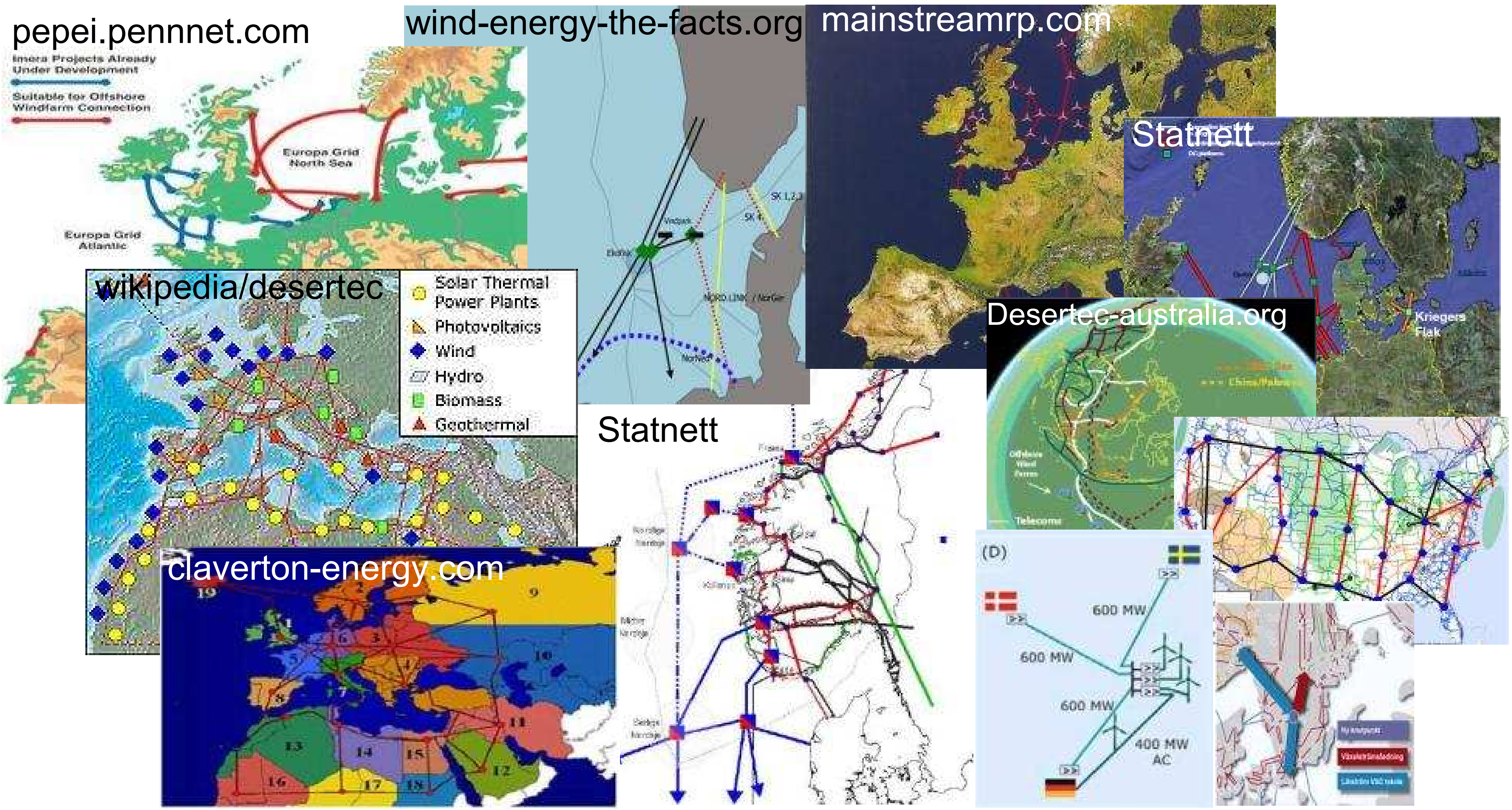
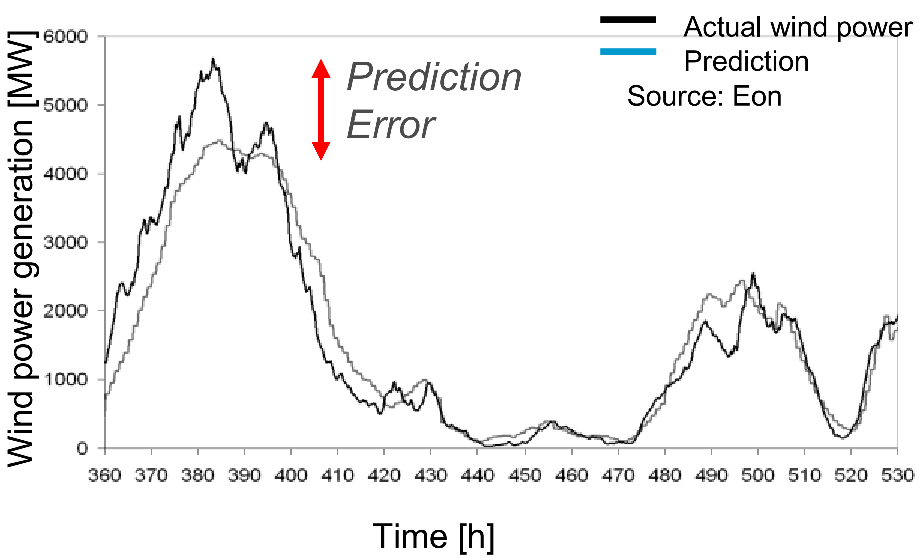
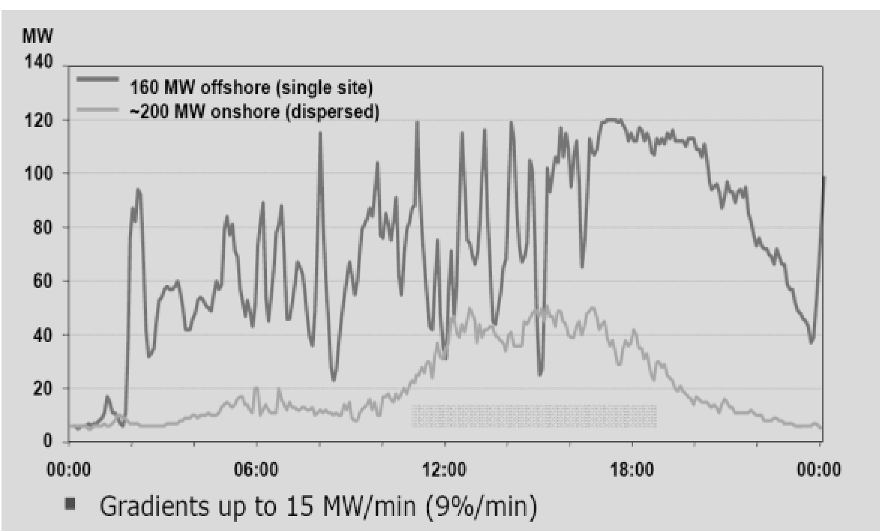
DC Grids in the Public Debate
Various Supergrid Initiatives



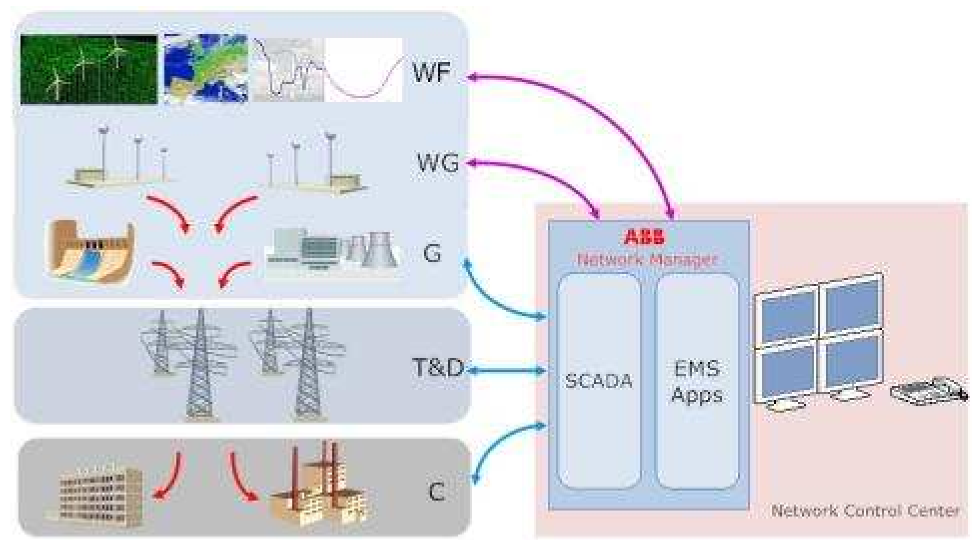
Operational Challenge of Renewable Sources
Manage Uncertainty



- Remedies: Improve forecasting algorithms, use energy storage, use traditional power plants
- Global trend toward bigger lumped parks, increases variations
- Integration of wind power into ABB Network Manager EMS

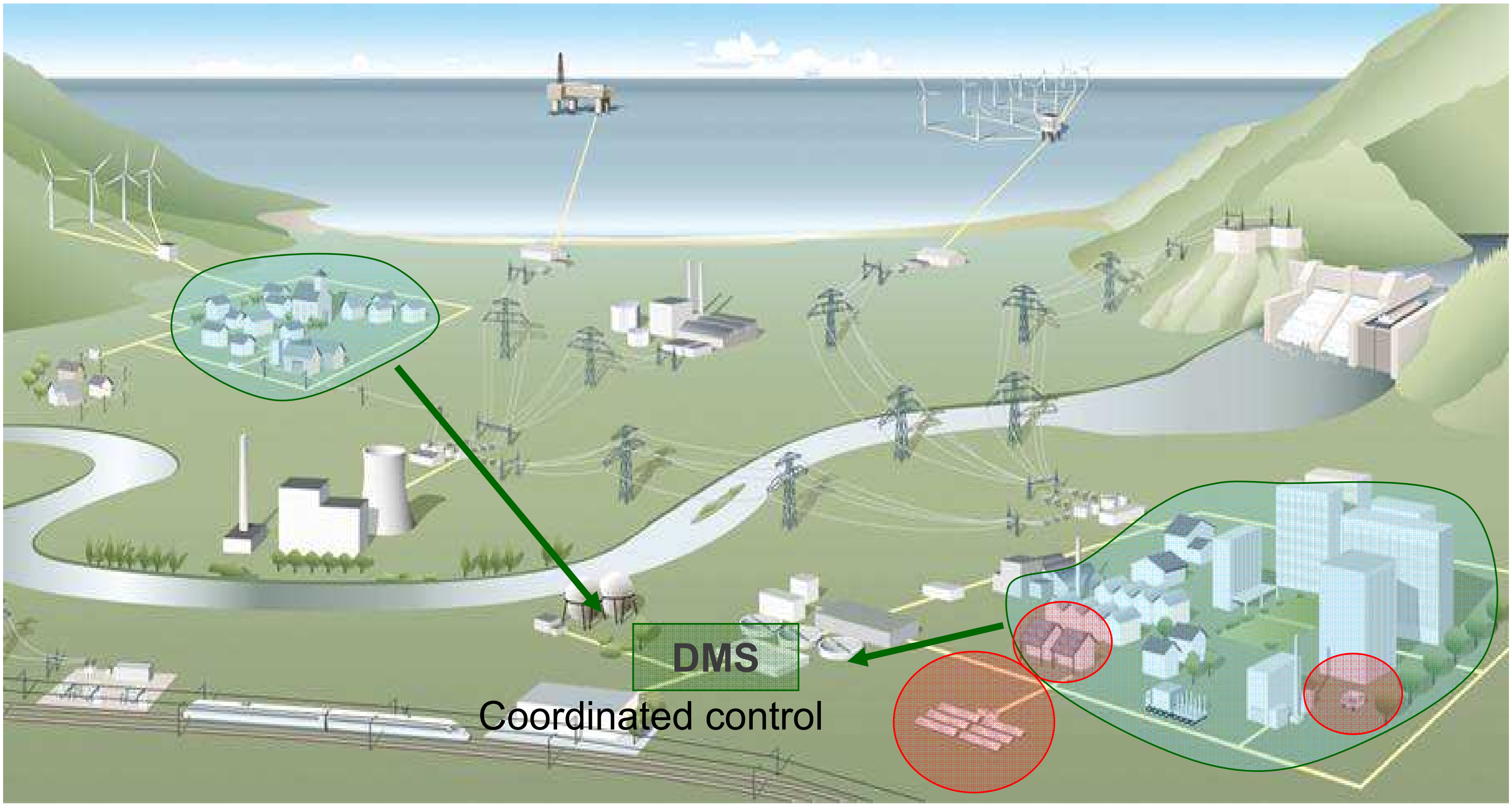


Source: Abildgaard, Energinet DK 2007



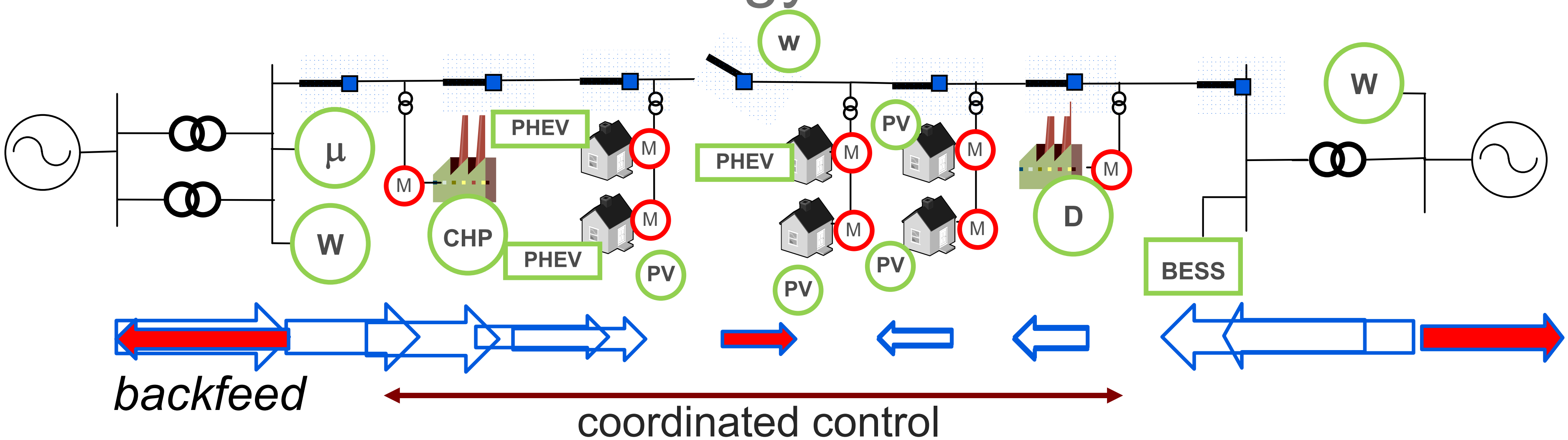
Integration of wind power into EMS

Integration of the Renewables
Distribution



Small but distributed energy sources

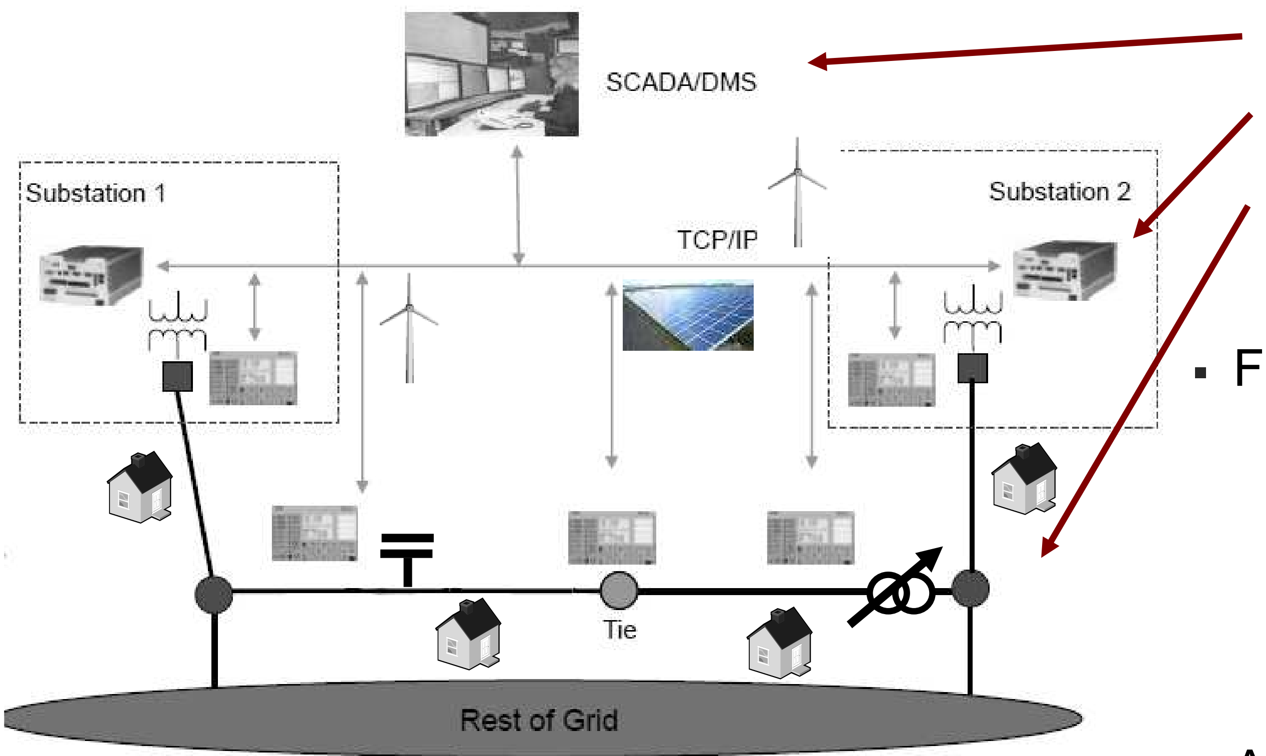
Distribution Grid with Renewables: Another Challenge
Small but distributed energy sources



- Integration of DER introduces
  - Possible backfeed into the grid
  - Intermittency uncertainty of renewables poses a challenge for grid operation
  - Many entities to control or interact with
- Thus requires
  - Protection coordination needs to be revisited
  - Incorporation of forecasting for renewable sources
  - Demands new and efficient algorithms, such as coordinated control

Management of the Distribution Grid with DER

Keep the grid healthy and optimize its operation



- Hierarchical control (various decision tiers)
  - Control center based logic
  - Substation or distributed logic
  - Device-to-device control logic
- Functions impacted
  - Voltage Var Control
  - Fault Detection Isolation Restoration
- Actuators for control in smart grid
  - Capacitors, voltage regulators
  - Demand Response
  - DER

Voltage and Var Optimization (VVO)
Improving Energy Efficiency of Distribution Grid

- Minimize (Grid losses + Peak Power Demand)

  Subject to:

  - Power flow equations

  (unbalanced multi-phase system, meshed network)

  - Voltage constraints

  (phase to neutral and phase to phase)

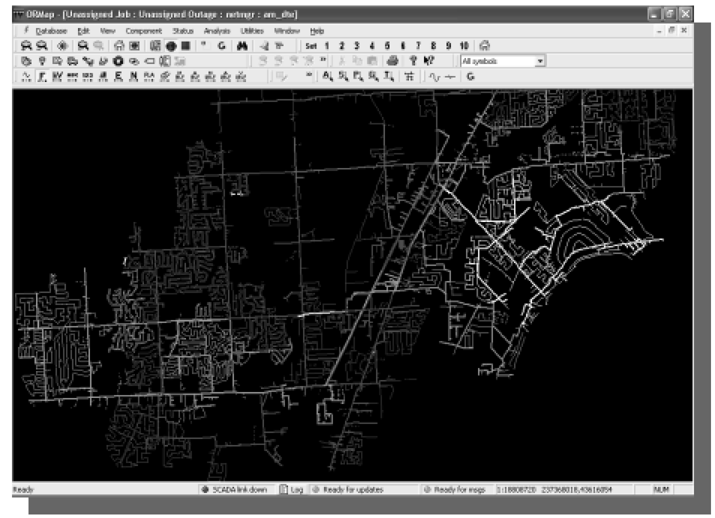
  - Current constraints

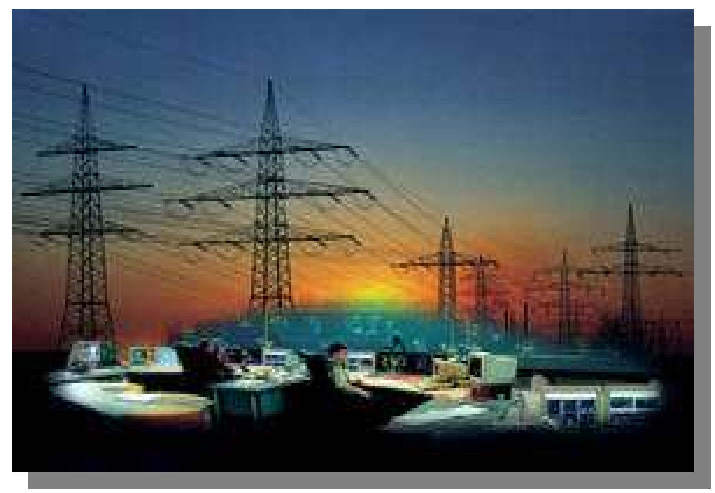
  (cables, overhead lines, transformers, neutral, grounding resistance)

  - Operational constraints of actuators

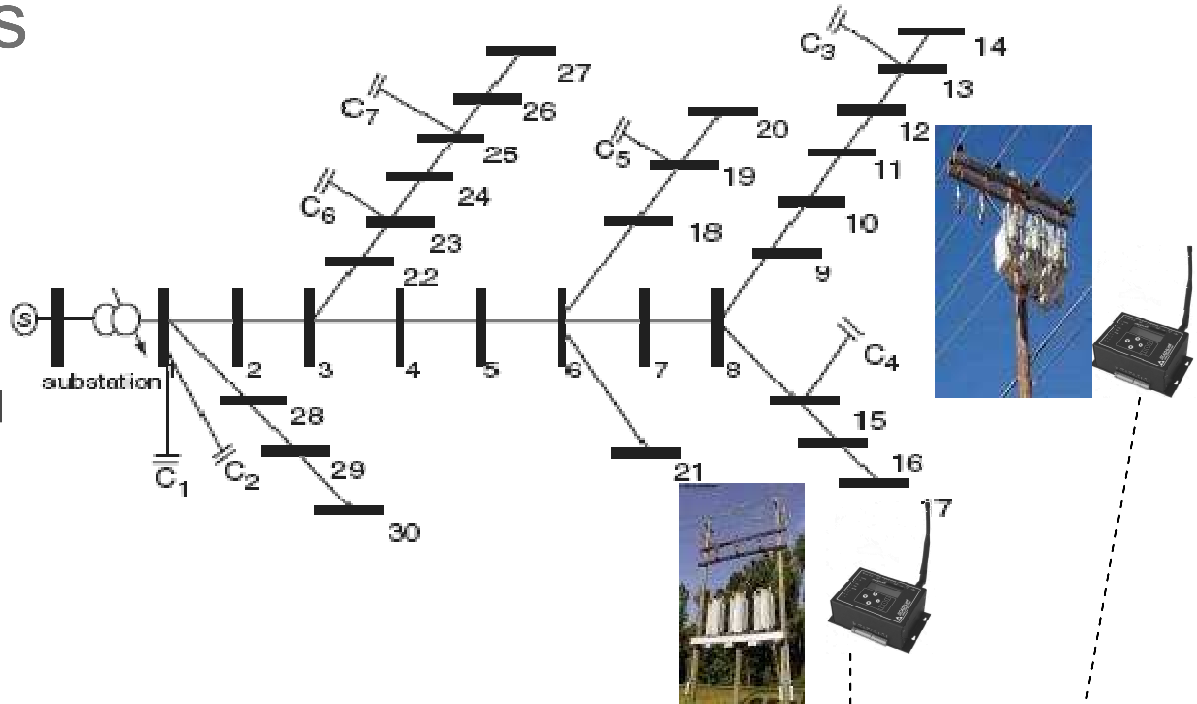
  (tap changers, shunt capacitors, …)

➔ Mixed Integer Nonlinear Programming Problem





Pictorial Depiction of VVO
System Elements



4) VVO finds best control for voltage regulators and Var resources

VVO server

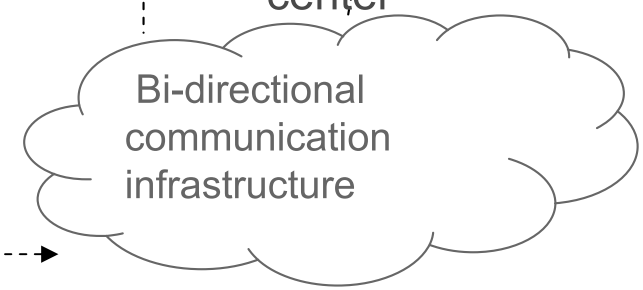
3) Load forecast based on measured data (SCADA or AMI)

1) Equipment status sent back to control center

Control Center

DSCADA/ DMS

2) System model updated using measurements



5) Control signals sent back to control equipment

Summary

HVDC Light Generation 4
Artists view

BorWin1 Off-shore platform

- Large-scale renewables, DER, smart-grids, … introduce newer challenges for reliable operation
- HVDC Light technology is mature and available for renewable connections
- Regional DC grids with one protection zone can be built today. Interregional DC grids can be built in the near future.
- Distributed Energy Resources require coordinated control
- Smart grid applications enable large data availability and larger models. Efficient and robust applications are necessary
- ABB continues to provide leading solutions in such areas

Thanks to Magnus Callavik, Ernst Scholtz, ABB

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