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The future role of storage in a smart and flexible energy system

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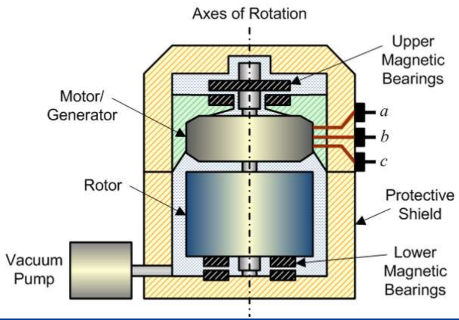
Content

- Changing environment and the challenges
- Need for storage
- Applications within different parts of the system
- Illustrative applications
- The possible role of hydro power
- The need for distributed storage
- Conclusions

Status and trend

The challenge

- The power system is in transition
- Traditionally the thinking was: Generation follows demand
- Electricity is “fresh food” with need for instantaneous balance and storage is essential for a robust supply
- Renewable energy sources are often intermittent



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Where are we today?

- Modern fossil fuel based power plants (and especially natural gas combined cycles) are becoming more and more flexible.
  - Their ramping up speed in response to rapid changes in demand is increasing.
  - They can provide reliable and flexible back-up power.

- In the short term, therefore, electricity storage needs to fill the gap between the ramping down time of wind and solar and the ramping up time of these back-up plants.

The future challenge

- Peaks and troughs in demand can often be anticipated and satisfied by increasing, or decreasing generation at fairly short notice.

- In a low-carbon system, intermittent renewable energy (RES) makes it more difficult to vary output, and rises in demand do not necessarily correspond to rises in RES generation.

- The challenge is to increase existing storage capacities and increase efficiencies.

Changing load cycles

- In the past, with one cycle per day, energy storage was rated mainly in GWh (energy capacity);
  - today the same systems are used up to 10 and 20 times per day;
  - the installed power in GW (given by the number and the size of the installed turbines) becomes more important, as the service requested has changed over the years.
- This dynamic behaviour of existing storage will increasingly move in the direction of quick and powerful response to the needs of the grid.
- Storage capacity also depends on the size of the reservoir.
- This determines the time and duration where this power is available.

Penetration levels - challenges

- When the intermittent renewable share is lower than 15% to 20 % of the overall electricity consumption, the grid operators are able to compensate the intermittency.
- This is not the case when the share exceeds 20-25%, as is reached at times in Denmark, Spain and Germany.
- When these levels of 25% and above are reached, intermittent RES need to be curtailed during the low consumption periods in order
  - to avoid grid perturbation (frequency, voltage, reactive power)
  - grid congestion, unless the RES excess can be stored.
- Alternative resources – back-up and/or storage are needed when demand does not fall at the same time as the fall in RES generation.

Alternatives principles

The possible role of gas

- Gas storage is closely linked to electricity storage.
- Some demand for storage, or seasonal variations in demand, can be covered by natural gas storage.
- Gas is an important fuel for electricity production and natural gas power plants have:
  - high efficiency (above 60% for the best available technology),
  - high flexibility and low CO2 emissions (replacing an old coal fired power plant by a natural gas fired power plant reduces the CO2 emissions per kWh up to 80%.
- In the future;
  - injection of biogas and hydrogen into the natural gas grid
  - longer term commercialisation of Carbon Capture and Storage will further decarbonise gas-powered generation

Role of storage in the future

- Energy storage will play a key role in enabling the EU to develop a low-carbon electricity system.
- Energy storage can supply more flexibility and balancing to the grid, providing a back-up to intermittent renewable energy.
- Locally, it can improve the management of distribution networks, reducing costs and improving efficiency:
  - ease the market introduction of renewables,
  - accelerate the decarbonisation of the electricity grid,
  - improve the security and efficiency of electricity transmission and distribution (reduce unplanned loop flows, grid congestion, voltage and frequency variations),
  - stabilise market prices for electricity,
  - ensuring a higher security of energy supply.

Balancing demand and supply

Applications in power system / Functionalities	Transmission grid central storage (national and European level)	Distribution grid storage (city level)	End-user storage (household level)
Balancing demand and supply	Seasonal / weekly fluctuations	Daily / hourly variations	Daily variations
	Large Geographical unbalances	Peak shaving	
	Strong variability of wind and solar		
	(electricity and gas storage need to be integrated)	(electricity and heat/cold storage need to be integrated)	(electricity and heat/cold storage need to be integrated)

Grid management

Applications in power system Functionalities	Transmission grid central storage (national and European level)	Distribution grid storage (city level)	End-user storage (household level)
Grid management	Voltage and frequency regulation	Voltage and frequency regulation	Aggregation of small storage systems providing grid services
	Complement to classic power plant for peak generation	Substitute excisting ancillary services (at lower CO_2)	
	Participate in balancing markets	Participate in balancing markets	
	Cross-border trading		

Energy efficiency

Applications in power system Functionalities	Transmission grid central storage (national and European level)	Distribution grid storage (city level)	End-user storage (household level)
Energy efficiency	Better efficiency of the global mix	Demand side management	Local production and consumption
	Time-shift of off-peak into peak Energy	Interactions grid-end user	Behaviour change
			Increase value of PV and local wind
			Efficient buildings
			Integration with district heating /cooling and CHP

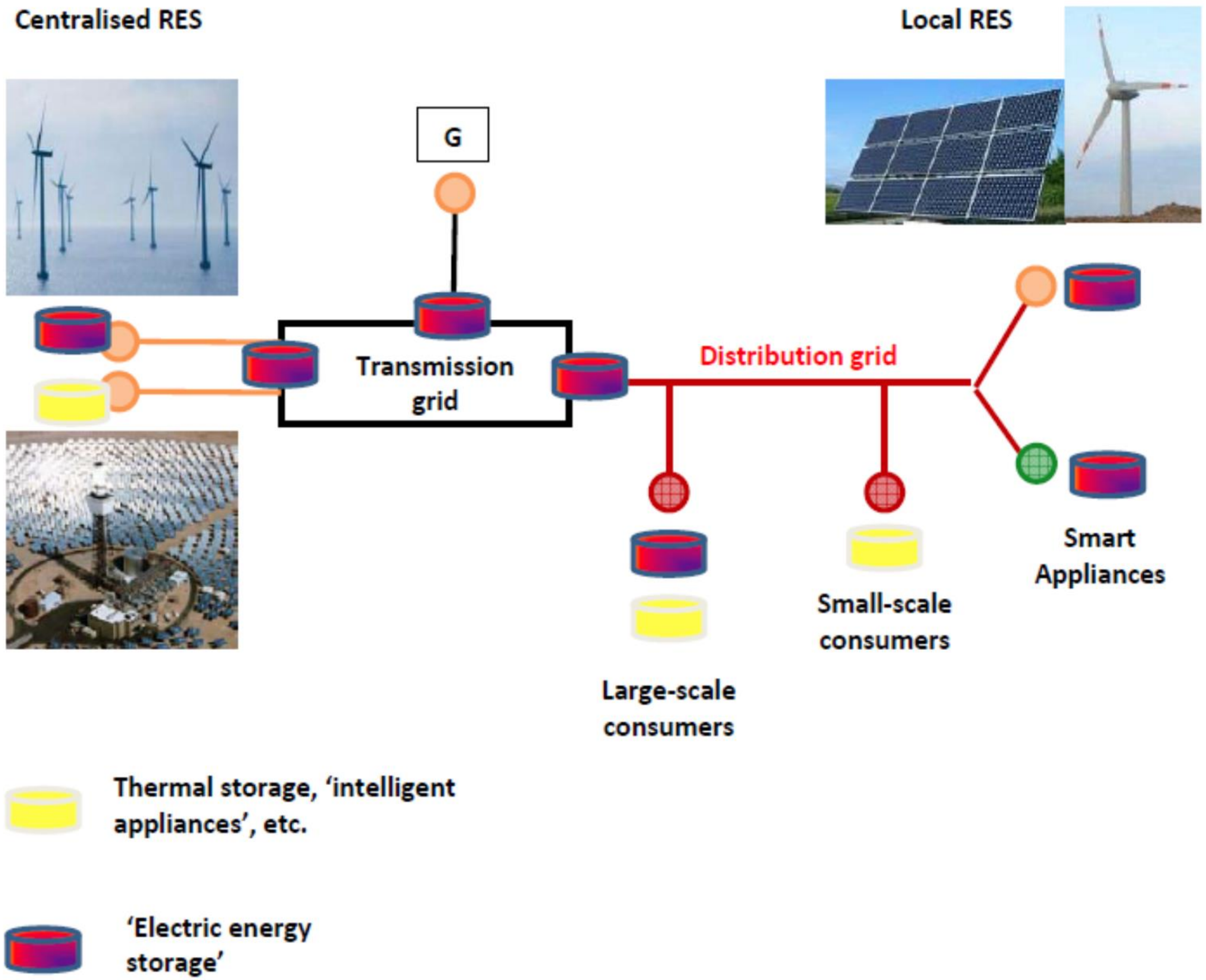
Integration issues

- Energy storage can be integrated at different levels of the electricity system:
  - **Generation level:** Arbitrage, balancing and reserve power , etc.
  - **Transmission level:** frequency control, investment deferral
  - **Distribution level:** voltage control, capacity support, etc.
  - **Customer level:** peak shaving, time of use cost management, etc.
- These different locations in the power system will involve different stakeholders and will have an impact on the type of services to be provided.
- It is important to ensure that electricity from RES keeps its RES label, even if it has been stored before the final consumption.
  - Possible feed in tariffs should not be affected by intermediate storage.
  - Only the share of renewables at the point of pumping should qualify as renewable electricity.

Integration issues (2)

- Energy storage technology can serve at various locations at which electricity is produced, transported, consumed and held in reserve (back-up).
- Depending on the location storage can be large-scale (GW), medium-sized (MW) or micro, local systems (kW).
- Energy storage needs, and patterns of access are changing (e.g. not only driven by demand side variations).
- Research and technological development is needed to enable the wider application of many known technologies, and to develop new ones.

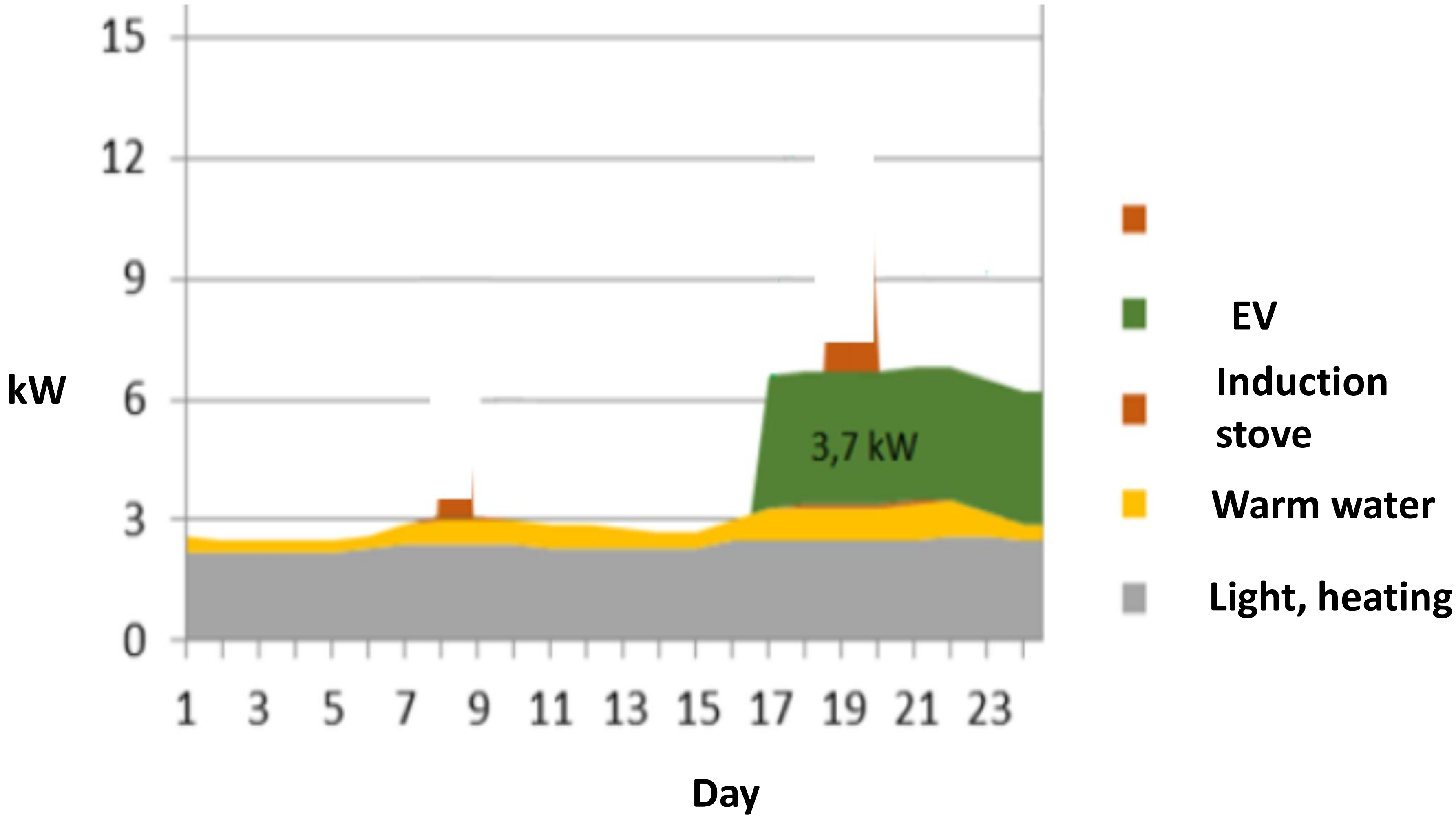
Applications of storage systems

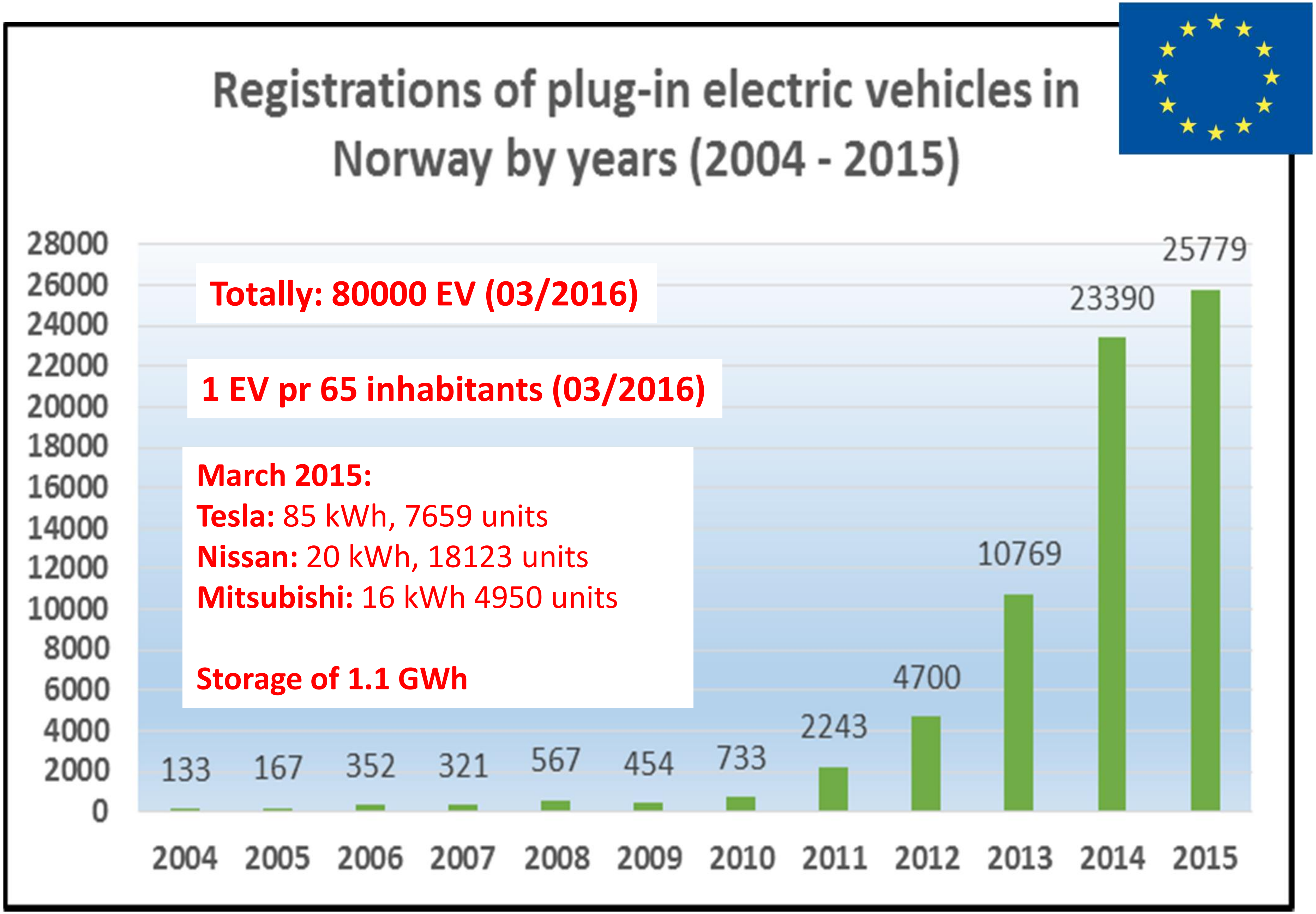


Example of need for storage in transport

- An electric ferry needs charging during unloading/loading (10 min)
- The local grid can not supply the needed amount
- A battery pack is used on each side of the fjord with continuous charging
- The ferry is then quickly charged

Power consumption profile – household




Registrations of plug-in electric vehicles in Norway by years (2004 - 2015)
Totally: 80000 EV (03/2016)
1 EV pr 65 inhabitants (03/2016)
March 2015:
Tesla: 85 kWh, 7659 units
Nissan: 20 kWh, 18123 units
Mitsubishi: 16 kWh 4950 units
Storage of 1.1 GWh
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
133
167
352
321
567
454
733
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4700
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23390
25779
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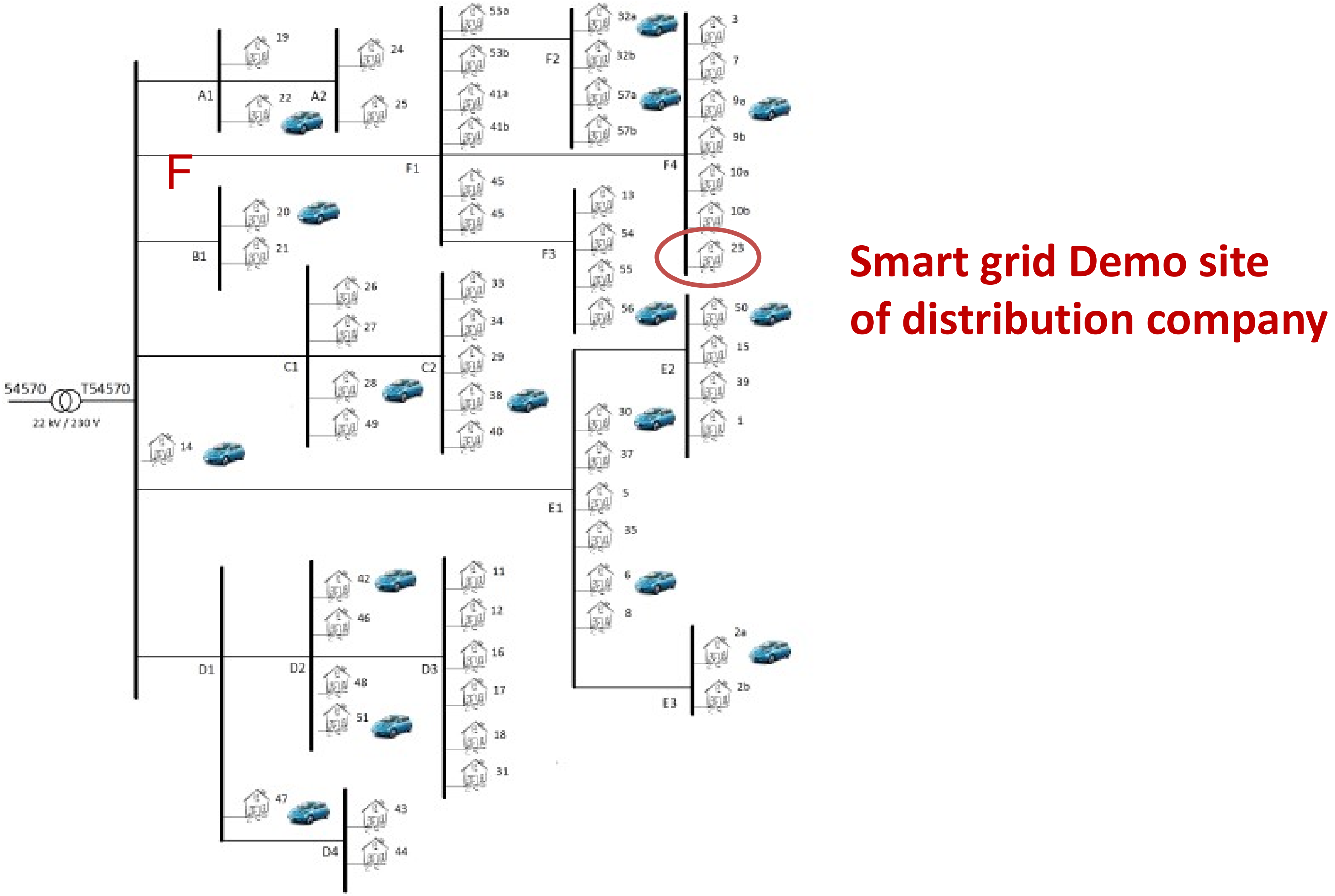


FIGURE 6.12: Allocation used for the balanced allocation scenarios with 20 percent EV adoption.

Voltage profile – different charging profiles Electric Vehicles

50% EV penetration

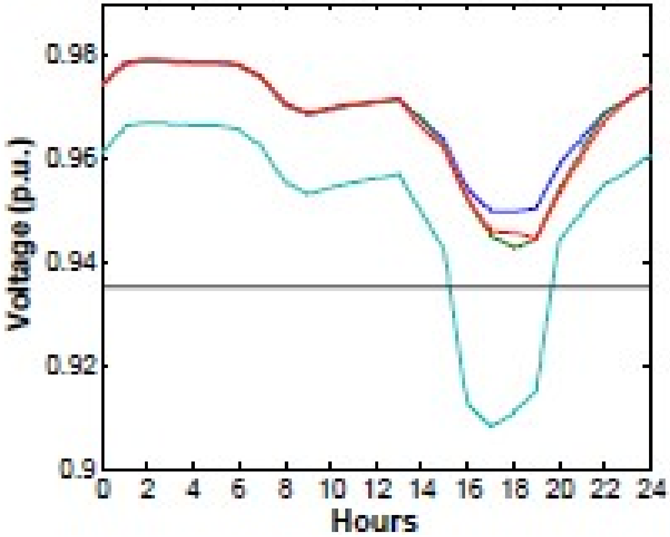


FIGURE 6.16: Voltage levels with 20 percent EV adoption connected to node F4 and dumb charging.

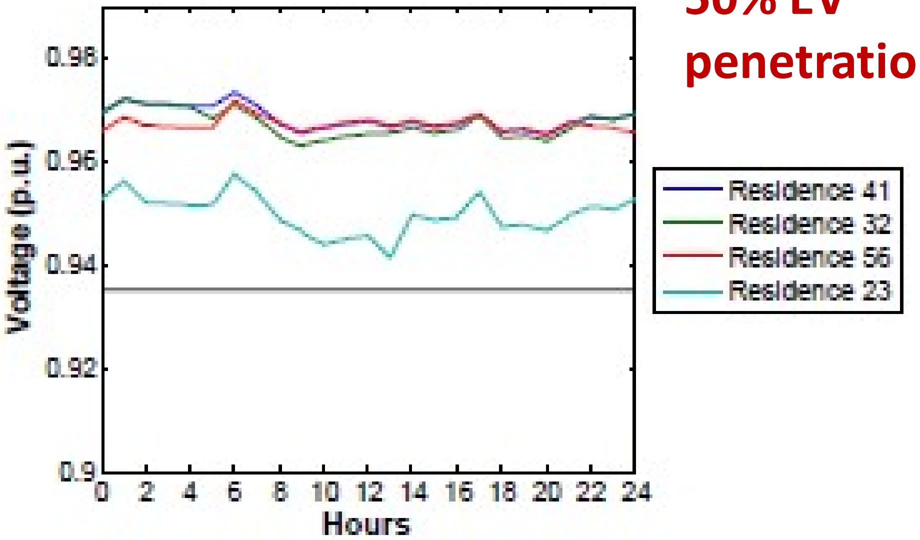
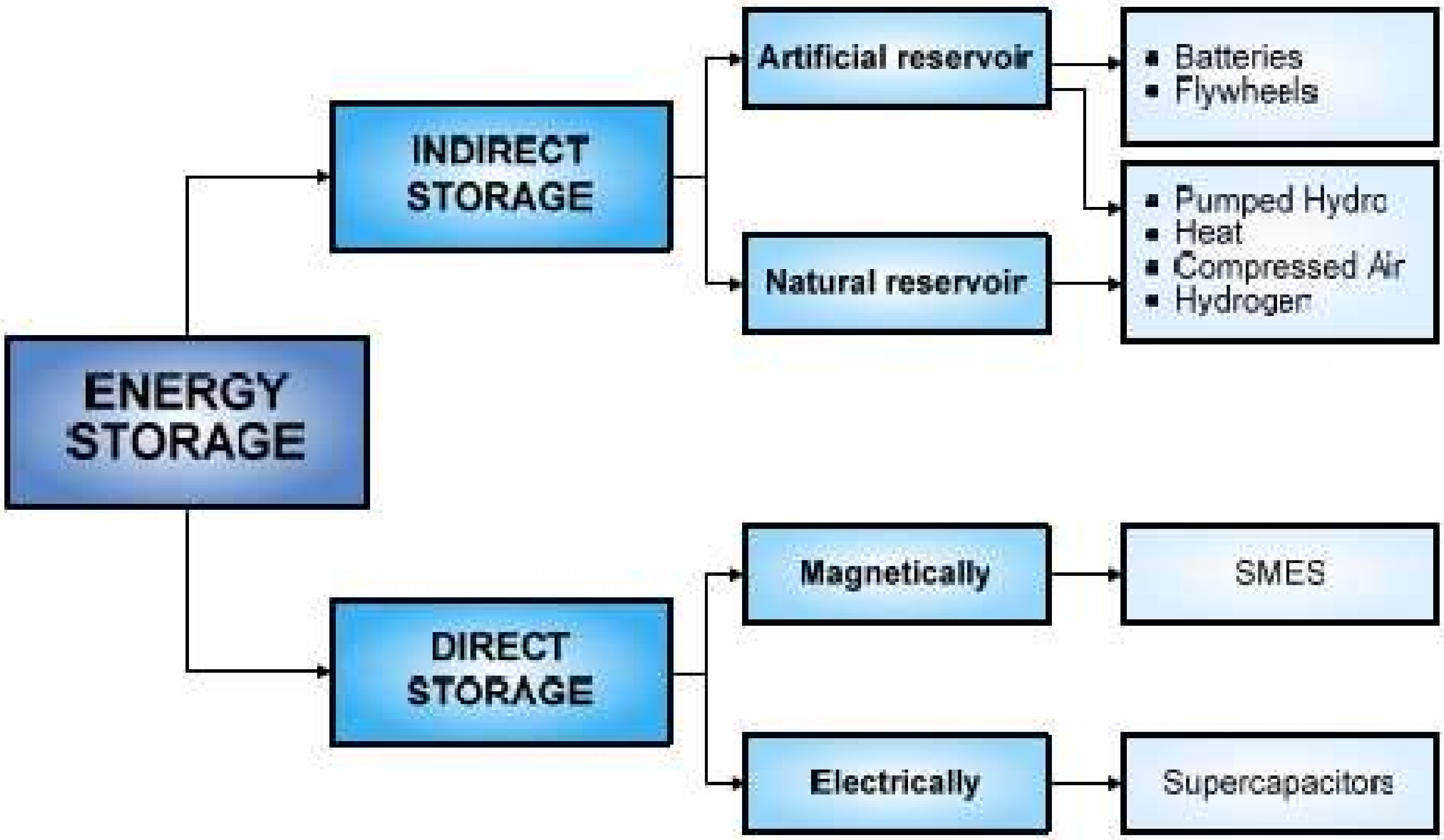


FIGURE 6.17: Voltage levels with 20 percent EV adoption connected to node F4 and smart charging.

Classes of storages



Grid storage systems

- Grid storage systems (MW) able to provide:
  - Power: super-capacitors, Superconducting Magnetic Energy Storage (SMES), flywheels,
  - Energy : batteries such as Lead Acid , Li-ion, NaS & Flow batteries
  - Energy & Power: LA & Li-ion batteries
  - Hydrogen Energy Storage / CAES / Pumped Hydro Energy Storage (PHES)(small scale, 10MW< P > 100MW, hours to days)

Bulk storage / End-user

- Large bulk energy (GW):
  - Thermal storage, pumped hydro;
  - Compressed Air Energy Storage (CAES);
  - Chemical storage (e.g. hydrogen - large scale >100MW, up to weeks and months)

- End-user storage systems (kW):
  - Power: super-capacitors, flywheels
  - Energy: batteries such as Lead acid and Li-ion
  - Energy & Power: Li-ion batteries

Drives for investments in storage

- Decisions to invest into the development of storage and deployment of adequate storage capacity will depend on the evolution of the whole energy system.

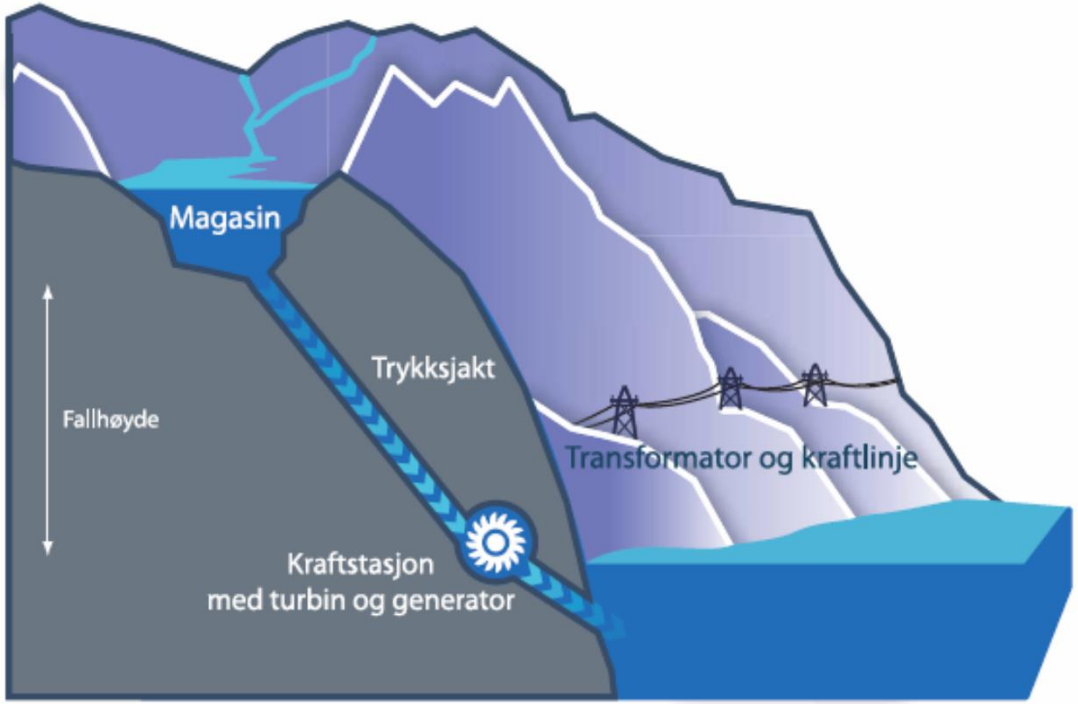
- They are closely linked to developments such as
  - electricity super-highways with large-scale RES in North Sea and North Africa combined with distributed/regional RES solutions;
  - penetration of electric vehicles;
  - improvements in demand response/demand side management/smart grids.

Hydro Power's role in the future Electricity Markets?

Hydro Power in Norway

- Electricity: ~ 100% hydro power
- Largest in Europe, nr 6 in the world
- 30% of hydro power cap. In European Union (50 % of storage)
- Installed capacity : ~ 29000 MW
- Generation average,: ~ 130 TWh
- Consumption: ~ 124 TWh
- Average inflow +- 20 %

Typical Norwegian Plant Layout



Typical characteristics:

- Plant built inside the mountains
- Tunnel system
- Large seasonal reservoirs (on average ~70 % of annual inflow)

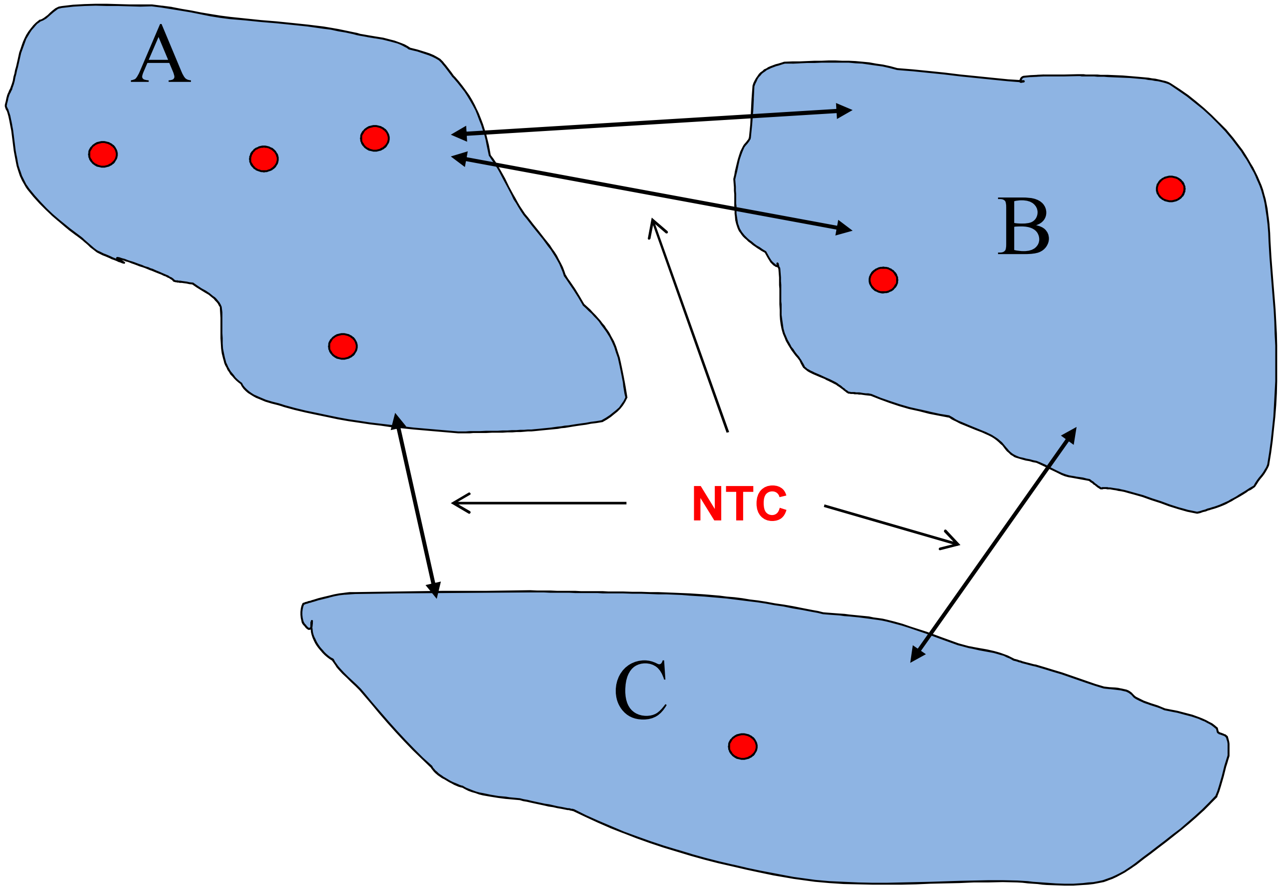
Some Issues of System Balancing

Dynamics of Power Systems and Balancing

- Imbalances of the system can be caused by:
  - Natural variation in demand and generation (normally a bit slow)
  - Large disturbances caused by tripping of large generation units or wind farms

- Dynamics after large disturbances have three characteristic stages:
  - Initial response determined by rotating masses
  - Power swings due to area imbalances (mismatch of angles)
  - Controller action of generation units (droop characteristics)

Balancing - Load and Generation profile dependency



Concluding remarks

- System development from a “generation follows load” to a flexible load/generation balancing approach
- Renewable and intermittent generation will significantly contribute to the generation mix
- Significant challenges in system development and operation
- Storage and flexible demand will be a key issue in getting a sustainable energy supply
- Storage for different purposes will have to be available

Thank you for the attention!