Demand Response

- Practical applications and network impacts in Finland

Future flexible distribution system - seminar
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Smart grids have **two main functions**, which are challenges to the distribution system:

1) **Enabler of energy-efficient and environmentally friendly open energy market**
   - interactive customer interface, integration of active resources, demand response, common market models and comprehensive ICT solutions

2) **Critical infrastructure of society**
   - fault and major disturbance management
   - self-healing networks
   - island operation and microgrids
Impact of massive development of RES regard to power system

- Example of situation in Europe in 2050

Case with only RES (wind, PV, and hydro).

→ Needs for solutions (additional generation, Demand Side Response, grid, storage,....), in order to ensure adequacy (+400 GW/ -200GW).
Power generation capacity added in the EU27 in 2012 (MW)

- **PV**: 16,672 MW
- **Wind**: 11,895 MW
- **Gas**: 10,535 MW
- **Coal**: 3,065 MW
- **Biomass**: 1,338 MW
- **CSP**: 833 MW
- **Hydro**: 424 MW
- **Waste**: 50 MW
- **Nuclear**: 22 MW
- **Fuel oil**: 7 MW
- **Wave and tidal**: 6 MW
- **Geothermal**: 5 MW

Decommissioned and Installed
Load curve of whole Finland at 7.2.2007
Fluctuation of national power demand and the spot price of electricity in Finland
Transformer load, consumption of piloted customer1 and the spot price of electricity

Lähde: Aalto Joni, Development opportunities for smart metering services …., Diplomityö, TTY, 2011
The benefits and market places of the DR/DSM from the viewpoint of different stakeholders

- **DSM**
  - **Customer**
    - Energy cost minimization
  - **DSO**
    - Peak power limitation
  - **Retailer**
    - Spot-markets
  - **Balance management**
  - **TSO**
    - Balancing power market
    - Reserve power market

  - Elspot-market
  - Elbas-market

  - Frequency controlled:
    - Normal operation reserve
  - Frequency controlled disturbance reserve
  - Automatic Frequency Restoration Reserves
  - Fast disturbance reserve
Demand Response – actors and needs

• **End customer (i.e. customer / prosumer)**
  – decreasing electricity purchase costs, optimizing consumption based on output of own generation, peak cutting, optimizing the size of main fuse

• **Energy retailer**
  – optimization of the procurement of the electricity (portfolio optimization), management of the balance between procurement and sales, novel products and pricing structures, new business opportunities

• **Distribution System Operator (DSO)**
  – peak cutting in normal and disturbance situation, using demand response as a substitute for back-up lines, optimizing the dimensioning of the network for long term network planning

• **Transmission System Operator (TSO)**
  – system level power balance and frequency control (balancing and reserve power) in normal and disturbance situations

• **Service provider / “Flexible operator”**
  – infrastructure, new service based business opportunities
The benefits and market places of the DSM from the viewpoint of different stakeholders

- **Customer**
  - Energy cost minimization

- **DSO**
  - Peak power limitation

- **Retailer**
  - Spot-markets
  - Balance management

- **TSO**
  - Balancing power market
  - Reserve power market
    - Frequency controlled normal operation reserve
    - Frequency controlled disturbance reserve
    - Automatic Frequency Restoration Reserves
    - Fast disturbance reserve
## Market places for Demand Response in Finland

<table>
<thead>
<tr>
<th>Market place</th>
<th>Type of contract</th>
<th>Min. size</th>
<th>Activation time</th>
<th>How many times activated</th>
<th>Price level 2014 *)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency controlled normal operation reserve</td>
<td>Yearly and hourly markets</td>
<td>0.1 MW</td>
<td>3 min</td>
<td>Constantly</td>
<td>15.8 €/MW,h (yearly market) + price of electricity</td>
</tr>
<tr>
<td>Frequency controlled disturbance reserve</td>
<td>Yearly and hourly markets</td>
<td>1 MW</td>
<td>5 s/50%, 30 s/100%, when f &lt; 49.9 Hz OR 30 s, when f &lt; 49.7 Hz and 5 s, when f ≥ 49.5 Hz</td>
<td>Several times per day</td>
<td>4.03 €/MW,h (yearly market)</td>
</tr>
<tr>
<td>Frequency controlled disturbance reserve (on-off-model)</td>
<td>Long-term contract</td>
<td>10 MW</td>
<td>Instantly, when f under 49.5 Hz</td>
<td>About once a year</td>
<td>~0.5 €/MW,h + 580 €/MWh + activation fee 580 €/MW</td>
</tr>
<tr>
<td>FRR-A</td>
<td>Hourly market</td>
<td>5 MW</td>
<td>Must begin within 30 s of the signal's reception, fully activated in 2 min</td>
<td>Several times a day</td>
<td>Hourly market + energy price</td>
</tr>
<tr>
<td>Balancing power market</td>
<td>Hourly market</td>
<td>10 MW</td>
<td>15 min</td>
<td>Several times per day</td>
<td>Market price</td>
</tr>
<tr>
<td>Fast disturbance reserve</td>
<td>Long-term contract</td>
<td>10 MW</td>
<td>15 min</td>
<td>About once a year</td>
<td>~0.5 €/MW,h + 580 €/MWh</td>
</tr>
<tr>
<td>Elspot **)</td>
<td>Hourly market</td>
<td>0.1 MW</td>
<td>12 h</td>
<td>-</td>
<td>Market price</td>
</tr>
<tr>
<td>Elbas **)</td>
<td>Hourly market</td>
<td>0.1 MW</td>
<td>1 h</td>
<td>-</td>
<td>Market price</td>
</tr>
<tr>
<td>Strategic reserves ***</td>
<td>Long-term contract</td>
<td>10 MW</td>
<td>15 min</td>
<td>Rarely</td>
<td>-</td>
</tr>
</tbody>
</table>

*) The prices are suggestive; more detailed terms and pricing principles are in agreements relating to each market place.
**) Nord Pool Spot
***) The Energy Authority

**Elspot**, **Elbas** and **Strategic reserves** are operated by the Energy Authority.

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**FRR-A** is a service for controlling short-term and fast frequency deviations. It is activated mainly by the power system operator to prevent additional grid disturbances caused by large-scale disturbances.

**Balancing power market** is a service for providing balancing power on a short-term basis.

**Fast disturbance reserve** is a service for providing disturbance reserve on a short-term basis.

**Elspot** and **Elbas** are balancing power markets that allow price-responsive power generation to participate in balancing power transactions.
An example of economical potential of DR in different market

- Simulated annual economical potential of 1 MW controllable load in different market based on price information in 2011-2013
Smart Metering in Finland

• Finland is a forerunner in large-scale AMR roll-out in worldwide, not only in coverage of installations but also in functionality and utilization of AMR system in various business processes of DSOs and energy retailers

• In 2009 the Finnish Government passed a new act, which states that at least 80% of the customers of each DSO must have AMR implemented by December 31, 2013
  – In practice almost all customers (~98%) are provided by a new AMR meter
  – The law requires the AMR meter that features hourly energy measurement as well as registrations of quality of supply and demand response functionality

→ balance settlement is based on measured hourly energy consumption of the end-users
→ enables dynamic pricing of the electricity in retail market

13.9.2010 - 19.9.2010
Hourly measurements of a household customer
Using AMR in various processes of DSO and retailer

- AMR system installation is not only energy remote reading, but it enables real-time two-way communication between customers and other actors and offers huge amount of data for developing new functions for Smart Grids, e.g.:
  - improved competition in electricity market, hourly measurements, dynamic tariffs, energy efficient actions, more detailed load models (even customer-specific), network operation of low voltage network, power quality monitoring, market-based demand response, software fuse, improved customer service, etc.
Load control by using AMR meters

End customer

- **End customer’s AMR meter**
  - **Katkolaite** (Kytkee kaiken kuorman pois)
  - **Rele 2** Alkarele (ohjauskaatumukset ohjelmatoimissa)
  - **Rele 1** Kuorman-ohjausrele (ohjausväline ohjausrele)
  - **Kuorma 1**
  - **Kuorma 2**

Distribution system operator

- **IT systems of DSO**
  - Tiedonsiirto mittarille (3G, PLC, GPRS, IP…)
  - Mittarin ohjelmointi
  - Statustietoja, luentotietoja
  - Luenta-järjestelmä

- Palveluväylä (ESB)
  - Sanomamuunnin
  - Asiakastietojärjestelmä
  - Mittautstietokanta

Energy retailer

- Sähkömarkkinat
  - EDIFACT

Diagram:

- **Katkolaite**: Cuts off all the loads.
- **Rele 2**: Control relay (can be programmed).
- **Rele 1**: Load control relay (can be controlled via signal).
- **Kuorma 1** and **Kuorma 2**: Loads.
- **IT systems of DSO**: Data transfer to the meter (3G, PLC, GPRS, IP…).
- **Luenta-järjestelmä**: Communication system.
- **Palveluväylä (ESB)**: Service pathway.
- **Sanomamuunnin**: Message conversion.
- **Asiakastietojärjestelmä**: Customer information system.
- **Mittautstietokanta**: Measurement database.
- **Sähkömarkkinat**: Electricity market.
- **EDIFACT**: Electronic Data Interchange for Administration, Transaction, and Commerce.
Load control potential by AMR today based on the enquiry to Finnish DSOs

**Relay 1 (direct control)**
- controllable in ~40% of AMR meters
- ~270 000 customers, who has controllable loads
- ~800 MW loads to be controlled
- Part of them can be controlled based on time (ToU)

**Relay 2 (ToU relay)**
- controllable in ~60% of AMR meters
- ~200 000 customers, who has controllable loads
- ~1000 MW loads to be controlled

Responses covered 74% of customers in Finland
Tariff structures in Finland

- **Energy retailer’s tariffs components**
  - basic fee (€/month)
  - energy-based fee (€/kWh), fixed or time-of-use (daytime / night time)
  - as a new product also dynamic tariffs (€/kWh), e.g. based on spot-price

- **DSO’s tariff components**
  - basic fee (€/month)
  - energy-based fee (€/kWh), fixed or time-of-use (daytime / night time)
  - power fee (€/kW) for bigger customers
  - new possible tariff structures under investigations
    - power tariff also for small customers
    - power band
    - various new combinations
    → incentives for DR from DSO viewpoint

- **Customers wants to minimize the sum of electricity costs**
Demand Response from DSO and energy retailer point of view

- DSO and energy retailer may have conflict of interest when using Demand Response functions
  - both actors can offer products (or services) which have effects on customers’ load demand and impacts on business of the other actor
    - energy retailer: spot-price based or other dynamic products
    - DSO: novel power or time-of-use based network tariffs
Network impacts of Demand Response

- Impacts of spot-price based product of retailer and various power-based network tariffs are studied by simulations in the real distribution network of one 110/20 kV primary substation supplying
  - 457 km MV and 793 km LV network, 469 secondary substations
  - 7612 customers, whose hourly AMR measurement data over several years were available
The “hypothetical” load control set-up assumed in the simulations

Simulated cases:
- control only based on spot-prices
- control only based on power based network tariff
- control (minimization) based on the combination of the both above cases
Simulated power based network tariffs

1. Power fee tariff (PT1)

2. Peak power based energy charge (PT2)

3. Hourly distribution charge based on hourly power, continuous version (PT3)

4. Hourly distribution charge based on hourly power, stepwise version (PT4)

5. Power band (e.g. 3, 5, 8, 10 ja 13 kW)
   - fixed monthly cost [€/month] based on the annual peak power
   - penalty based on the number of overruns or the magnitude of overrun
The hourly spot-price (area price in Finland)

[Graph showing the hourly spot-price of electricity in Finland from 1.11.2011 to 31.10.2012.]
Network impacts of Demand Response

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Original hourly AMR-data of 7612 customers used in load flow calculation of original situation

Simulated hourly load curves of each 7612 customers over the whole year based on different minimization criteria to be used in load flow calculations in different case studies
Peak powers of secondary transformers

- peak powers are presented in percentages of the transformers' ratings
- the vertical orange dash lines represent the average peak power level and the vertical red line the more or less critical limit 100%.
Peak powers of secondary transformers

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- the vertical orange dash lines represent the average peak power level and the vertical red line the more or less critical limit 100%.
Average annual total costs of the customers with different types of distribution tariffs in different simulated case studies

- Remark: Average annual total costs of the customers is 1617 €/a, when optimization is done using spot-price based energy price and customers’ present network tariff.
Demand Response from DSO and energy retailer point of view

- DSO and energy retailer may have conflict of interest when using Demand Response functions
  - both actors can offer products (or services) which have effects on customers’ load demand and impacts on business of the other actor
    - energy retailer: spot-price based or other dynamic products
    - DSO: novel power or time-of-use based network tariffs
- Impacts of spot-price based product of retailer and various power-based network tariffs are studied by simulations in the real distribution network
  - Spot-price based load control may increase peak powers in the distribution network
  - Power based network tariff mitigate the peak powers in the network due to the spot-price based load control
  - Total costs of customers can be minimized by taken both viewpoints into account
Realization of Demand Response in different market places in Finland

1) **Day-ahead (Elspot) market:** Spot-price based (dynamic hourly tariff) demand response can be realized by the load control relay used in Time-of-Use based control. There are over 1000 MW loads (e.g. electric storage heating, water boilers) to be controlled. This means ~7% of the whole Finnish power system peak demand.

- to be applied in practice still call for robust, reliable and enough fast communication and data interfaces between IT-systems of energy retailers and DSOs
Realization of Demand Response in different market places in Finland

2) **Intra-day markets (Elbas, balancing power):** Practical realization is more challenging due to lack of enough reliable and fast communication and data-interface practices, and installations of AMR meters and switchboards at customers site. However, there are about 1000 MW load to be controlled.

3) Present AMR –technology cannot be used as such for fast control actions e.g. for reserve markets. For example, using local frequency measurements still need further development.

4) "Software fuse" –functionality of AMR meters can be applied for simple realization of power based distribution tariff at customer site. However, the power based tariff can be applied also without it.

5) More advanced systems (e.g. HEMS) are needed, if small customers’ loads were offered to reserve markets, or e.g. in using customer’s own production in full for customer’s own loads, or in more advanced control of power limit.

6) Building Automation and Control Systems (BACS) can be applied to more demanding control processes in bigger building of commercial and public sector, where clear business benefits may be found, e.g. in control of ventilation or cooling loads.
Piloted HEMS solution in Elenia Oy for few customers

- Theregate HEMS solution
- Interfaces to
  - AMR meter for total consumption (5 s interval)
  - equipment (i.e. loads and temperature measurements)
  - spot price of electricity
  - customer Web application
- Pilots of
  - power limit based load control of direct electric space heating
  - spot-price based control of water boiler
Steering principle of the power limit based load control

- **Threshold value exceeded. Activate Load 2.**
- **P < hysteresis value, so Load 1 can be deactivated.**
- **P < hysteresis, deactivate Load 2.**

**Time (min):**
- \( t_1 \)
- \( t_2 \)
- \( t_3 \)
- \( t_4 \)
- \( t_5 \)
- \( t_6 \)
- \( t_7 \)
- \( t_8 \)

**Normal mode, P < tr:**
- **P > tr, activate Load 1.**
- **P > hysteresis, wait before deactivate Load 2.**
- **P < threshold, wait.**

**Power (kW):**
- **Threshold**
- **Hysteresis**
Experiences on a pilot customer
(direct electricity space heating, fireplace, wood warmed sauna)

Yearly power consumption of the pilot customer as duration curve

Priority list of the controllable heating loads and duration of the time that the load has been switched off on 22.11.2012

<table>
<thead>
<tr>
<th>Load</th>
<th>Load off</th>
<th>Nominal power (W)</th>
<th>Average power drop (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Kitchen</td>
<td>1:16</td>
<td>600</td>
<td>300</td>
</tr>
<tr>
<td>2 Washroom</td>
<td>0:54</td>
<td>550</td>
<td>500</td>
</tr>
<tr>
<td>3 Children's bedroom</td>
<td>0:29</td>
<td>2000</td>
<td>550</td>
</tr>
<tr>
<td>4 Master bedroom</td>
<td>0:15</td>
<td>800</td>
<td>350</td>
</tr>
</tbody>
</table>
Experiences on a pilot customer - operation of power limit based load control
Experiences on a pilot customer - effects of load control to load curves

- Typical weekday in December in 2010, 2011 and 2012
  - HEMS pilot was in operation in 2012 (green curve)

  → time of the peak load due to the water boiler in the late evening has moved to cheapest spot-price hours during night times
  → loads during daytime are at lower level
Experiences on a pilot customer  
- effects of load control to load duration curves

- Load duration curves in February of 3 years with no temperature correction  
  → fewer peak powers and a small lump at 4-5 kW load level in 2013
Demand response versus energy saving

Load duration curve

- Demand response
- Energy saving

Hours of the whole year
Alternation of loads for connection point peak load reduction (e.g. due to power based distribution tariff)

- Co-ordination of controllable loads like electric vehicle, water heater, electric heating and sauna stove may prevent overloading
  - alternation controller
  - prioritization of demands

- Electric vehicle charging will remarkably increase electricity demand (power)
  - charging during the peak load may overload the electricity connection
  - otherwise the capacity of connection should be increased → costs
  - if overloading is occasional, more efficient utilization of connection is wise
Smart Metering

- Smart Metering has been seen as an essential part of Smart Grid vision, especially for
  - interconnection of distributed generation
  - load control and demand side management
  - efficient use of energy
  - quality of supply
  - active distribution network management
Smart Metering towards Interactive Customer Gateway

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  - efficient use of energy
  - quality of supply
  - active distribution network management
Interactive Customer Gateway

Market players
- TSO, DSO, retailer, wholesaler, aggregator

Grid
- Demand management
- Power quality monitoring
- Supply security management

Interactive Customer Gateway
- Generation management

Energy storages
- Batteries, capacitors, electromechanical, hydraulic, etc.

Loads
- Direct load control
- Power quality management
- Power balance management
- Safety management

Generation
- PV, wind, biogas, fuel cell, etc.

Direct control signals
- Demand profiles
- Elasticity profiles
- Price signals

Information systems

Controllable, non-controllable, customer-oriented prioritisation

Mobile storages
Market models for realising DR

The full utilisation of market based demand response requires the development of new business models and tools e.g. for aggregators operating between customers and electricity market.
DR operator (i.e aggregator or VPP) as new service business actor

*Key issue is how to divide costs and incomes!!!*

Equipment to be controlled

Customers

Electricity market

- Customers
- Equipment to be controlled

Billig information:
- energy
- operations
  - number / time

Control information:
- starting / stopping
- operating time
Thank you for your attention!

Any questions?