How to develop and manage a power system with more than 20% penetration of wind power?

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EWEC 2009, 18th of March, 2009, Marseille, France

A realistic snapshot of the sector…

- **Several countries and regions in <u>Europe already have high wind penetration (>10%)</u>.**
- **Wind generation is highly variable in time and space and it doesn't offer guarantee of power. Very high <u>(>20%) penetration requires large added reserves</u> (and costs…);**
- **<u>Operation strategies</u> to cope with wind generation from a high to a very high level <u>are being developed</u>: there are <u>solutions already identified</u> and/or in use for the most common grid/system constraints.**

In realistic terms with the existing constraints to reinforce the transmission network, on a "business as usual" scenario, it may take several decades to reach 20% wind penetration on the European scale.

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How to address the known problems?

A. Limited Capacity of the grid;

B. Wind that doesn't offer Security of Supply, may require significant Added Reserves and also impacts on conventional Power Unit Scheduling;

C. Operation and management great "challenges":

  – in power systems with significant amounts of rigid generation (either non dispatchable renewable or nuclear), to foresee large integration of wind may produce Energy Congestion and a difficult Surplus Management;

D. Large wind integration affects the robustness of the system operation.

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Answer: "one by one…"

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Tools, Methods and Solutions:
1. For the Grid Capacity

The transmission grid limited capacity is…

1) The most classical "technical" barrier

- *- Although is really an economic, environmental and social one, not a technical…*

2) Common to all new power plants, RES or not.

3) Requiring a new transmission grid planning approach:

Taking into consideration the difficulties felt by all TSOs for the construction of new transmission lines it becomes "mandatory" to improve the existing network efficiency and utilization;

- *by using online monitoring (temperature, wind, loads, etc),*
- *by introducing new components as FACTS and phase shift transformers or;*
- *by upgrading degraded components as cables, protections and transformers –*

all these are urgent measures for TSOs.

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Solutions: Smart dealing with Grid Capacity

GIS location of the wind resource "as geographical wind dams" and grid connection demands from the wind farm developers, enable the DSO and TSO to define, if necessary:

1. *When and where to extend the transmission network to avoid large investments for low wind sites or small wind farms.*
2. *Grid planning should take into consideration the special characteristics of wind generation, i.e., its time and space variability and consider grid reinforcement vs grid monitoring and wind power control. Curtailment may prove to have high economic benefits and should be assessed.*
3. *Combined probabilistic and deterministic approaches are the most appropriate, with the wind modeled with spatial correlation factors resulting from the wind resource GIS mapping.*

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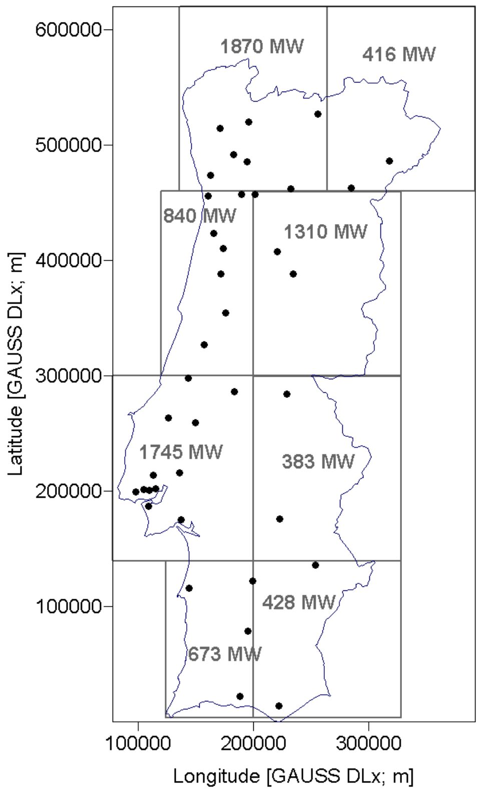
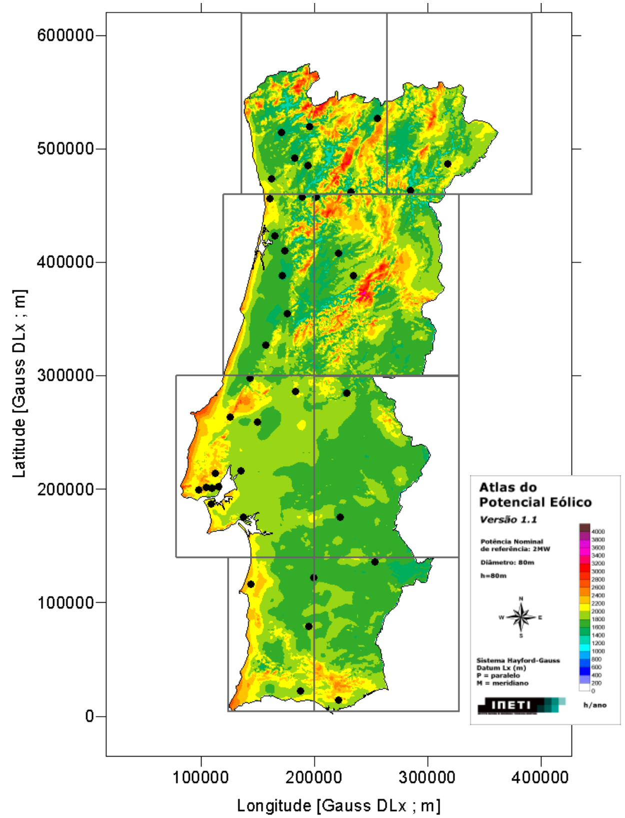
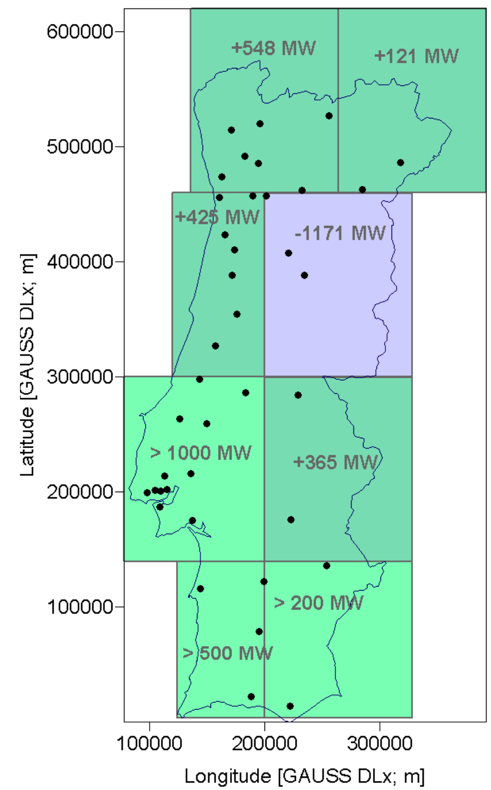
Taking the grid into wind power planning...



a) Grid capacity in 2013 (~7000 MW)



(b) Onshore sustainable wind resource 5900 MW (aprox.) + >1000 MW offshore



(c) Deficit/superavit by region

Local distribution of wind resource vs. TN capacity

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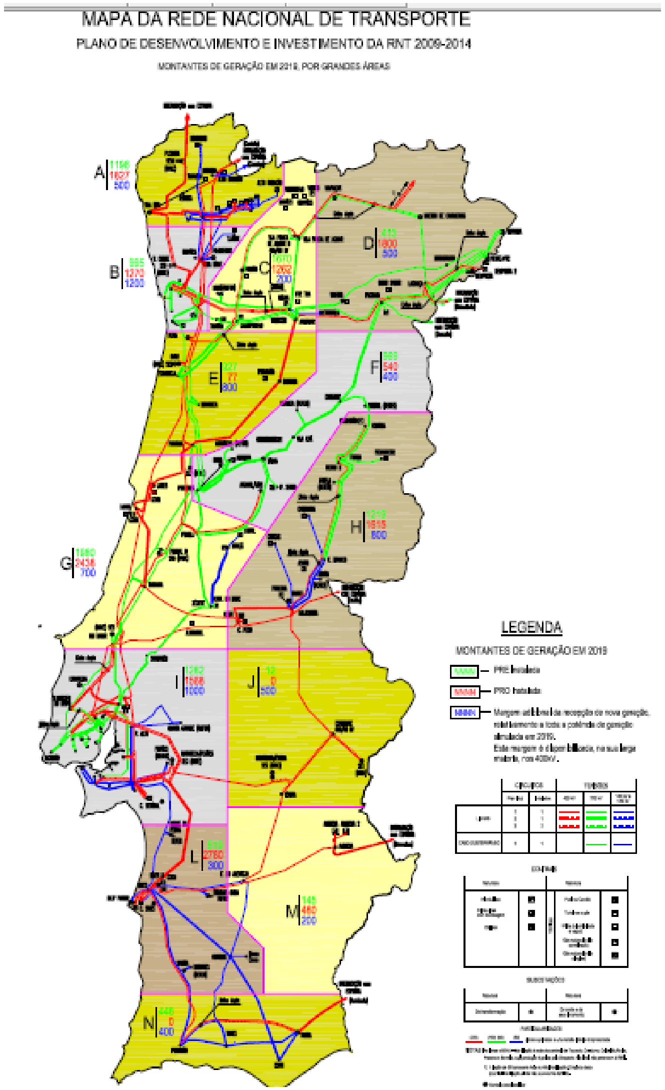
... and taking the wind resource into grid planning



Source: REN

Find RES and load synergies and characterize the existing externalities,

The grid development plan to assess the wind power integration should also characterize the correlation with other RES (mainly hydro and solar, where applicable) to incorporate externalities and enable to accommodate the maximum RES penetration

Technical Barriers to High Wind Penetration

B. Security of Supply. Balancing and Unit Scheduling

1) Balancing Power

Wind is (totally) time dependent and gives (almost) no guarantee of firm power… there are added costs for wind integration in some power systems, specially for penetration >10%

2) The "Wind Power Variability"

Wind forecasts are improving every day, being used by all TSOs in Europe with acceptable deviations within the useful time ranges for power system operation. The larger the control system the lower the correlation and the smoother the wind power output.

3) Wind Generation Robustness

The main concern of every TSO with high penetration is the sudden disconnection of all or most of the wind generation as a response to a fast grid perturbation, normally referred as a "voltage dip".

The key to overcome all these issues is to add flexibility to the power system.

Different generation mixes face different challenges…

C. Operational Energy Congestion. Surplus Management

1) In power systems where the **energy mix is flexible** and has a "portfolio approach" with complementary regulation capabilities, the cost with added reserves associated with the large integration of wind in the system is lower

   - e.g. high penetration of hydro plants with storage capacity. In countries /control areas as Portugal and Norway the flexibility given by the high hydro penetration easies things.

However…

2) an issue commonly referred in these systems is the possibility of **surplus of renewable generation** (e.g. "wind + hydro") that raises the uncomfortable issue of either disconnecting wind generators or spilling water

   - which would be turbined in the absence of wind. The issue is (again) more economical than technical. Interconnection and available ancillary services on larger scales contributes to solve this problem.

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Tools, Methods and Solutions:
2. The wind technology contribution

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From "farming the wind" to the (Virtual) Wind Power Plants era…

Innovative Characteristics of the Wind Power Plants

- Management of wind parks by clusters ("local wind power dispatch centers") – already in use in Spain and Portugal;
- Additional variable reactive power control: e.g tg ϕ within [-0.2, +0.2];
- Curtailment of wind production for forecasted no-load periods;
- Participation in the primary frequency control (e.g. 5% of P);
- LVRTF – Low voltage *ride through fault* capability;
- Solutions for "Wind/RES energy storage", e.g. in pumping stations, when available and cost-effective.

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Wind Power Control: DSOs and Virtual Wind Power Plants

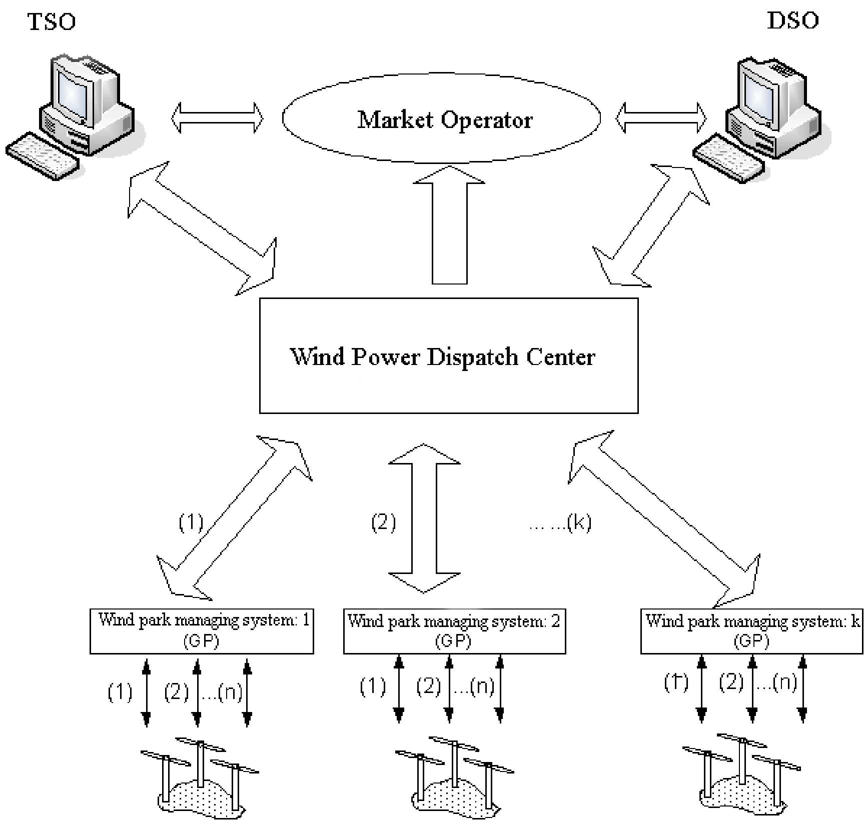
Installation of Wind Dispatch Centres

"Generation Aggregation Agents"

*wind power dispatch centres enable to monitor and adapt the wind production injection to the network operating conditions without compromising security operational levels thus enabling to implementi the concept of **"Virtual Wind Power Plants"***

The 1st "Wind DSO" started operation in Portugal in 2009 and has 400 MW connected.*

The 2nd already has more than 300 MW and is under tests.*



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(*)source: Enerconpor

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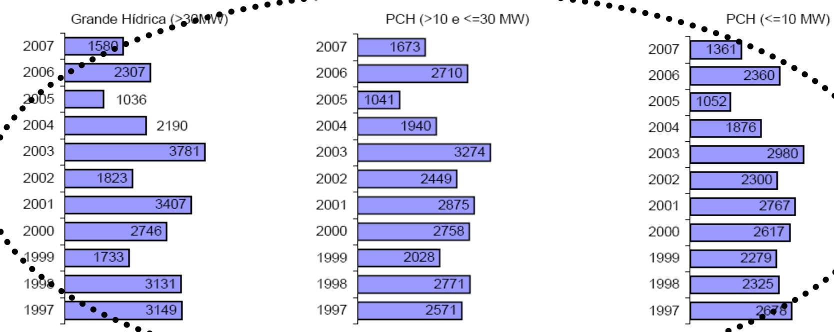
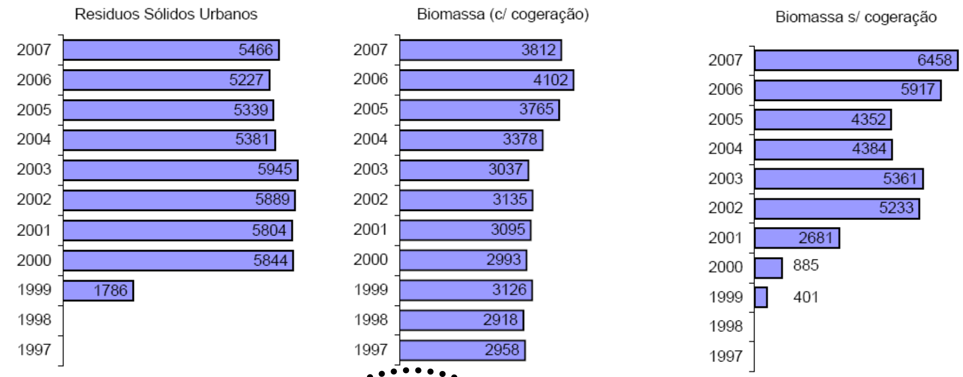
Extend the VWPP concept to Virtual RES Power Plants

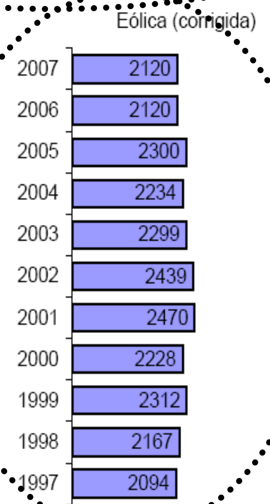
Large, small and micro hydro



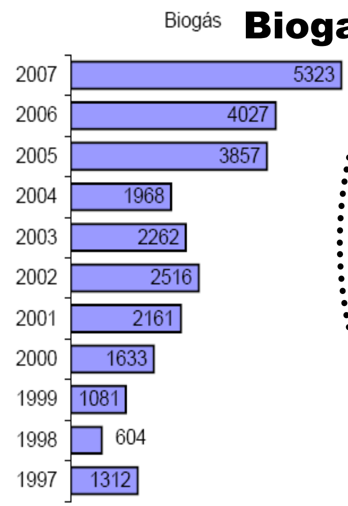
RSU, biomass (w/ and without cogeneration)

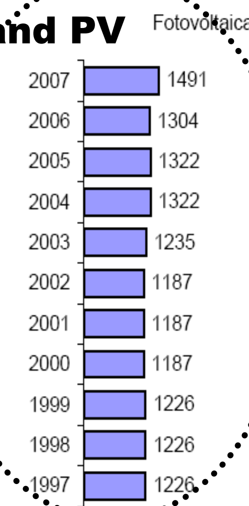


Wind



Biogas and PV





source: DGEG

Yearly full hours of operation by RES technology

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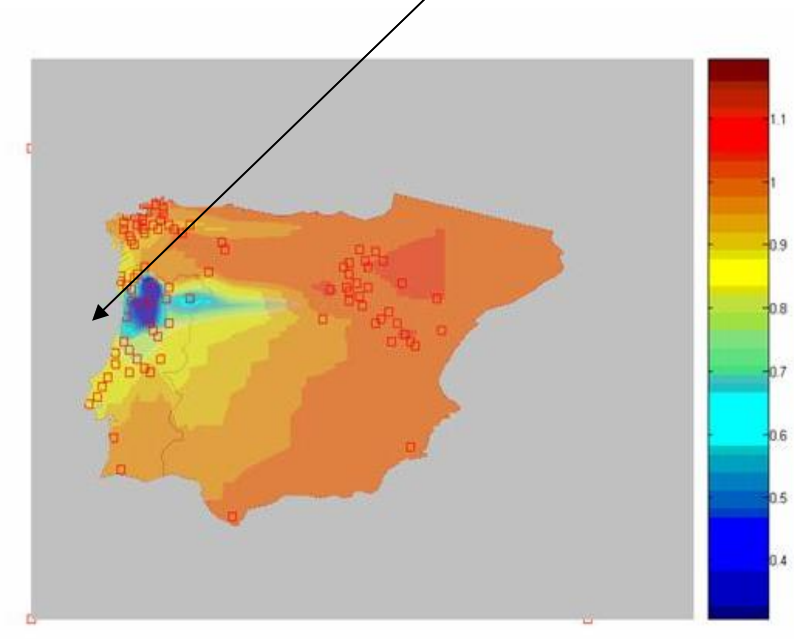
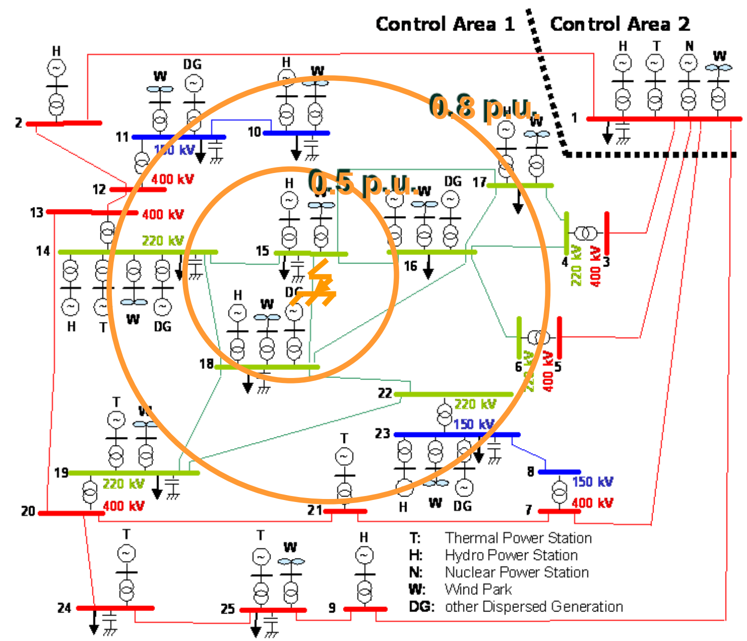
Increase wind power controllability: RTF capability, but by "E-classes"

- Low voltages due to short-circuits may lead to the disconnection of large shares of (old tecn) wind power production





Ride through fault capabilities attenuate the problem. Introduction of "E-classes" will enable to keep WT costs controlled and add robustness

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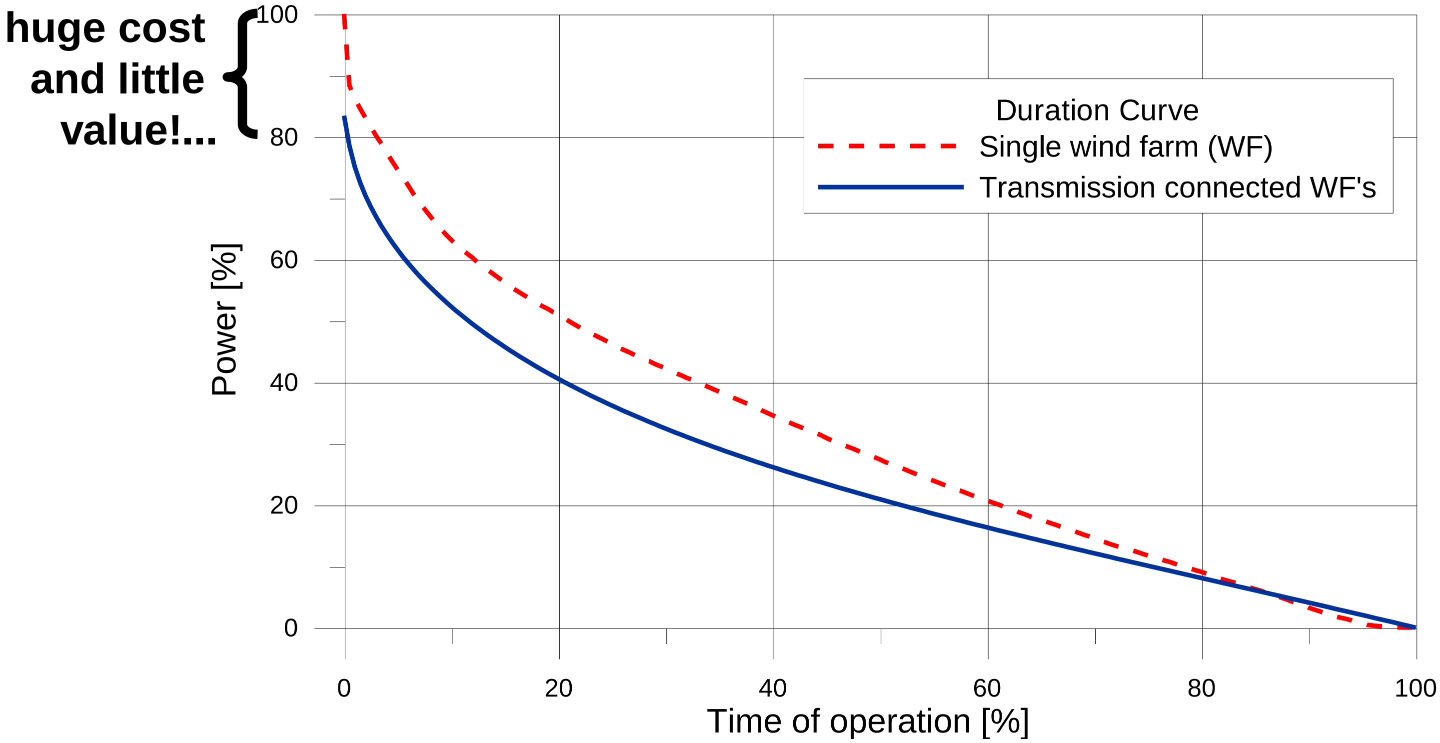
Innovative Concepts of the Wind Power Plants already in use

Wind Power Control and Curtailment



The uncorrelated fluctuations of the power output of an aggregate of wind power plants allows to take that effect into the design of the electric infrastructure and sub-sizing both the transmission line and the transformer. On a power system/control area scale this has a huge impact (~10% connected capacity)

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Tools, Methods and Solutions:
3. For the Power System

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Power Systems Tools already in Use

Storage of Renewable Energy

- **The concept of wind energy storage in reversible hydro power stations - and other highly variable time-dependent renewable primary sources - is already in use in Portugal.**
- **When hydro pumping storage is available, the methodologies able to identify the best combined wind/hydro pumping storage strategies should be used. Other storage techniques should be investigated**
  - *compressed air/gas, H2, flywheels, etc*
- **Wind energy storage enable to optimise the daily operation strategy and allows to:**
  - *Minimize deviations to participate in structured markets;*
  - *Contribute to the secondary and tertiary power reserves;*
  - *Increase of wind contribution for the regulation capacity*

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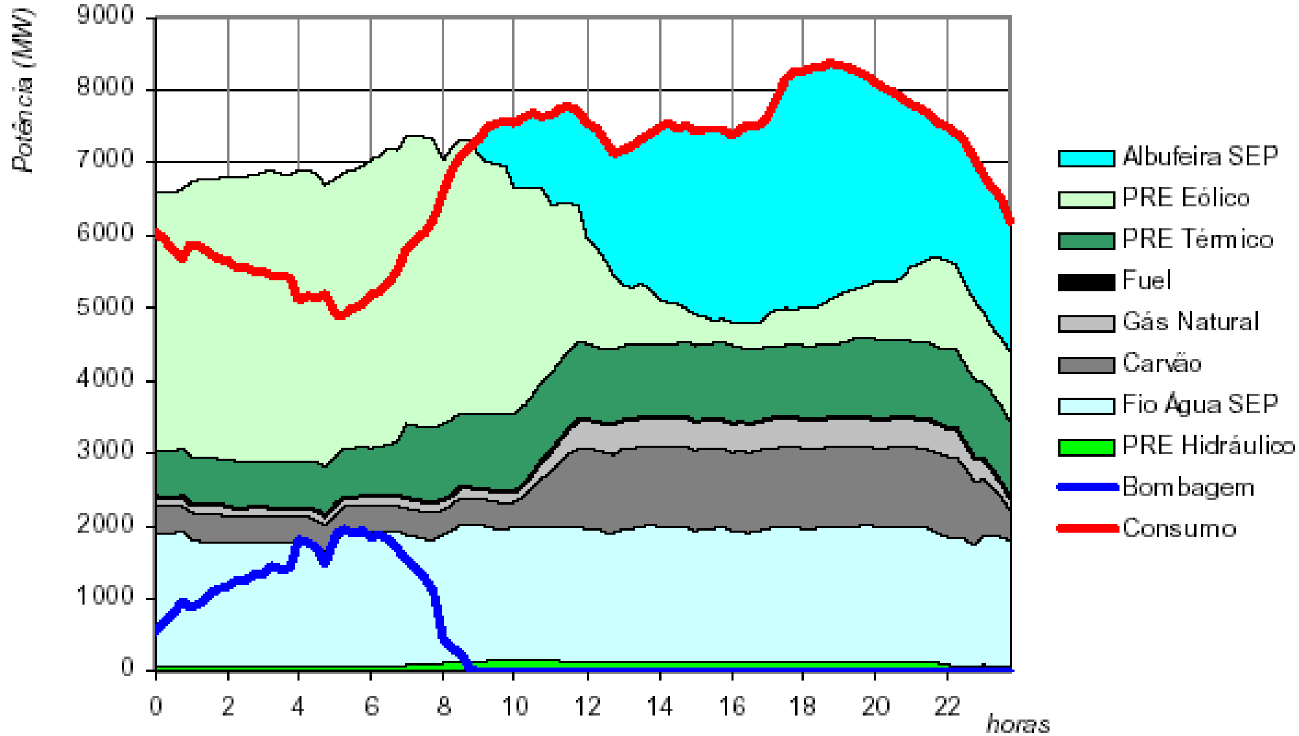
PT Energy mix in 2011: the need for storage



Scenario of generation profile for a <u>wet windy day</u> in 2011.

The constraint in Portugal is excess of renewable generation (wind + run-of-river hydro) during no-load

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Power Systems Tools already in Use

New strategies and equipments

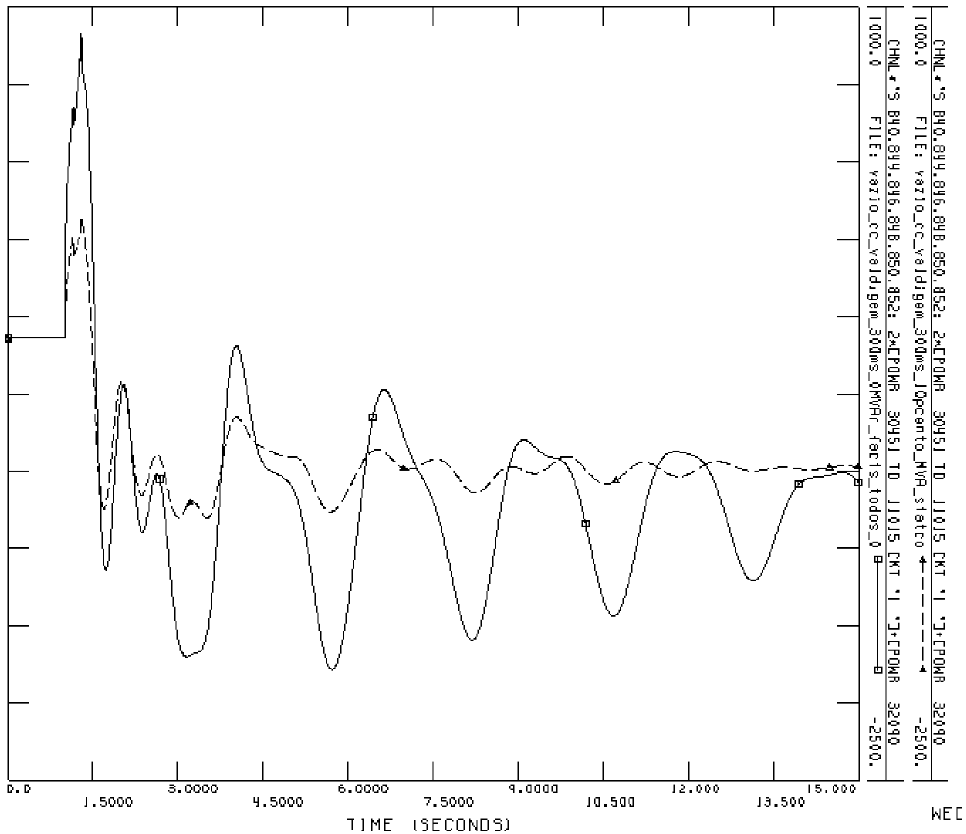
FACTS

It is possible to install FACTS in strategic buses of the network:

i) to mitigate the impact of short circuits;

ii) help to prevent the disconnection of large amounts of wind power for under voltage protection relays actuation (much cheaper than equip all WT's with LVRTF) ;

iii) strongly contributes to the damping of the oscillations.



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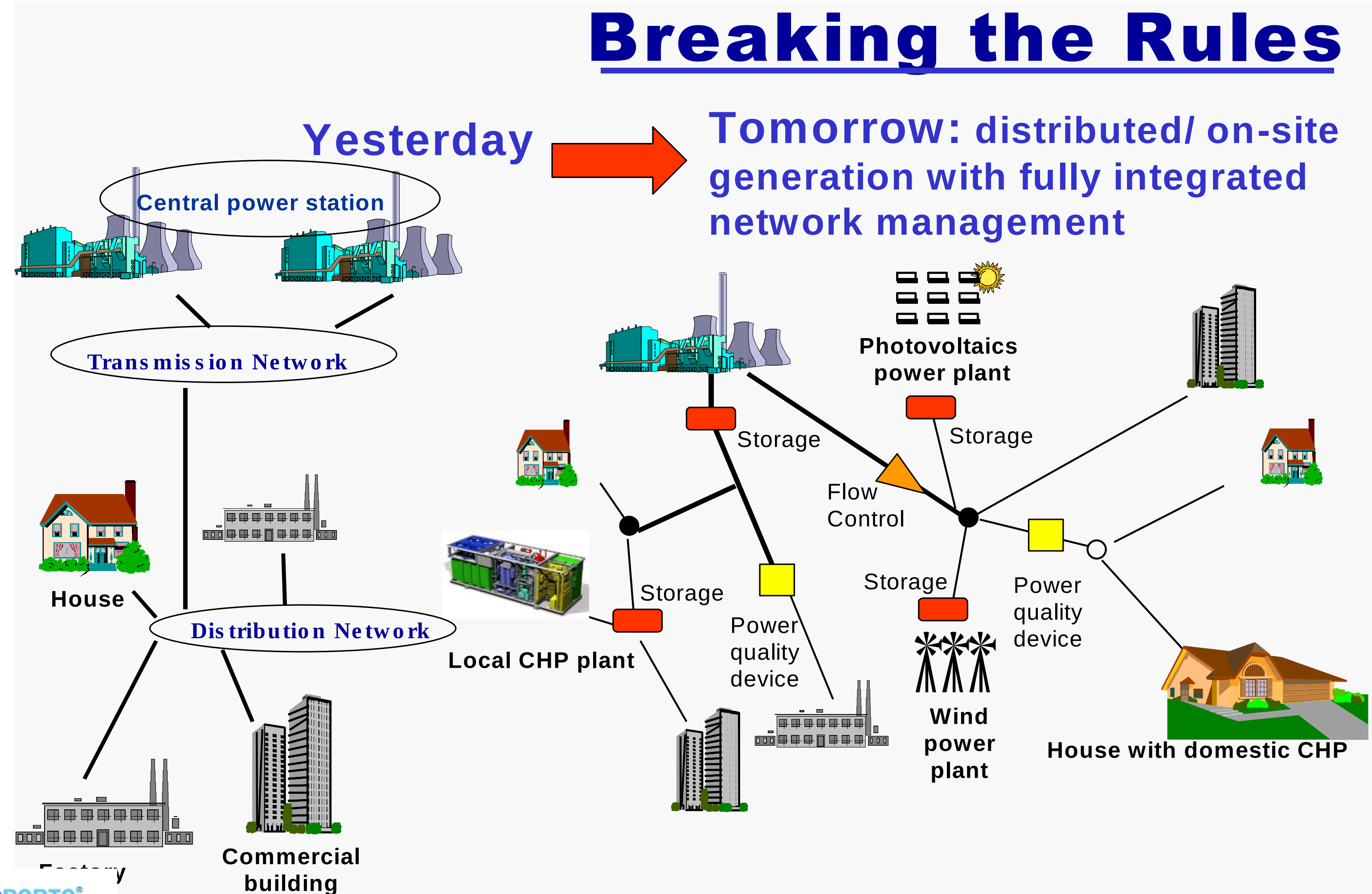
The 21st Century Power System

The 21st Century Power System



Optimizing The Power System Operation And Use

Towards the 21st century European Power System

1. *New wind **power dynamic models for power system stability** studies;*
2. *Real-time assessment transmission capacity*
3. *Use of **DGS as grid active voltage** controllers.*
4. ***Coordination of ancillary** services on a European scale*
5. ***Integration of balancing markets** and **coordination of reserves** within EU grids/control areas.*
6. ***Modeling** the behavior of the **power system/grid with large scale integration of renewable generation** through steady state and dynamic (transient) simulation platforms with Renewable Energy Sources (RES) and non-linear system devices*
7. *To Implement solutions to allow for **efficient and robust system operation** with significant amounts of highly variable generation*

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Optimizing Grid Infrastructure…

… for the Integration of Large Scale Variable Generation

1. *New **asset management** and **grid planning methods** for transmission and distribution grids*
2. *Development of **systems and components to maintain power quality** while encouraging the integration of new distributed power players*
3. *Development of transmission **grid planning tools for renewable power plants siting and sizing** taking into account the energy resource.*
4. *Definition and **planning of European "renewable energy corridors** " both offshore and onshore.*

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Information & Communication Technology

... for Active Distribution Networks.

The "Enernet" concept (1):

1. *Communication infrastructures for **smart metering***
2. *Dependable and secure **ICT for smart grids**: challenges posed by distributed generation and smart metering.*
3. ***Smart Meters as Internet hubs**: information management, security and usability issues*
4. ***Distribution automation and self healing** by managing DG and responsive loads*
5. *Dealing with the **integration of electric plugged in vehicles***
6. ***Distributed r**enewable **generation and local storage***

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The "Enernet" concept (2):

1. *Principles and strategies of using* ***DSM for maximizing the RES generation***
2. *Using of* ***DMS for overall system costs reduction*** *and power reserves optimization (flexible scheduling)*
3. ***Smart energy management*** *for DG and DSR*
4. *New products: Balance (call options) and capacity markets*

Virtual Renewable Power Plants (VRPP)

1. ***Enhancement of DGS (distributed generation systems) use*** *by regional/local treatment of biomass for electricity generation integrated with wind and PV applications. Introduction of the energy station vs power station concepts.*
2. ***Clustering of wind generation (****onshore and offshore) for power output smoothing, control and curtailment.*
3. ***Correlation of renewable distributed resources****, assessment of the excess of renewable energy generation and need for added large/local energy storage capacity (e.g. pumped hydro, VRB batteries and plug-in vehicles)*

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Synthesis (1/2)

- The wind industry has experienced a remarkable increase in its power system interface and performance.
- Technical studies to assess the impact of high wind penetration are still being accomplished in many countries, however it is already clear that the wind industry has moved into the right direction with the integration of functionalities as LVRTF, remote condition monitoring and power control.
- Cooperation of TSOs, DNO's and the wind industry exists, but clear (and realistic!) European targets and milestones must be assumed by all.

Synthesis (2/2)

- **The solution to add flexibility to the system lays with the "breaking the rules" approach:**
  - **DSM and distributed storage (SmartGrid);**
- **The common barriers that prevented the large wind penetration will probably very soon turn into,**
  - **"what wind turbine E.class should be installed in what wind power plant;**
  - **"when, where and under what circumstances should the wind power stations be deloaded or ramped?" to provide primary frequency control".**
  - **How to select the best aggregation agent for our wind power plant?**

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