Methodologies and Dynamic Models of Wind Turbines for Large Grid Integration Assessment

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A realistic snapshot of the power sector…

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

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% renewable/wind penetration on the European scale.

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How to address the known problems?

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

B. 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;

C. Large wind integration affects the Robustness of the system operation.

D. Limited Capacity of the grid;

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Answer: "one by one…"

Tools, Methods and Solutions

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, lines, protections and transformers –*

all these are urgent measures for TSOs.

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Technical Barriers
to High Wind Penetration

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 keys to overcome these issues are 1) to add flexibility to the power system, and 2) study/simulate all possible occurrences using comprehensive, inclusive models …

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Different generation mixes face different challenges...

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.

Tools, Methods and Solutions: The wind technology contribution

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

Innovative Characteristics of the Wind Power Plants

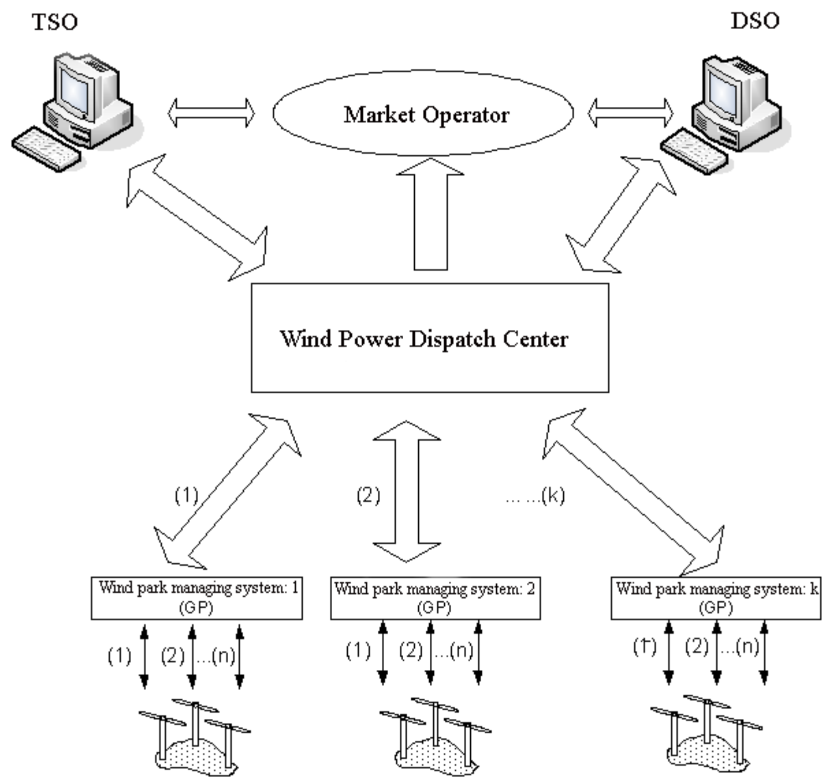
- Management of wind parks by clusters ("local wind power dispatch centers") – already in use in Spain and Portugal;
- Active voltage regulation through additional variable reactive power control: e.g tg ϕ within [-0.2, +0.2];
- Curtailment of wind production for forecasted no-load periods;
- Participation 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 and, eventually, hydrogen generation.

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 implement the 1st step of the **"Virtual Wind Power Plants"** concept*



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.*

(*)source: Enerconpor

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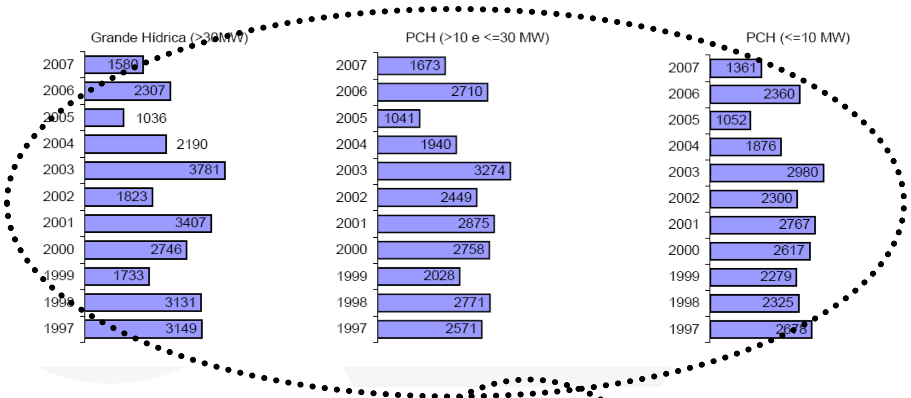
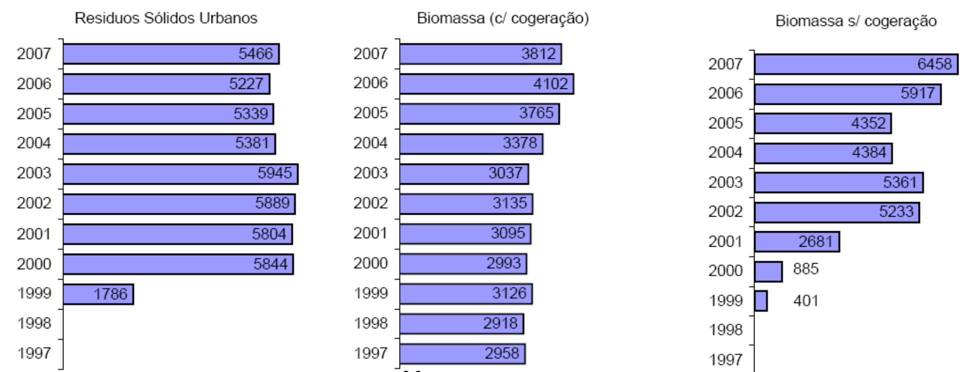
Extend the VWPP concept to Virtual RES Power Plants...

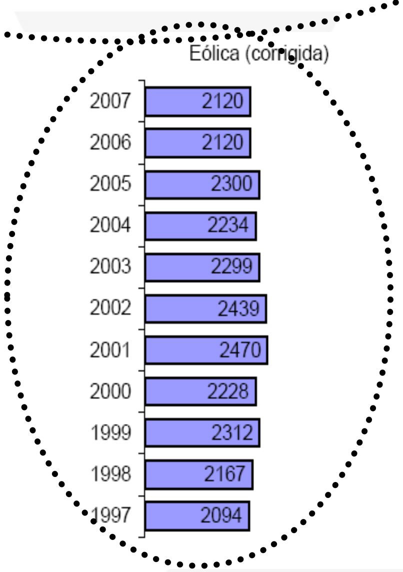
Large, small and micro hydro



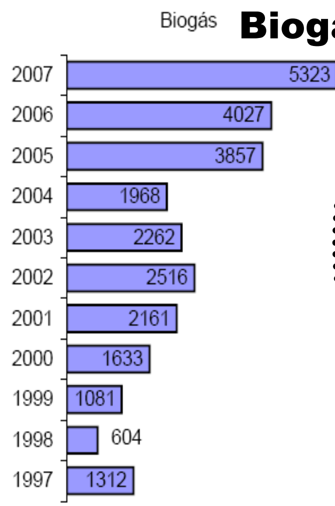
RSU, biomass (w/ and without cogeneration)

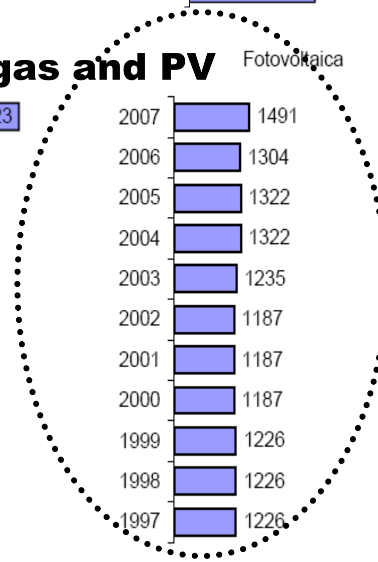


Wind



Biogas and PV





source: DGEG

Yearly full hours of operation by RES technology

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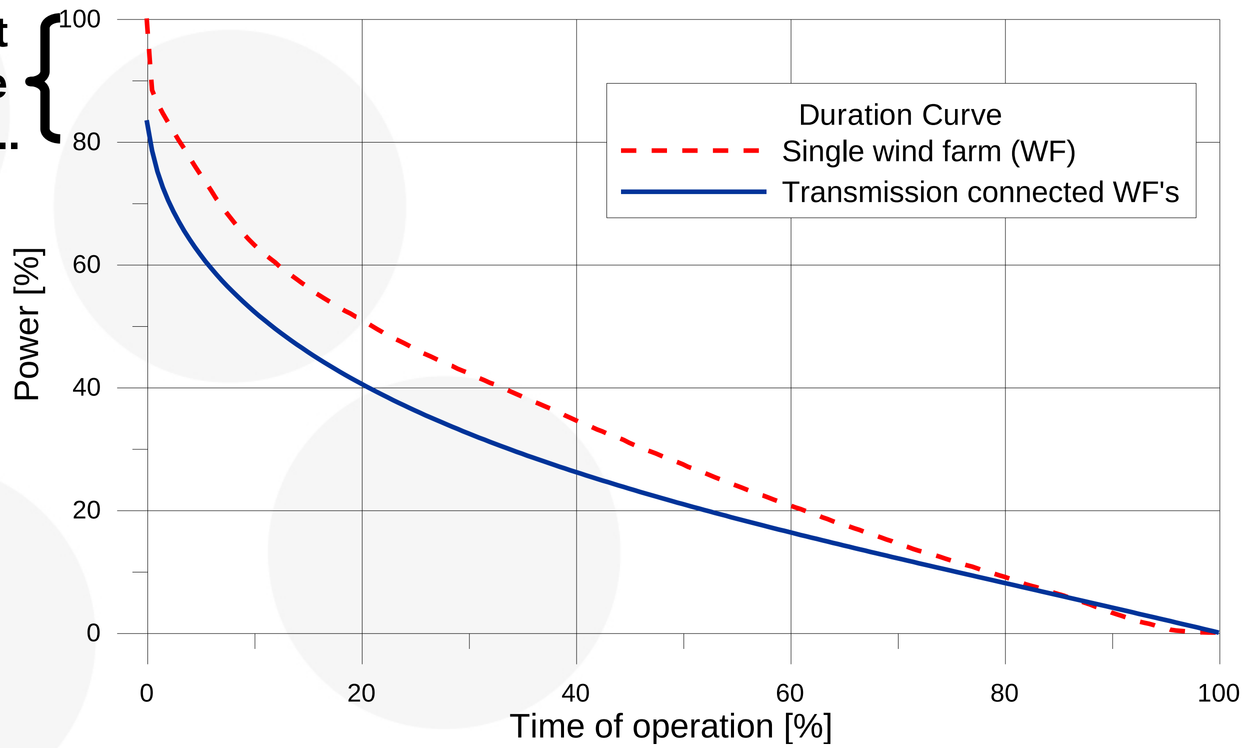
...enables the use of their natural complementarity.

Innovative Concepts of the Wind Power Plants already in use

Wind Power Control and Curtailment

huge cost and little value!...



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)

Virtual Renewable Power Plants (VRPP) will enable the …

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, power control and partial 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, FC/H2, VRB batteries and plug-in vehicles)*

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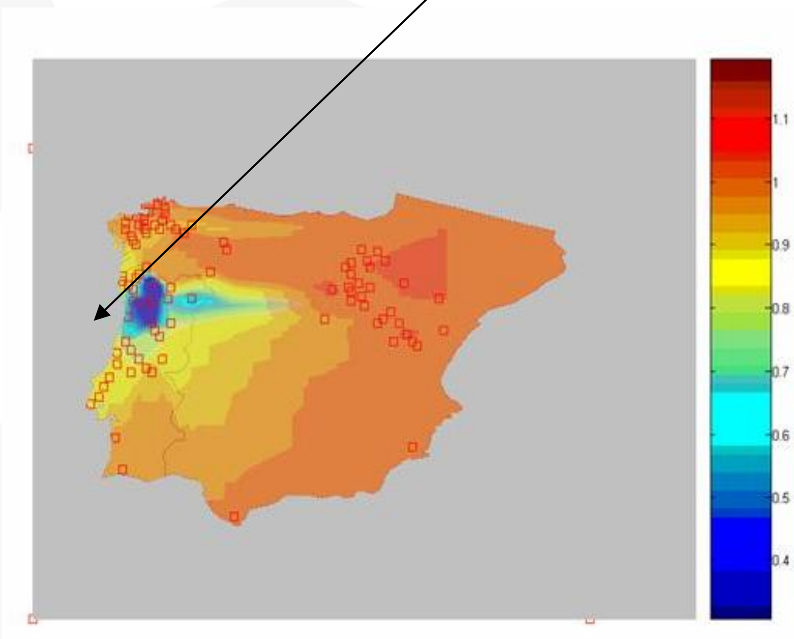
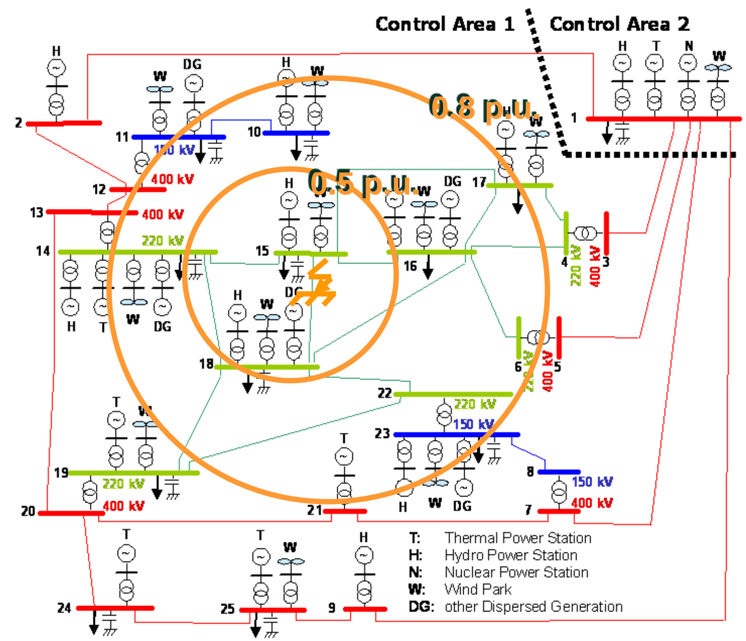
Increase wind power controllability: RTF capability, but by "E-classes"

- **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 to the system

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Tools, Methods and Solutions: for the Power System

Power Systems Tools already in Use

Storage of Renewable Energy

- The concept of wind energy storage - and other highly variable time-dependent renewable primary sources - in reversible hydro power stations 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
  - *H2/Fuel Cells, compressed air/gas, flywheels, etc*
- Wind energy storage enables 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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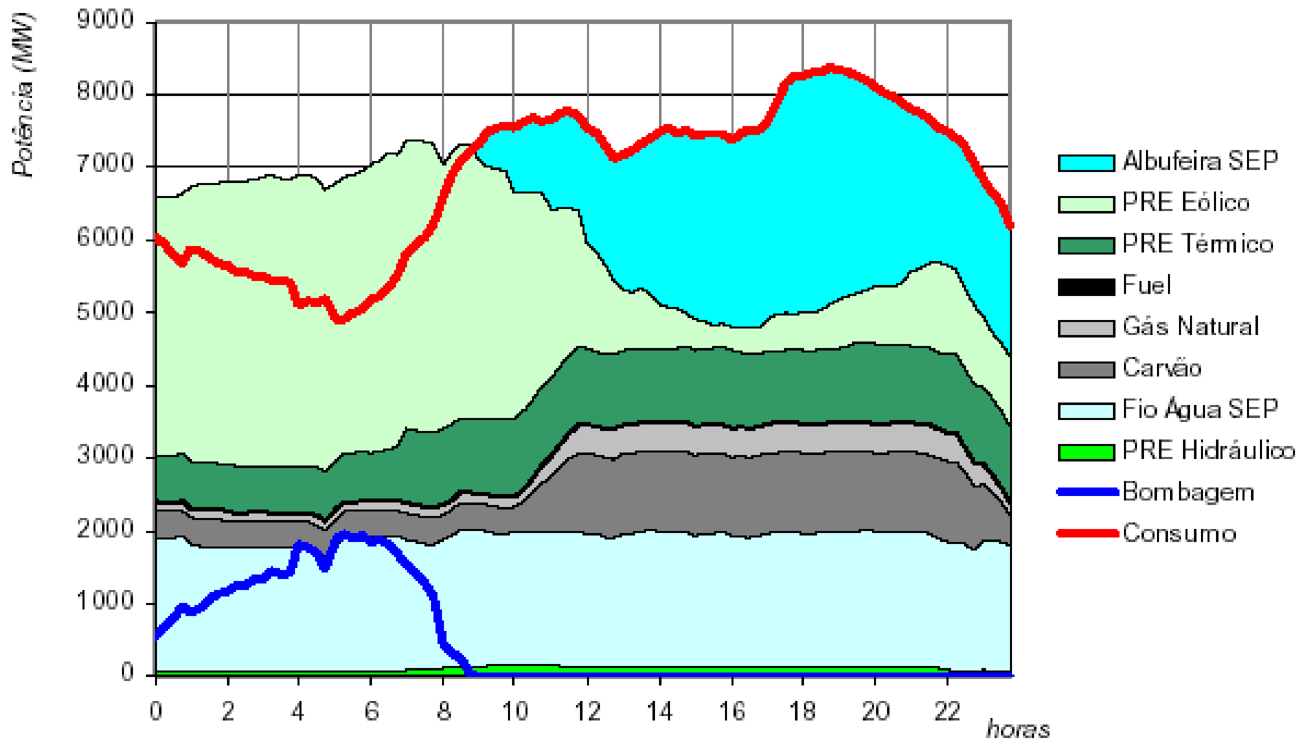
PT Energy mix in 2011: the need for storage and added flexibility

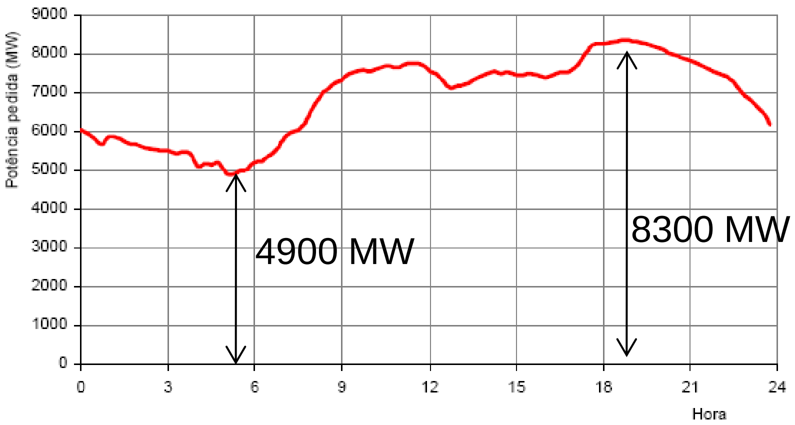


Scenario of generation profile for a
<u>wet windy day</u> in 2011.

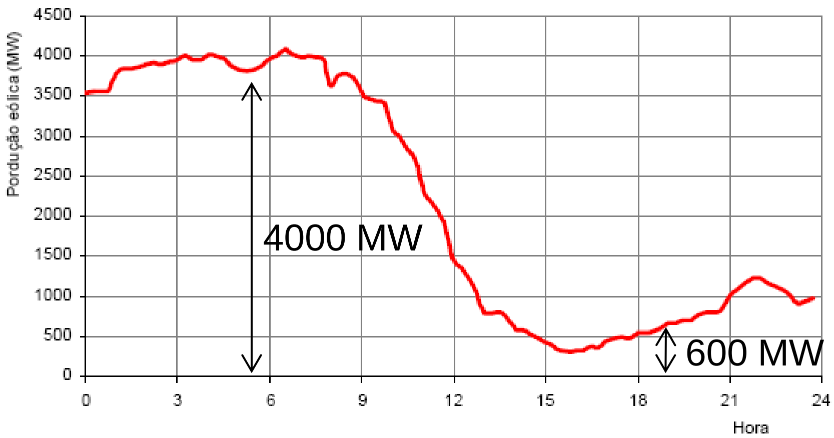
The constraint in Portugal is excess of renewable generation (wind + run-of-river hydro) during the no-load hours

Load/Wind correlation in Portugal

Load diagram



Wind power daily profile



Load profile in 2011 (typical Spring/Autumn day scenario)

Forecasted wind generation on a windy day (with 5700 MW of wind, after 2010...)

All studies and scenarios of PNBEPH were deterministic (!).

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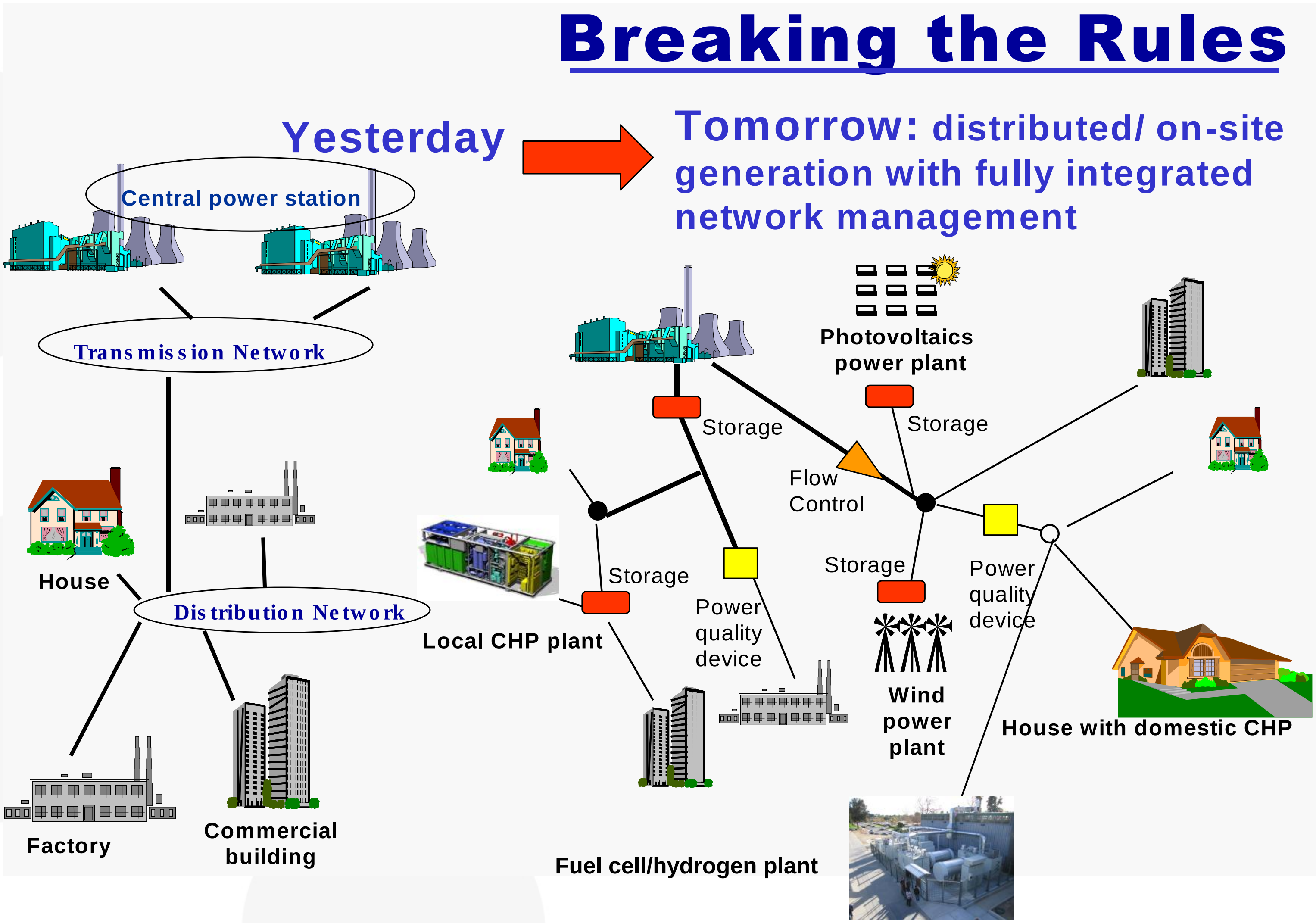
The 21st Century Power System: what remains to be done to achieve large wind integration?...

The 21st Century Power System



Optimizing The Power System Operation And Use

Towards the 21st century European Power System. The concepts:

1. *Real-time assessment transmission capacity*
2. *Use of DGS as grid active voltage controllers.*
3. *Coordination of ancillary services on a European scale*
4. *Integration of balancing markets and coordination of reserves within EU grids/control areas.*
5. *To Implement solutions to allow for efficient and robust system operation with significant amounts of highly variable generation and storage*

   (VRPP, DSM, FC/hydrogen, plug-in vehicles …)

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Wind Power Plant Models for the 21st Power System

Optimizing the 21st century European Power System Operation

There are not enough accurate off-the shelf tools to describe the dynamic, non-linear behavior of Wind Power Plants and, by doing that, increasing the degree of confidence of the TSOs. The sector needs:

A. ***Simulation platforms*** *with distributed Renewable Energy Sources (RES) and non-linear system devices*

B. ***To model*** *the behavior of the* ***power system/grid with large scale integration of renewable generation*** *on large/European scale using the classical power system approaches*

Tradewind and EWIS projects constitute excellent 1st steps

C. *New wind* ***power dynamic models for power system stability*** *studies including aggregation and clustering of wind turbines;*

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The role of wind turbine dynamic and transient models in large wind integration

1. ***The 20% renewable penetration (mainly wind) forecasted for 2020***, *may reveal itself a too risky task in technical terms if the European TSOs do not possess the* ***requested tools to simulate the system under extreme occurrences.***

2. *It should not be asked to the* ***system operators to (apparently) reduce the robustness of their systems*** *without providing them with the simulation models that enable to characterize the wind power plants response to every possible occurrence.*

3. *It is questionable if the European Power Systems will be manageable with a 20% penetration of variable generation (on an yearly basis)* ***without more sophisticated simulation tools*** *and a more detailed knowledge of the renewable power plants transient behavior*

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The role of wind turbine dynamic and transient models in large wind integration

1. *In the future it is probable that the network areas are classified in terms of* ***transient response capability of wind turbines***
   - *ride through fault and others;*
   - ***Voltage and frequency regulation*** *will be asked for some WT/grid areas*
2. ***Wide power control and curtailment of wind power*** *will be a reality.*
   - *The better the wind power plant models and power control capability, the least the curtailment*

Lately, a significant number of dynamic models was presented…

- **Dynamic Models of Wind Turbines. A Contribution towards the Establishment of Standardized Models of Wind Turbines for Power System Stability Studies**

  by Abram Perdana

- **Generic Aggregated Wind Farm Model for Power System Simulations. Impact of Grid Connection Requirements**

  by J. Soens, J. Driesen, D. Van Hertem, R. Belmans

- **Aggregated Wind Park Models for Analyzing Power System Dynamics**

  Markus P¨oller and Sebastian Achilles

- **Development Of Wind Turbine Generator Model For Power Systems Simulation Tools**

  by Marc Sala, Alex De Broe, Elizabeth Giraud, and Ignacio Rivera

- **Dynamic wind turbine models in power system simulation tool DIgSILENT**

  Anca D. Hansen, Clemens Jauch, Poul Sørensen, Florin Iov, Frede Blaabjerg

- **Wind Turbine Generator Models for Simulation of Power System Dynamics with the Eurostag Software – DISPOWER Project**

  Coord. by Jürgen Schmid

- **A Dynamic Wind Generation Model for Power Systems Studies**

  by Ana Estanqueiro

- **In IEA Wind Task 21 “Dynamic Models of Wind Farms For Power System Studies”, 8 different models were developed and tested, to a certain extent…**

  Coord. by J.O. Tande

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Optimizing the Power System Operation with Large Wind Integration

What wind turbine dynamic and transient models are requested for large integration?

1. *Preference should be given to **physical models** rather than identification models (usually the ones provided by the manufacturers):*

   *- To ensure **full validation**, **result replication** when embedded in other grid models or platforms and wide applicability by TSOs*

2. *In most situations, it is not practical (or even useful!...) to address each turbine by itself*

   *- **Aggregation models for wind power plants** are the key to represent large integration in large power system models*

3. ***Benchmark** and **standard modular development of models** will enable to define common inputs and data for all models of all turbines*

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The main difficulties with WT dynamic models for power system simulation

1. TSO's need to model wind generation to implement strategies and solutions to allow for efficient and robust system operation with significant amounts of highly variable generation (20% wind penetration):
   - to define new unit scheduling strategies depending on the wind generation scenario,
2. It is mandatory for the WT manufacturers **to provide inputs and wind turbine data** to represent the wind turbine behavior and its impact in the power system.
   - If they don't want to kill the "golden egg's chicken"...
3. But researchers need to assess what input data is **absolutely necessary** and what are the formats that **safeguard the industrial confidenciality** of the process

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Synthesis: Dynamic models

Tradewind and EWIS projects enabled the development and application of steady state models on a European scale to assess the dominant power flows and energy congestions induced by wind;

The next step is the dynamic characterization (on smaller scales) , but:

Existing power turbine/plant models still require input data too detailed and usually classified by the wind industry;

Recent work on IEC 61400-21 standard development together with other IEC efforts underway may create common platforms for wind turbine model development and validation;

But the final solution lays on development of effective aggregate dynamic transient models of large wind turbine clusters - as Virtual Wind Power Plants - and their embedment in the Power System existing simulation platforms.

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Synthesis methodologies

- 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 is moving into the right direction with the integration of functionalities as LVRTF, wind turbine clustering and power control.
- The solution to add flexibility to the system lays on the "breaking the rules" approach:
  - CHP for heat storage (DK), DSM, H2 generation;
  - Electric vehicles and distributed storage (SmartGrid);
  - Other?

final slide 1/2

Questions for 2020:

- “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?
- What the frequency to update the aggregate TSO wind generation models due to:
  - New added capacity;
  - Repowering;

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