Wind Power in Power Systems

Challenges, Impacts, and New Solutions

Université de Genève.
Groupe Énergie: Conferences du Jeudi

Ana Estanqueiro
LNEG - Instituto Nacional de Engenharia, Tecnologia e Inovação, I.P.

Wind Power in Power Systems

Abstract:

The capacity of wind power installed all over the world experienced an enormous increase in the past 10-15 years. This increase raises concerns about the impact of these electric power sources on the operation of local grids and, on a larger scale, on the power system operation.

The seminar addresses the intrinsic characteristics of wind power, namely its continuous fluctuating and non-dispatchable nature and the impacts that large amounts of wind generation (as well as other fluctuating renewables) may have in the design and operation of present and future power systems.

The most relevant challenges for power systems with high penetration of wind power are highlighted: e.g. increase of reserves; wind power forecasting; spatial smoothing; impact on markets structure and the existing IEA recommendations to assess their impact on the grid and power system are addressed.

From a point of view of regional grids, the impact of wind generation on local power quality parameters (reactive power flow, voltage profile, flicker emission and harmonics) are addressed.

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A snapshot of the wind power sector...

- Several countries and regions in Europe already have high wind penetration (>10%).
  - Denmark, Portugal, Spain, Ireland,...
- Wind generation is highly variable in time and space and it doesn't offer guarantee of power.
  - Very high (>20%) penetration requires added power system tools;
- 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 and events, but not for all...

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The wind power grid integration main challenges...

A. Wind Technology Challenges

- Aggregation of Wind Power Generation
  - Deployment of Virtual Wind/Renewable Power Stations
- Added Power Forecast and Control of Wind Power Stations
  - Curtailment of Wind Power
  - Renewable Energy Storage
- Empowering Wind Technology With System Ancillary Services
  - Contribution to frequency and voltage regulation
  - Effective use of Inertia
  - Value of RTF (Ride Through Faults)

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The wind power grid integration main challenges...

B. Grid / Power System Challenges:

- The transmission and distribution grids have a Limited Capacity to integrate large amounts of Wind Power;
- Wind Power may introduce local or regional Grid's Congestion;
  - But may also help to solve it, when existing;
- Wind power generation has an impact on the local grid's Power Quality.
  - Voltage profile,
  - Flicker emission
  - Harmonics

The wind power grid integration main challenges...

C. Power System Design and Operation Challenges:

- **Wind Power doesn't offer Security of Supply, may require significant added Reserves and also impacts on conventional Power Unit Scheduling;**

- **Operation and management major challenges:**
  - **in power systems with significant amounts of rigid generation (either non dispatchable renewable or, e.g., nuclear), to foresee large integration of wind (and other variable RES) may produce Energy Congestion and a difficult Surplus Management;**

- **Large wind integration affects the Robustness of the system operation and requires the development of new principles and strategies of operation of Electricity Markets.**

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A. The wind technology contribution

New developments and wind technology operational capabilities

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Wind Power in Power Systems

Main Limitations of the Wind Technology

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, especially for wind penetration >10%

2) The "Wind Power Variability"

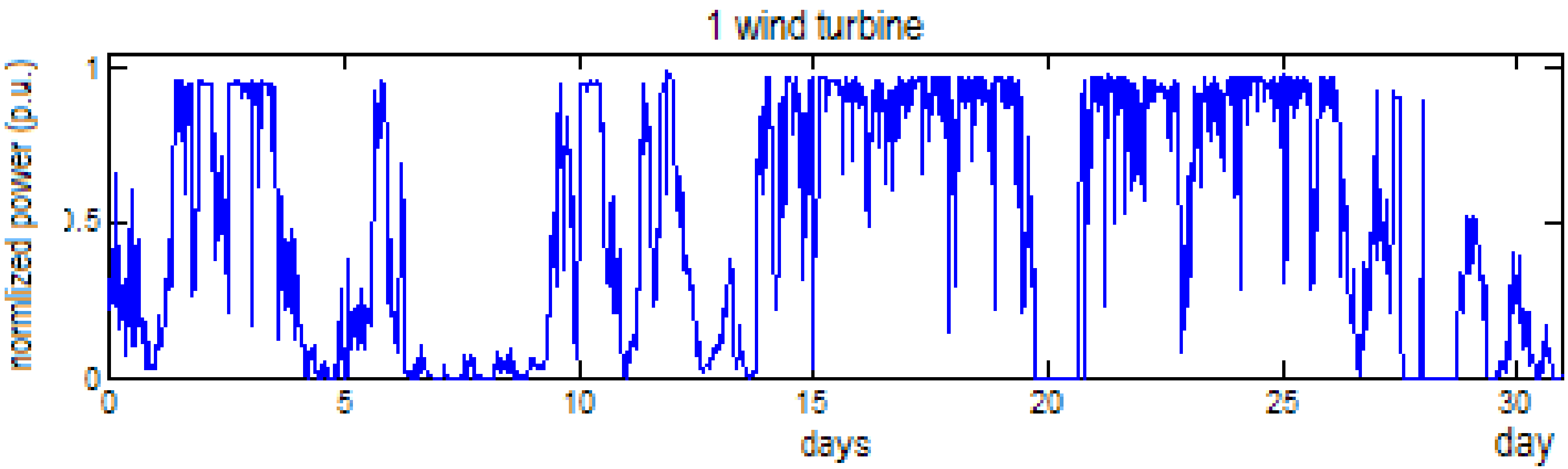
Wind forecasts are improving every day, being used by all TSOs in Europe and North America with acceptable deviations within the useful time ranges for power system operation. The larger the control system the lower the forecast error and the smoother the wind power output.

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".

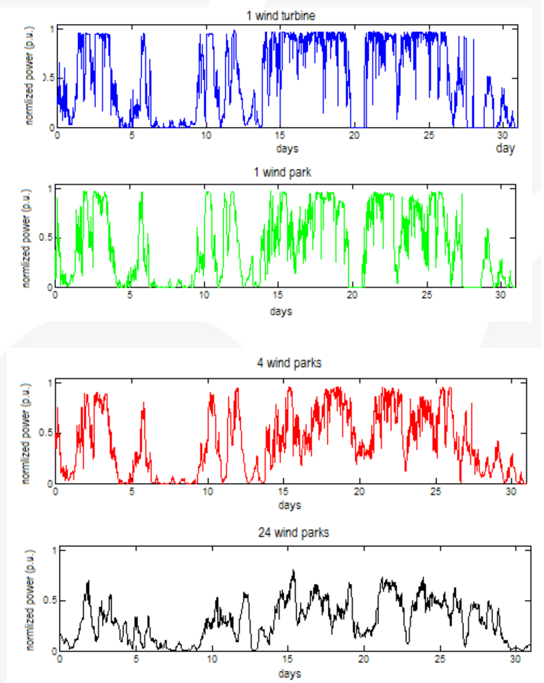
However…

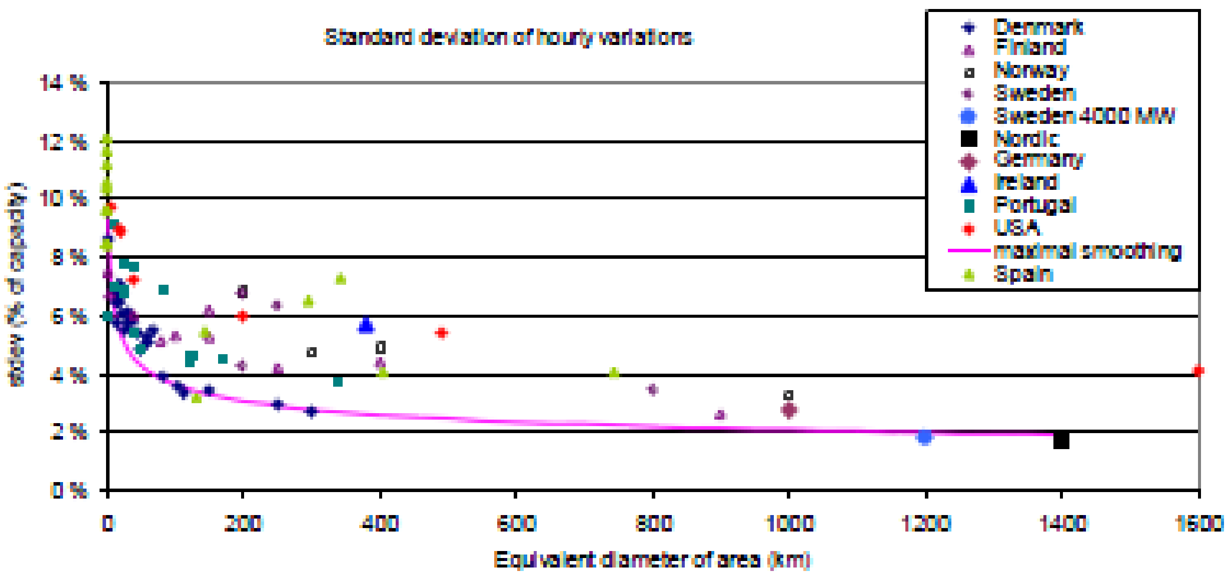
This is the typical output power from a single wind turbine:



Wind Power smoothing effect

… there is an accentuated smoothing effect of the wind power fluctuations produced by the geographical dispersed wind power plants





Wind Power Control:
DSOs and Virtual Wind Power Plants

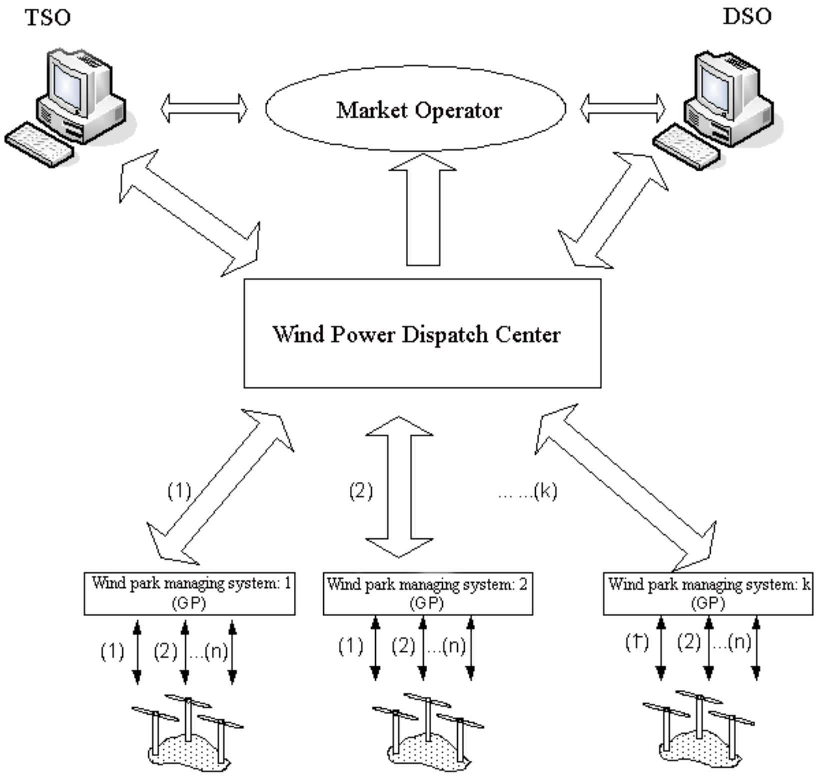
Installation of Wind Dispatch Centres

"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*

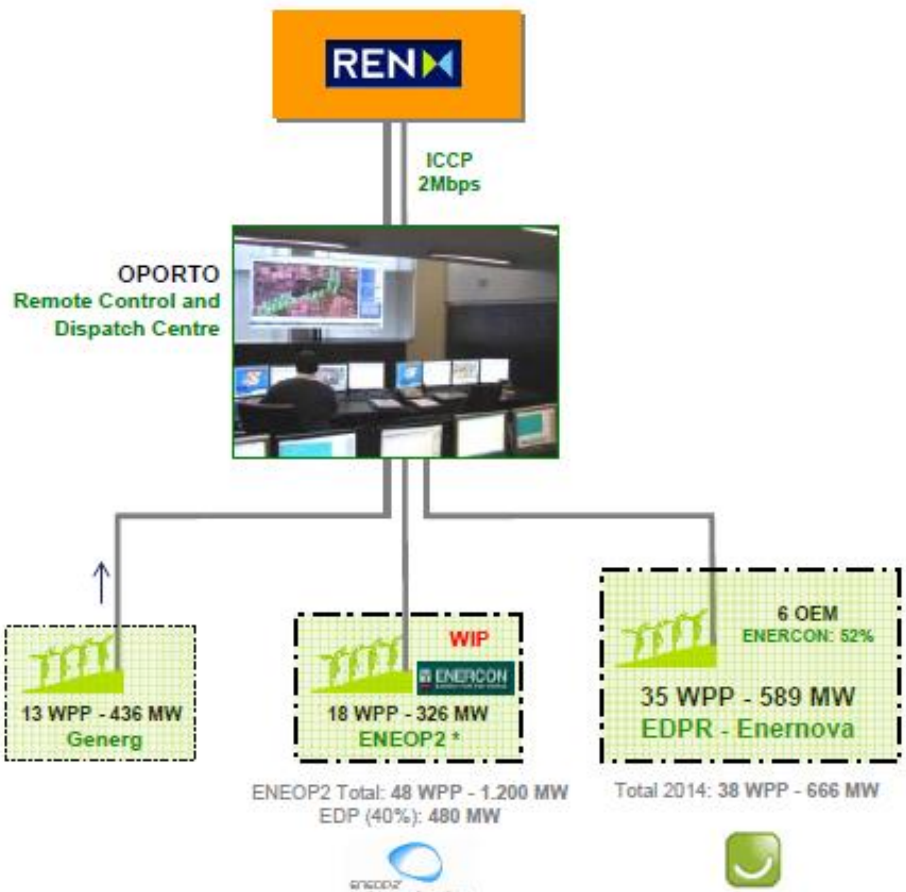
The 1st "Wind DSO" started operation in Portugal in 2009 and already connects 1350 MW of aggregated wind generation.

A second wind cluster is planned to reach 900 MW.



Wind Power Control:
DSOs and Virtual Wind Power Plants

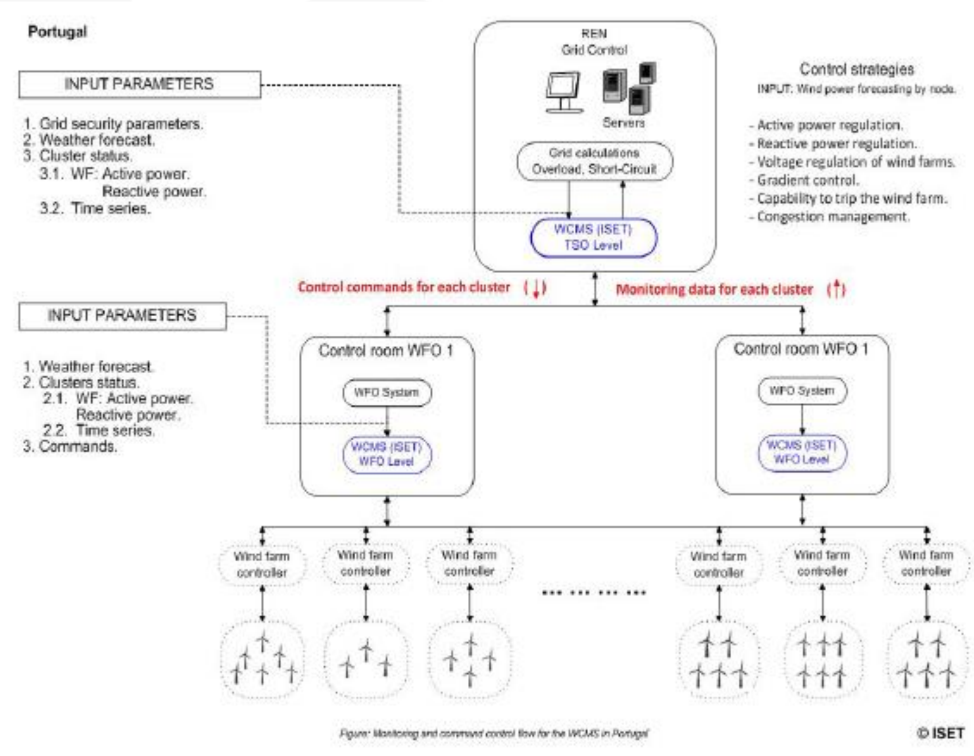
1st Wind Dispatch Centre (VWPP) in Operation in Portugal (2nd in the World): 1350 MW



oject Windgrid)

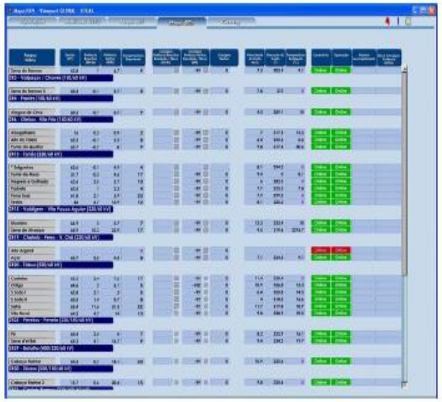
Wind Power Control: DSOs and Virtual Wind Power Plants

The wind power control centre aggregates data from wind power plants and performs the interface with the TSO:



Wind Power Plants Matrix:

Interface with REN:



source: REN, IWES (Project Windgrid)

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

Possible Characteristics of Modern 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 pumped hydro storage plants, when available and cost-effective and, eventually, hydrogen generation (or any other energy vector).

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Wind Power Virtual Power Plants (Dispatch Centres) operational principles

- Infrastructures and HR to guarantee 24h/day, 365 days/year operation.
- Real time operational data exchange with the portuguese TSO – REN through a dedicated, redundant 2 Mbps link.
- ICCP (IEC- 60870-6-503, TASE 2) used as data communications protocol.
- WPP meteorological, electrical data and # WTG available gathered and sent with 12s sampling frequency;
- Cluster has the ability to send commands to the WPPs;
- Contractually prepared to receive and execute P, Q set-points defined by the TSO/DSO.

source: REN, EDPR (Project Windgrid)

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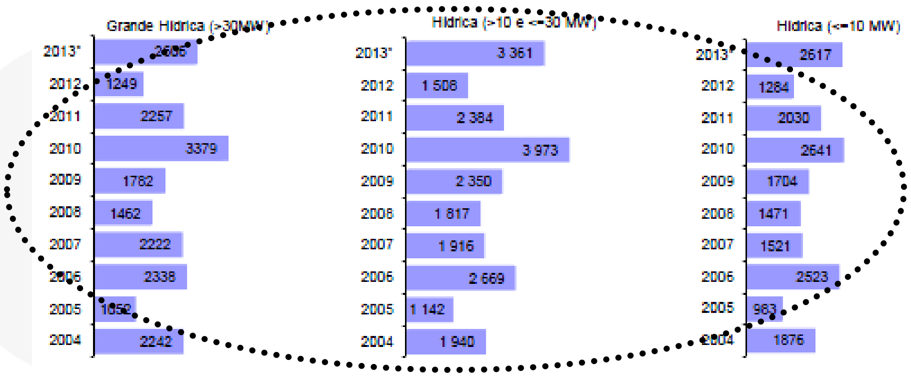
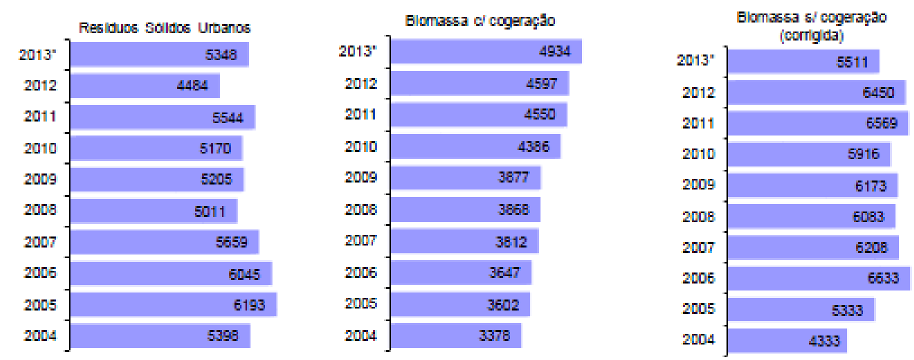
The next step: Extending the VWPP concept to Virtual RES Power Plants...

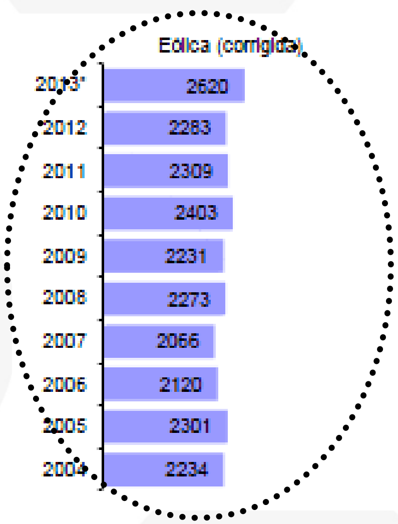
Large, small and micro hydro



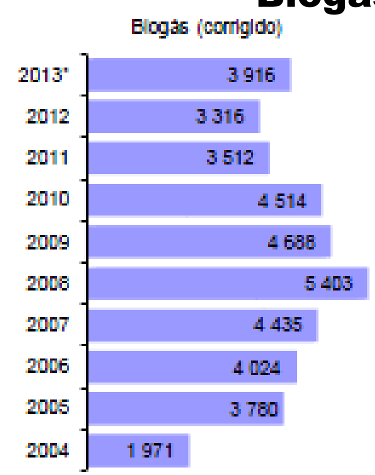
RSU, biomass (w/ and without cogeneration)

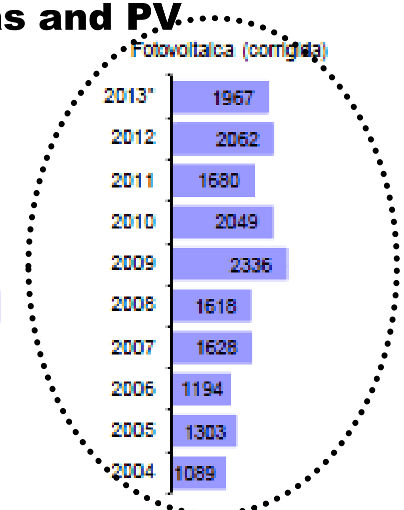


Wind



Biogas and PV





source: DGEG

Yearly full hours of operation by RES technology

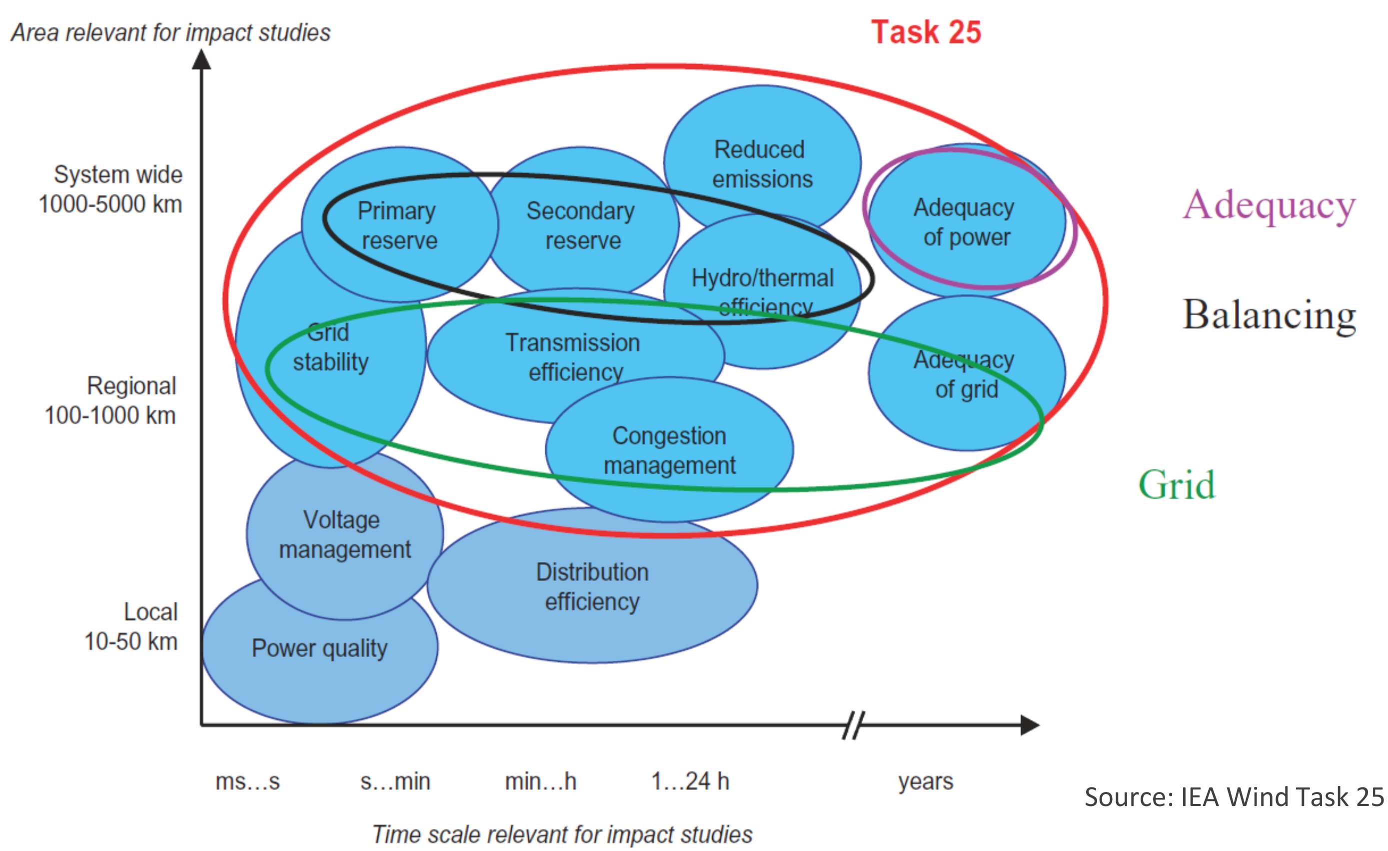
...enabling the use of their natural complementarity.

B.&C. Grid and Power System challenges

New Tools, Methods and Solutions

Wind Impacts on the Grid and Power System

Classification of the most relevant power system phenomena and the impacts introduced by wind generation



Source: IEA Wind Task 25

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, renewable or not.

3) Requires 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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Optimizing Grid Infrastructure…

… for the Integration of Large Scale Variable Generation requires:

- *New __asset management__ and __grid planning methods__ for transmission and distribution grids*
- *Development of __systems and components to maintain power quality__ while encouraging the integration of new distributed power players*
- *Development of transmission __grid planning tools for renewable power plants siting and sizing__ taking into account the energy resources and available optimization techniques.*
- *Definition and __planning of European "renewable energy corridors__ " both offshore and onshore.*
- *__Reinforce__ the Transmission System at wider scales.*

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Possible 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/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 + 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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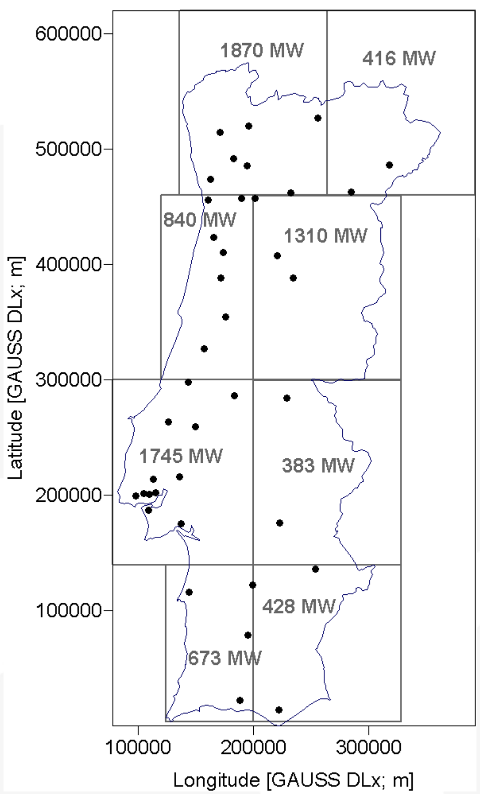
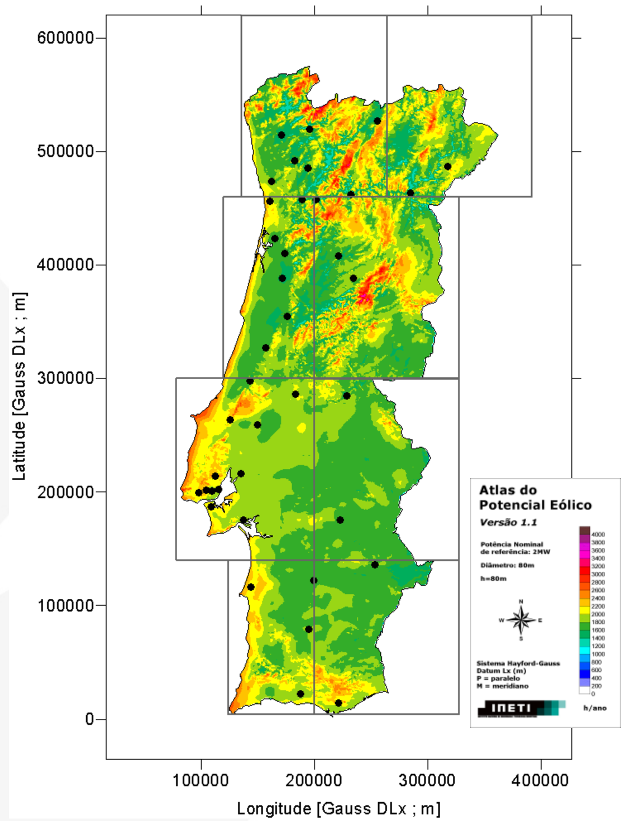
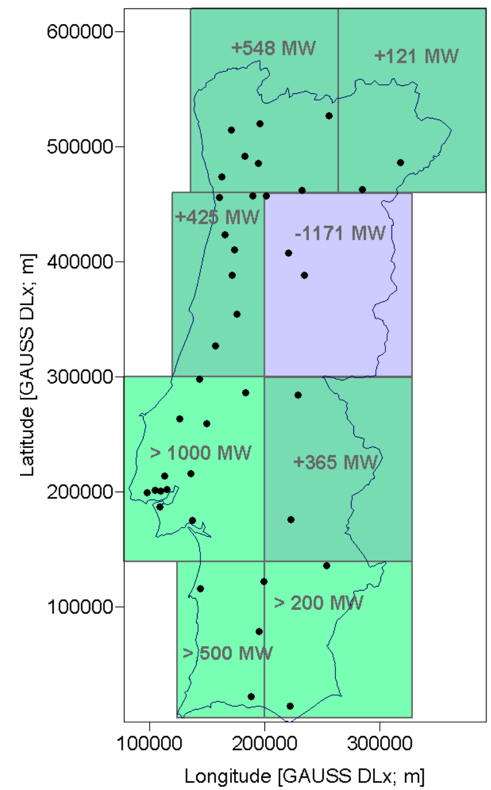
I.e. taking the grid capacity into wind power planning…



a) Grid capacity in 2013 (~7000 MW)



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



(c) Deficit/superavit assessment by region

Local distribution of wind resource vs. TN capacity

See also: T. Simões, P. Costa and A. Estanqueiro. methodology for the identification of the sustainable wind potential. The Portuguese case study. DOI:10.1109/PSCE.2009.4839951 In proceeding of: Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES.

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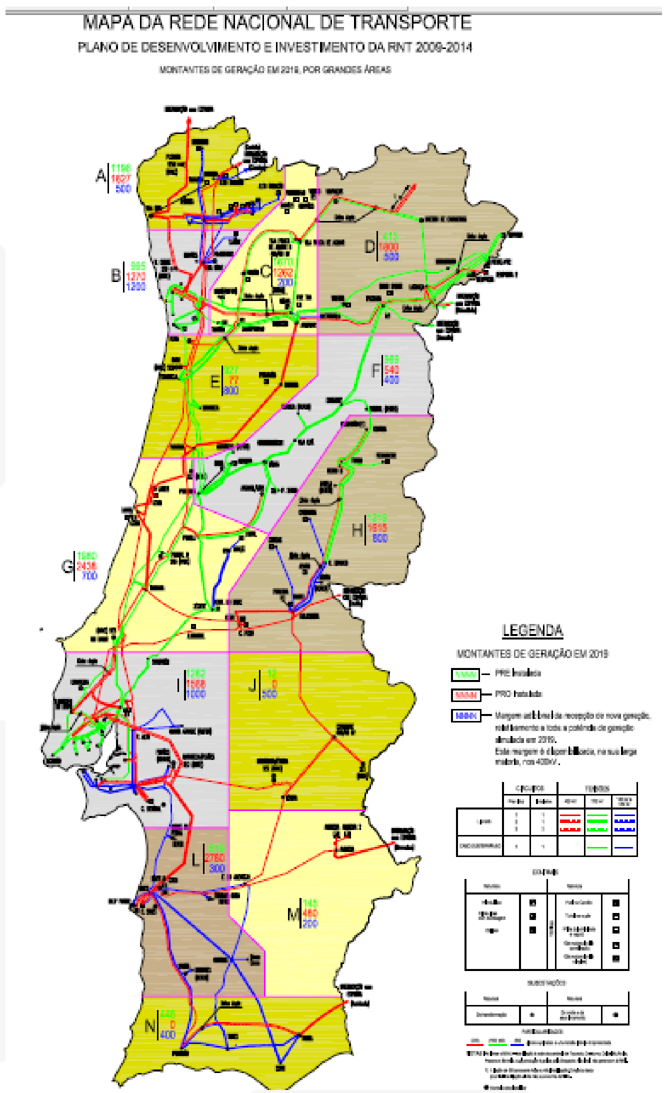
… and taking the wind resource into grid planning



Source: REN

Identify distributed 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 at minimum costs.

Use Information & Communication Technology (ICT) = "Smart" Grids

… for Active Transmission and Distribution Networks. The "Enernet" concept (1/2):

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***

Enable Demand Side Management: New Energy Markets and Players

The "Enernet" concept (2/2):

1. *Principles and strategies of using **DSM for maximizing the RES generation***
2. *Use all **storage capacity** available and build all new possible in the future*
3. *Using of **DSM for overall system costs reduction** and power reserves optimization (flexible scheduling)*
4. ***Smart energy management** for DG and DS*
5. *New products: Balance (call options) and capacity markets with shorter closure offers*

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Different Power Systems (generation mixes) face different challenges...

The Power System's Flexibility concept

In power systems where the energy mix is flexible (i.e. has easily adjustable regulation of generation vs consumption) 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

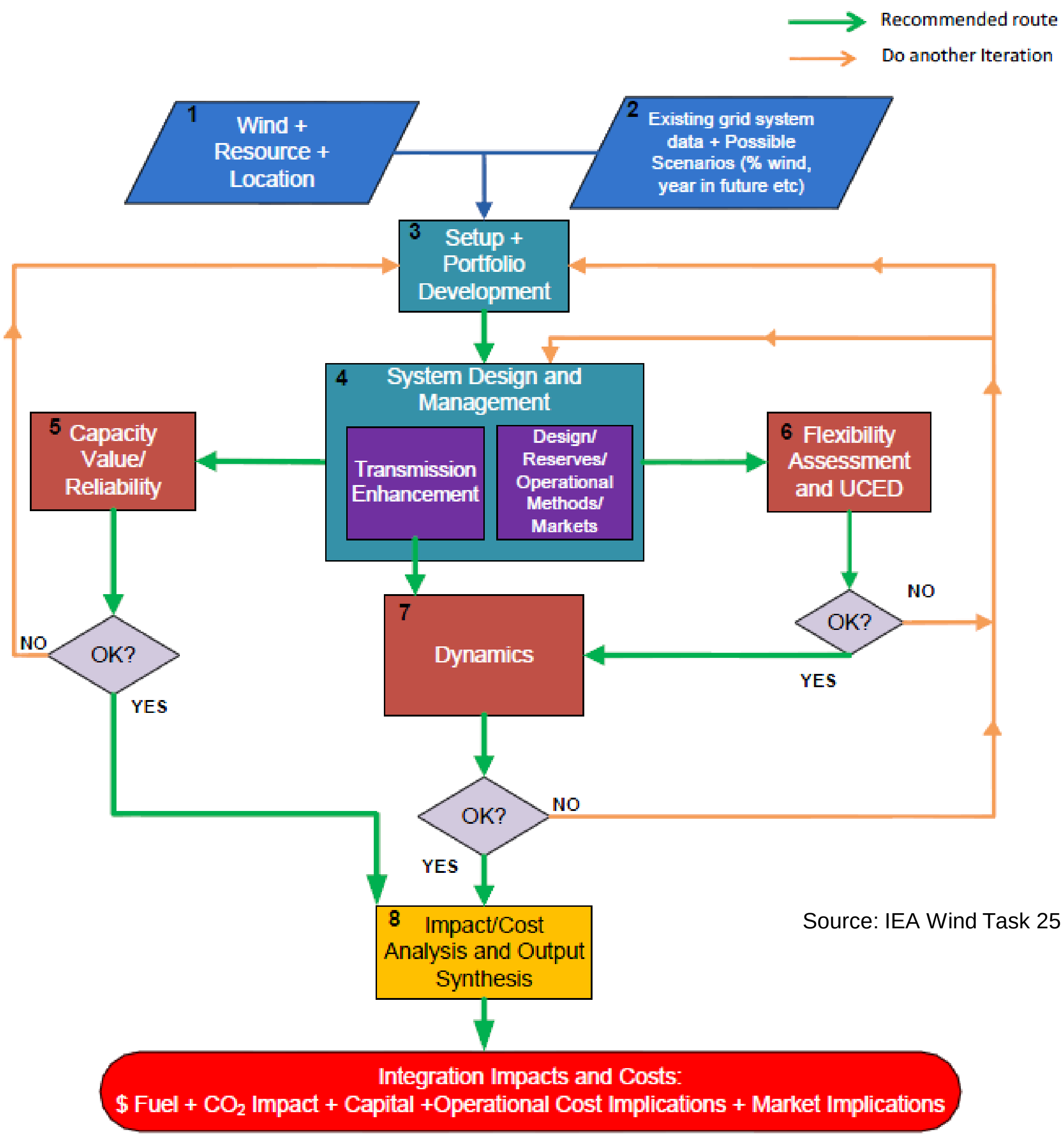
–e.g. high penetration of hydro plants with pumped storage capacity (PHS) . In countries /control areas as Portugal, Sweden and Norway the flexibility given by the high hydro penetration easies things.

However…

an issue commonly referred in those 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 can contribute to solve this problem.

IEA Wind Task 25 Recommended Practises



Source: IEA Wind Task 25

New strategies and equipments

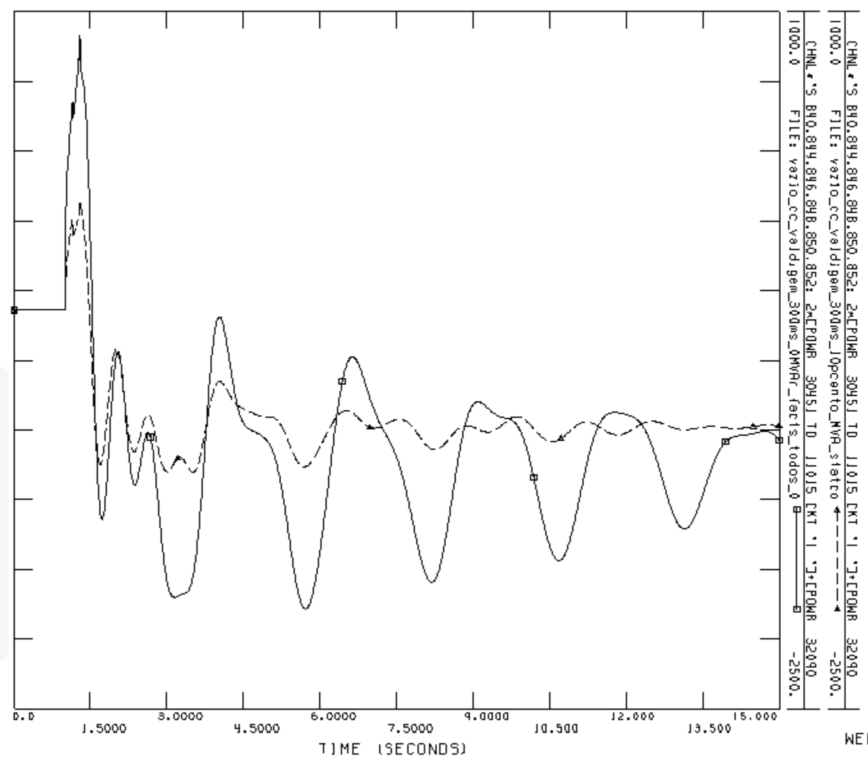
FACTS

It is possible to install FACTS[1] 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 old WT's with RTF) ;

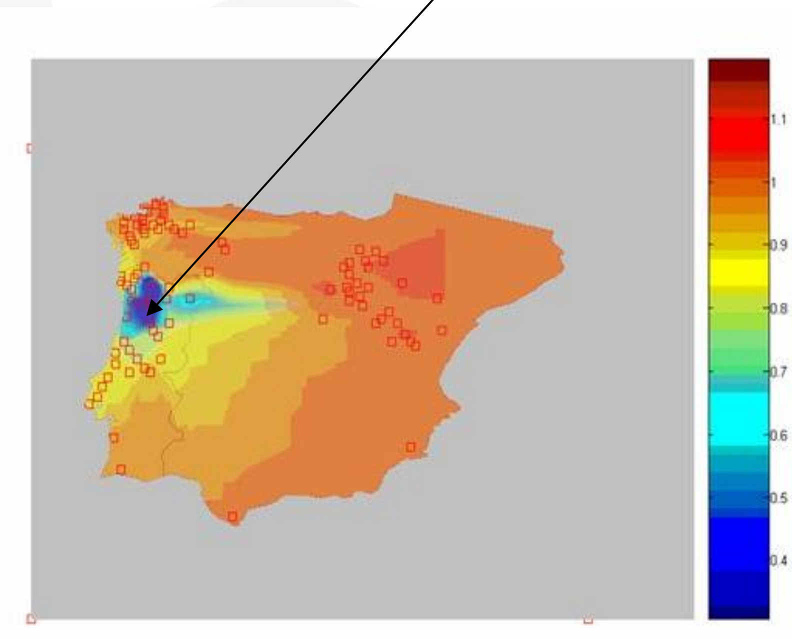
iii) strongly contributes to the damping of oscillations due to transient events.

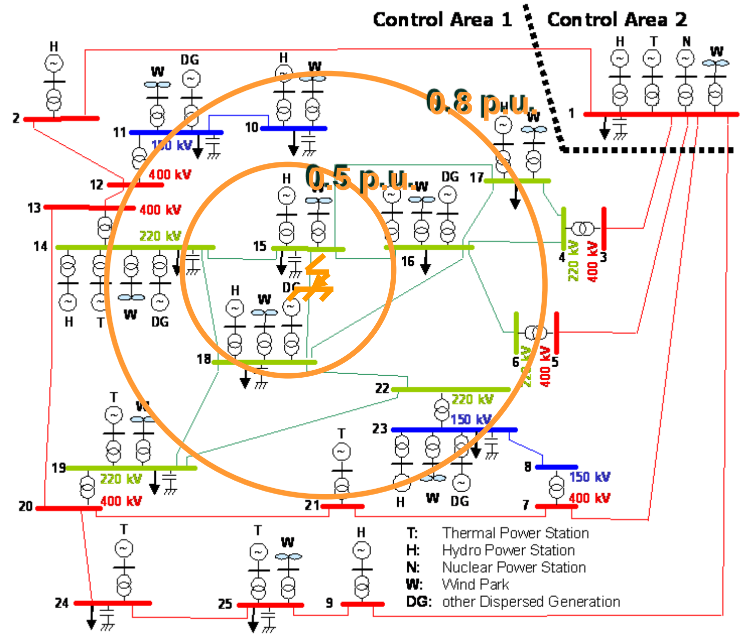


[1]Flexible Alternating Current Transmission Systems

New Power Systems Tools already in use

Increase wind power controllability: e.g. RTF capability, by “E-classes”Low voltages due to short-circuits may lead to the disconnection of large shares of (old tecn) wind power production

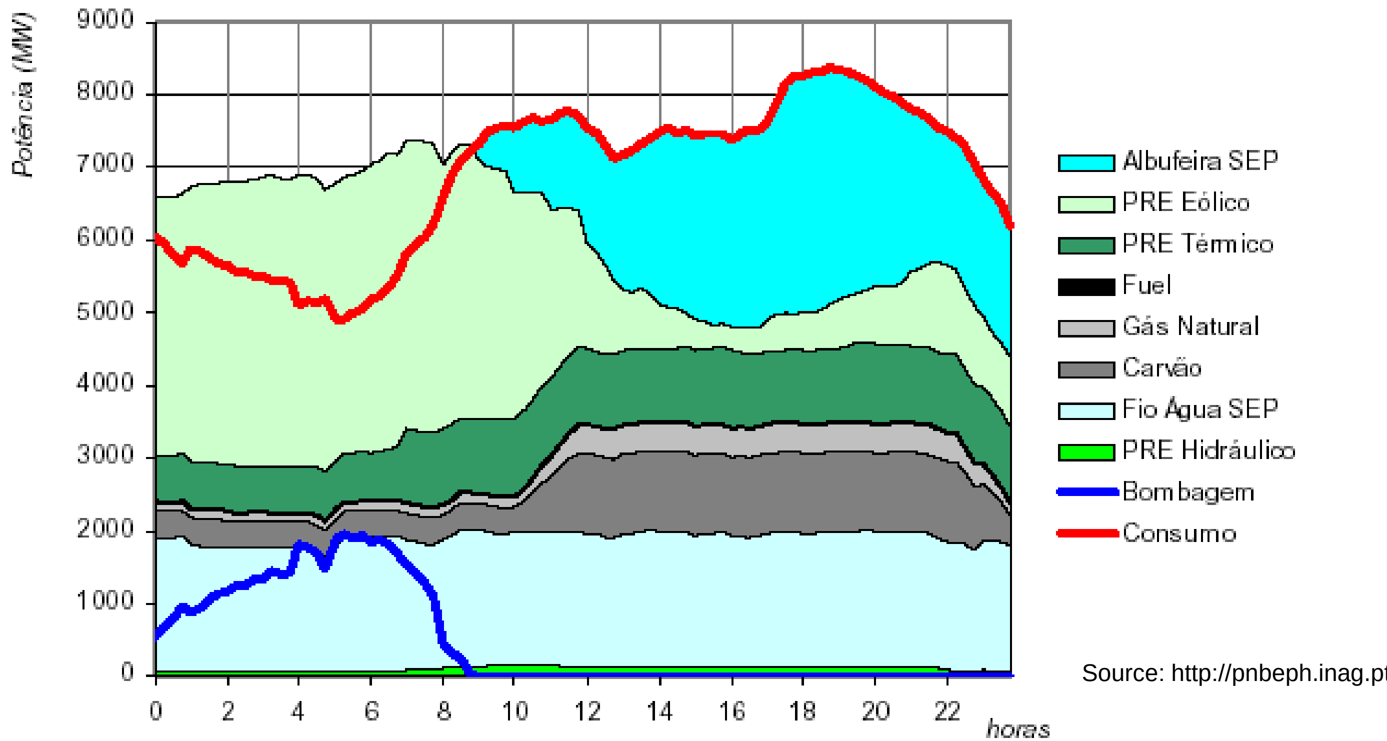




Source: INESC-Porto

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

The deployment of storage and added flexibility



Scenario of planning generation profile (in 2007) for a wet windy day in 2011.

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

Power Systems Tools: 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 some countries (e.g.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, e-vehicles, CAES, batteries, 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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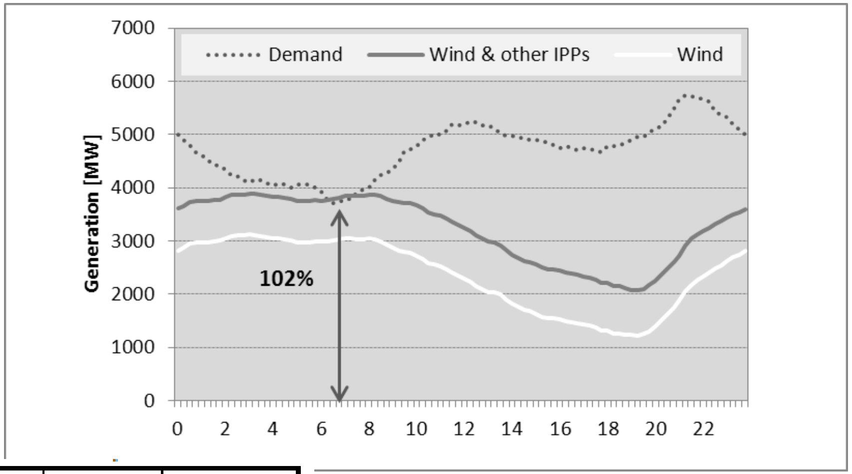
Energy markets
with very high penetration of Wind Power are a (big) challenge still being addressed...

But the quality of the Power System's service remains excellent under extreme operation conditions!

In the meanwhile, in a Power System with very high wind penetration…

… a windy day in 2011:

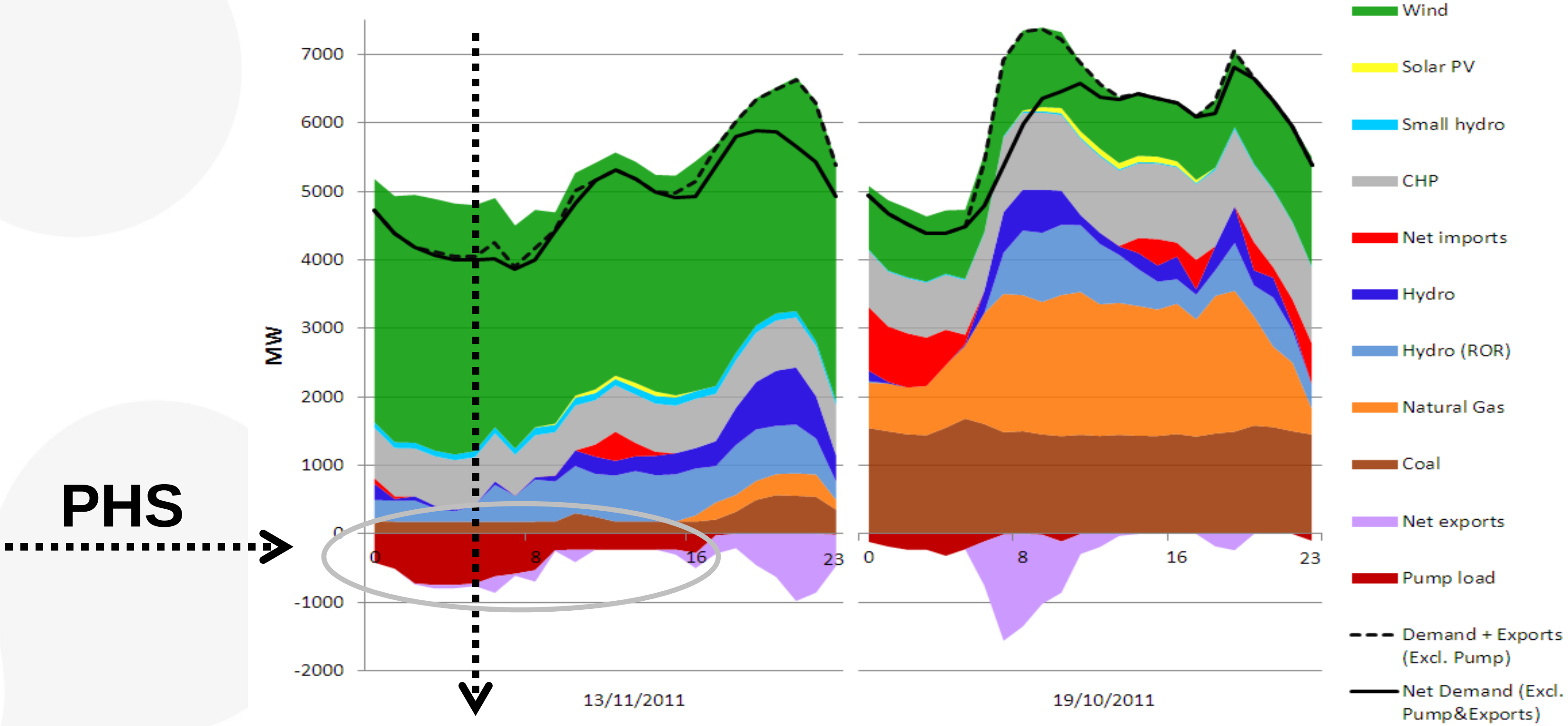


Day	Time	Min. Load [MW]	Min. Load & Pump [MW]	Max. Wind Power [MW]	Max. Non-regul. Power [MW]	Max. Wind Penetr. [%]	Max. Penetr. (incl. pump.) Non-reg. P [%]
15.Nov.09	7:30	3708	4365	2785	3958	70%	78%
31.Oct.10	2:15	3862	4137	3182	4093	75%	90%
15.May.11	6:45	3727	4206	3115	3811	81%	102%

The portuguese Case Study

The power system mix during:

a windy/wet day; a normal day;



93% wind+ROR,
117% (theoretically)
non-dispatchable

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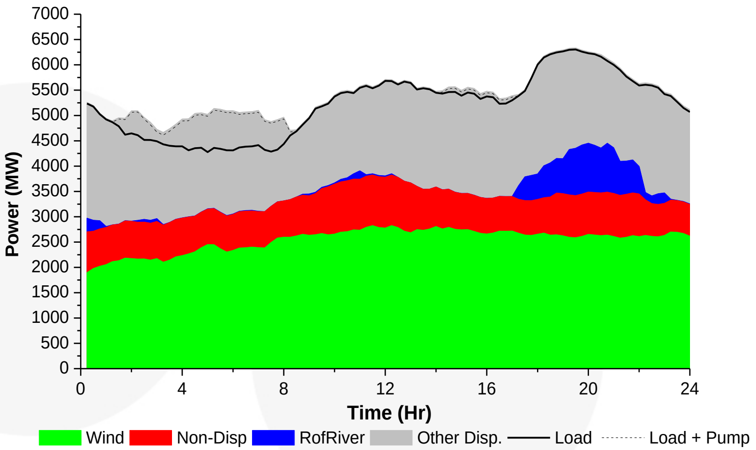
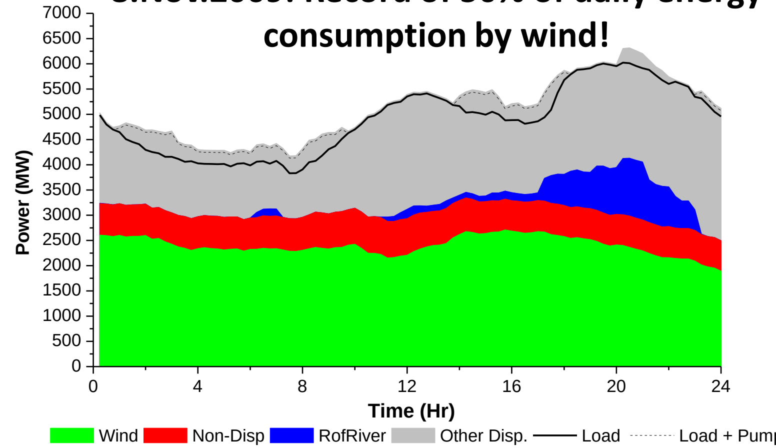
The “extreme” 2009/10 winter

7.Nov.2009: First wind power record : 2825 MW



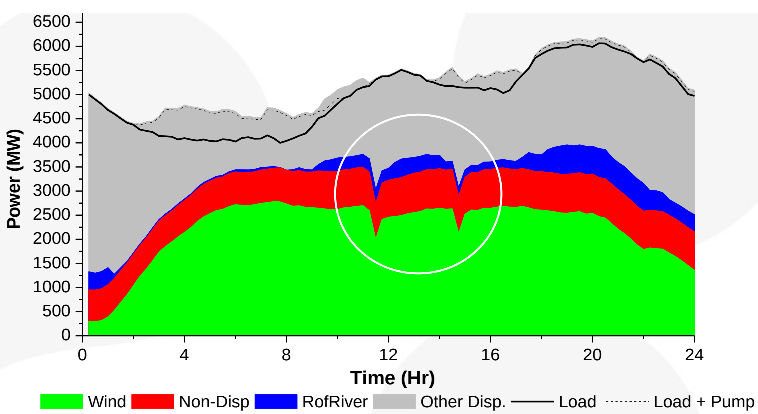
80% of installed capacity, the max. percentual design value.
Everything went well, the excess was stored.

8.Nov.2009: Record of 50% of daily energy consumption by wind!



Same situation. Storage of RES excess and a little export.
Almost no run of the river

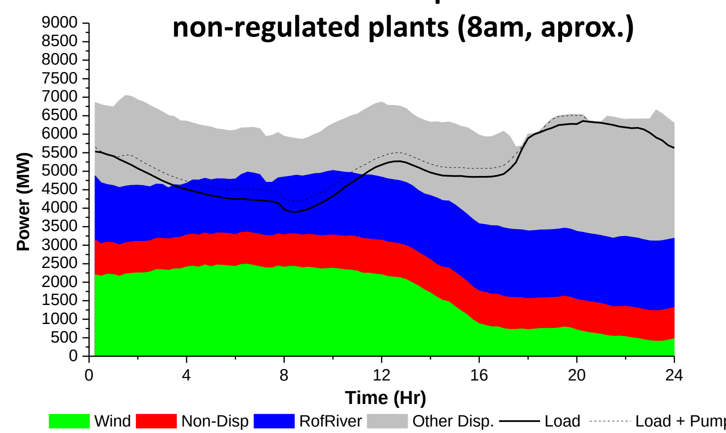
15.Nov.2009: 71% of inst. wind penetration!



source: www.ren.pt

2785 MW wind power for ~3700 MW of no-load consumption. Little ROR and export.

1.Jan. 2010: 117 % penetration of non-regulated plants (8am, aprox.)



1st of January -the demand had a very low value while the wind and run of the river plants were both peaking... The system had the absolute maximum penetration of 117% of non-regulated power plants...

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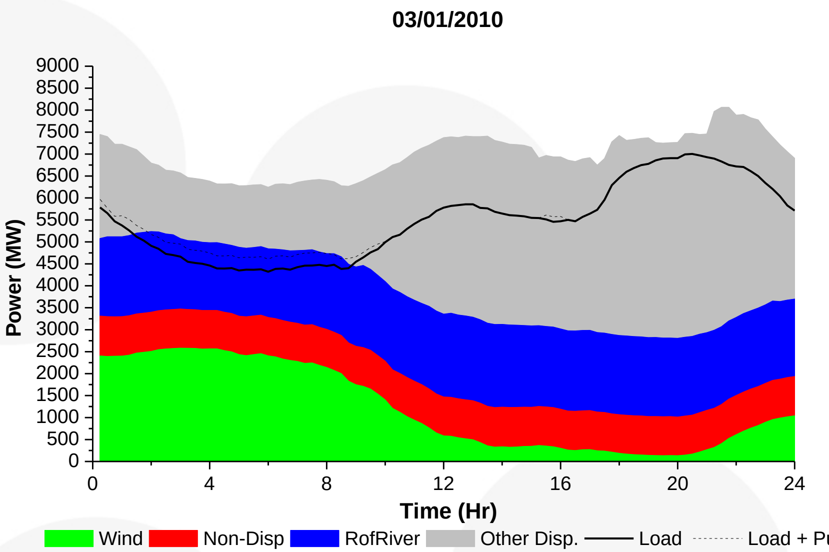
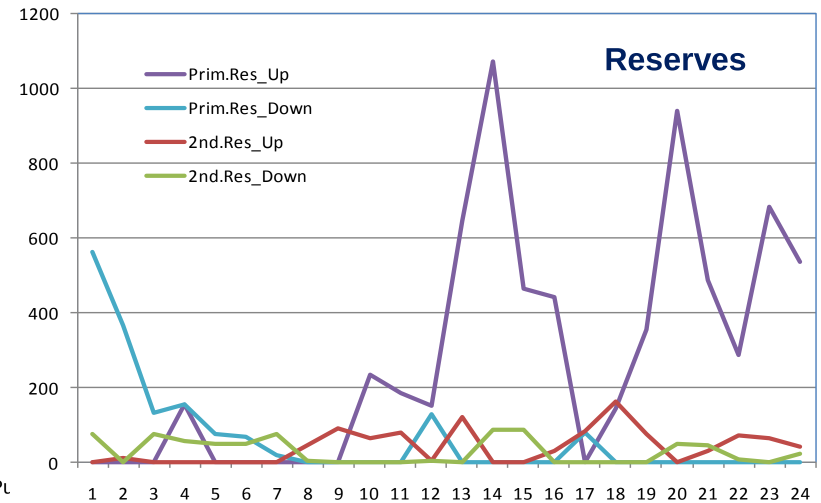
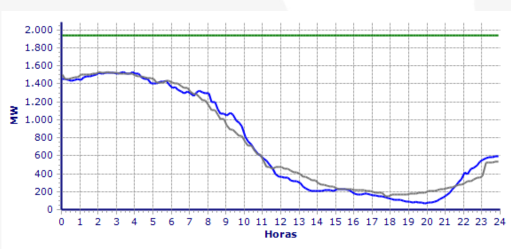
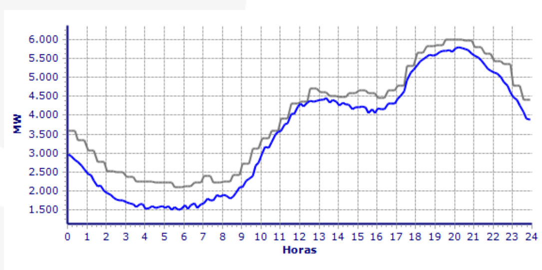
The extreme 2009/10 winter (3.Jan.2010)

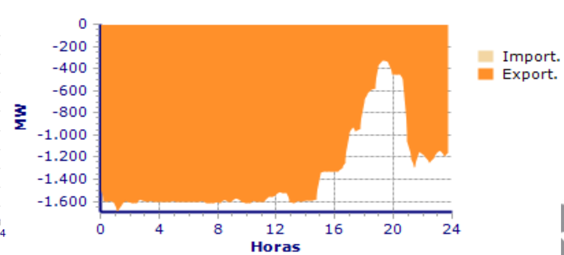
106 % penetration of non-regulated plants, 49% of wind











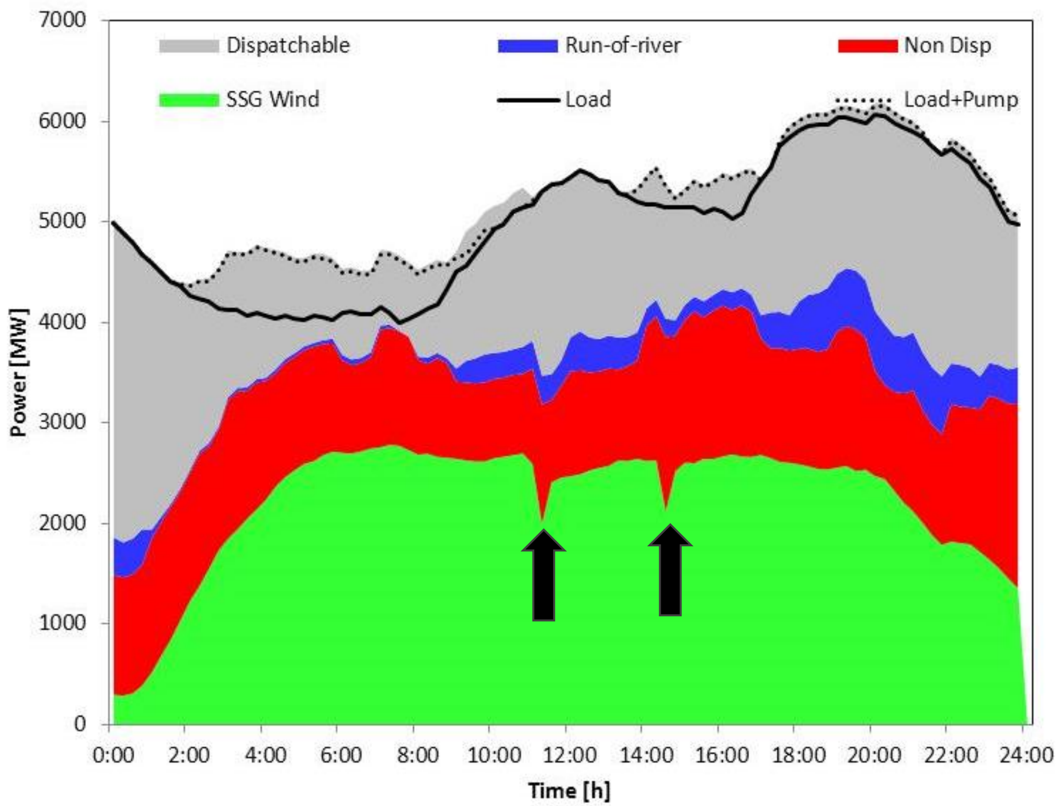
Wind forecast **Load forecats** **Import/export**

source: www.ren.pt

final slide 1/2

Learn by doing: 15.Nov.2009

2978 MW out of 3500 installed (85%...); 103% non-regulated, almost no pumping capacity...



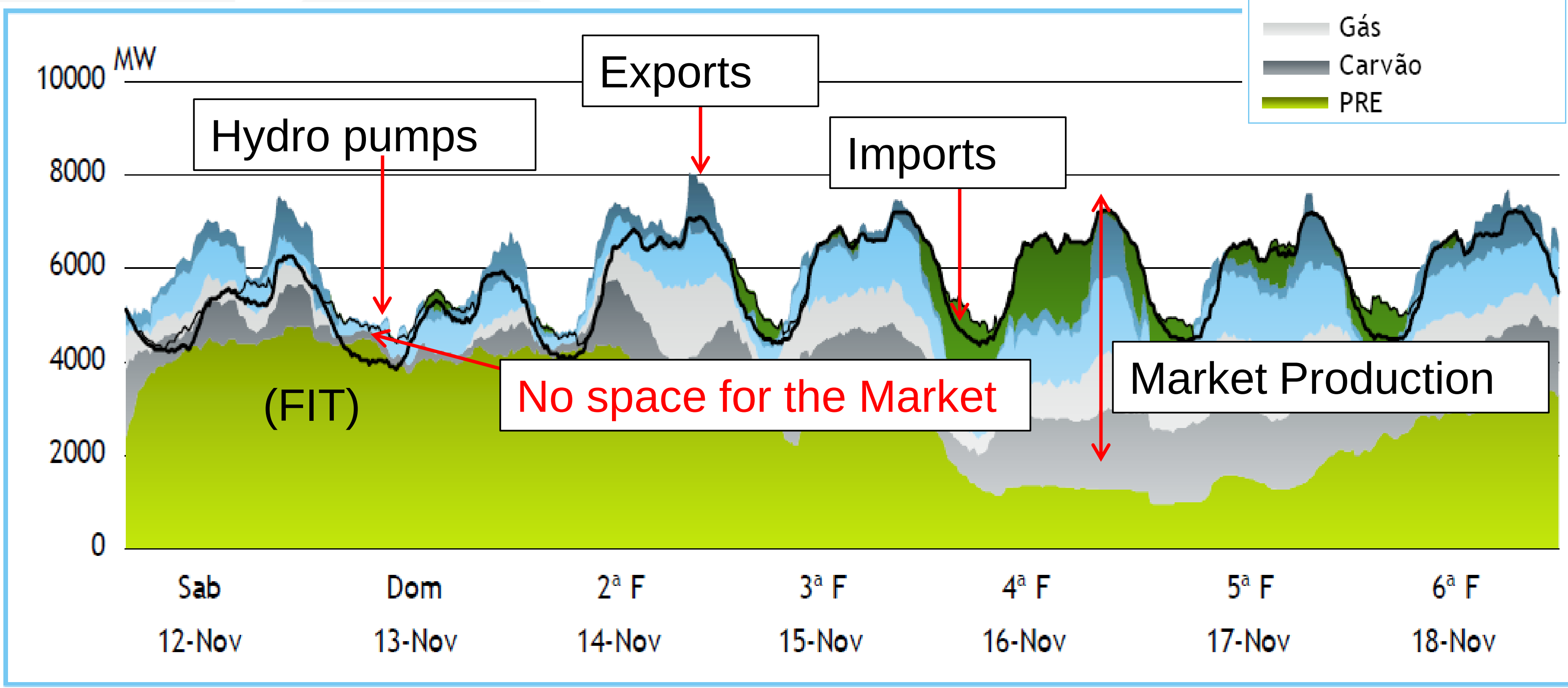
a storm on 15th November, 2009 caused a 2.42 GW steady increase of wind power production during 5.5 hours (72% of installed wind capacity).
Due to the storm two grid fault incidents occurred in which , more than 1.3 GW, respectively 51 and 52% of the wind generation, was lost. Each was recovered in less than 15 minutes (average ramp rate - 484.8 MW/h).

>100% theoretically non-dispatchable at 7am... Two serious incidentes ocurred, not due to wind power, but faults in transmission lines (due to high winds)

source: www.ren.pt

The impact of High Wind (and other Variable RES) Production on the Market

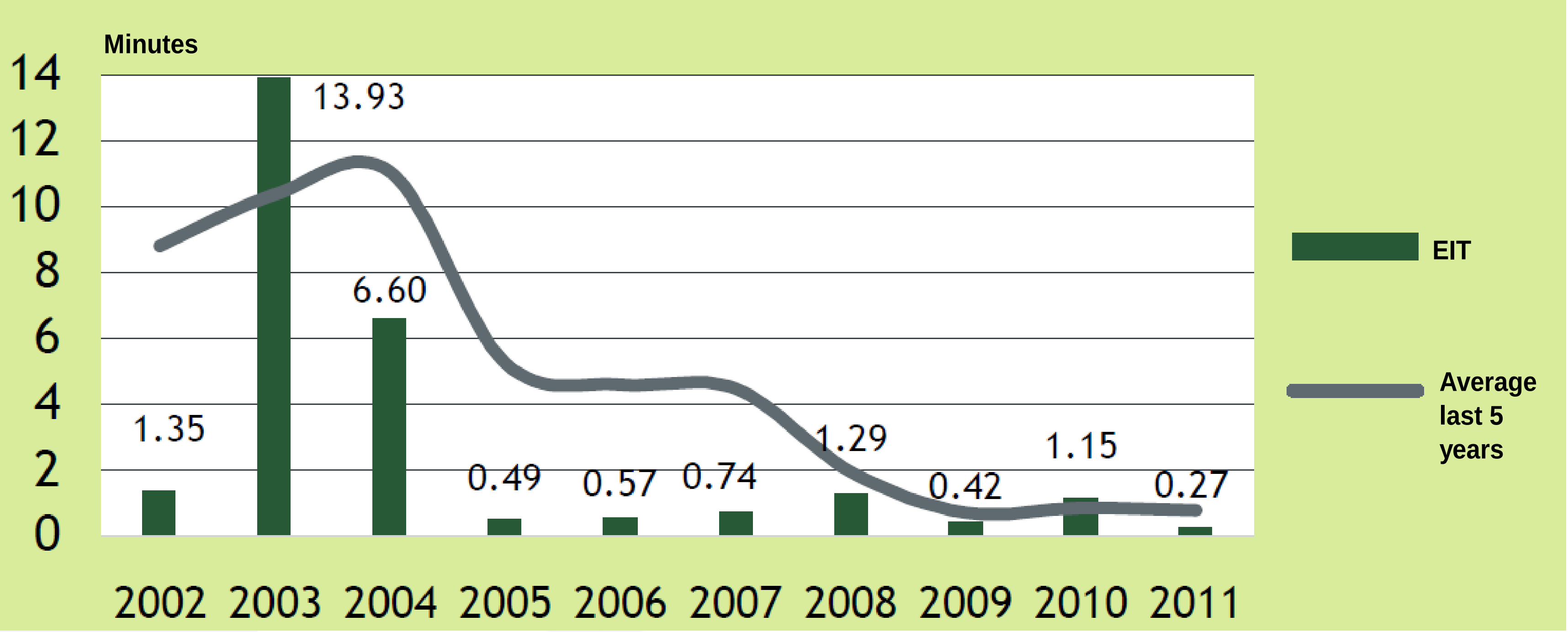
There was a need to curtail RES generation due to excess of special regime sources (RES and CHP) and reduced load



source: R. Pestana (REN), Interesting High Penetration Hours: What Have we Learned in Portugal at 93%, UWIG ,Tucson , 2012.

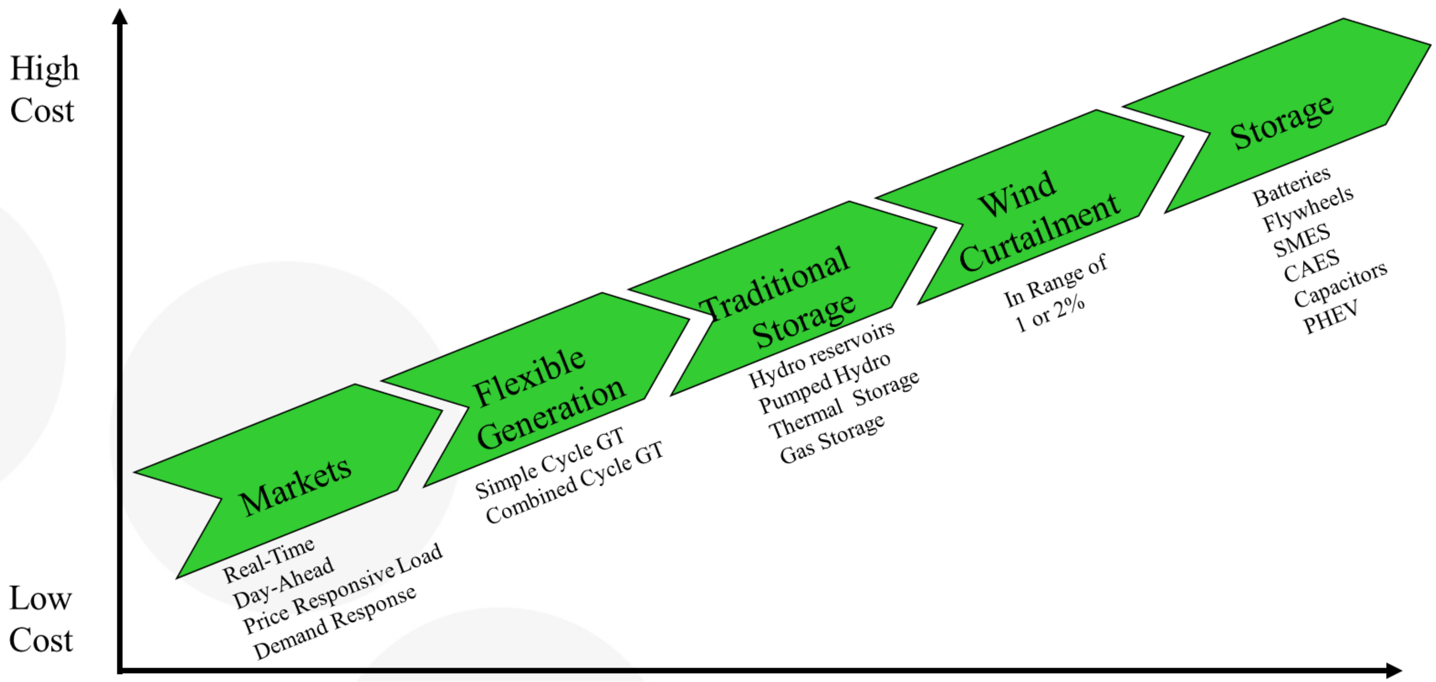
Grid and System's Power Quality

- The Equivalent Interruption Time at transmission level remains excellent



0.27 minute means a reliability of 99,99995%

source: R. Pestana (REN), Interesting High Penetration Hours: What Have we Learned in Portugal at 93%, UWIG ,Tucson , 2012.



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

Optimizing The Power System Operation And Use

Towards the "Smart" European Power System. The basic concepts:

1. *Real-time assessment (and optimization) of transmission capacity.*
2. *Spread use of DGS as grid active voltage controllers.*
3. *Coordination of ancillary (system) services on a European scale.*
4. *Integration of balancing markets and coordination of reserves within EU grids/control areas;*

   Market rules and closure times need to be adapted to wind and PV low errors on forecasting (typical anticipation periods are 6h and 2h).

5. *To implement solutions to allow for efficient and robust system operation with significant amounts of highly variable generation and storage and more system flexibility;*

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

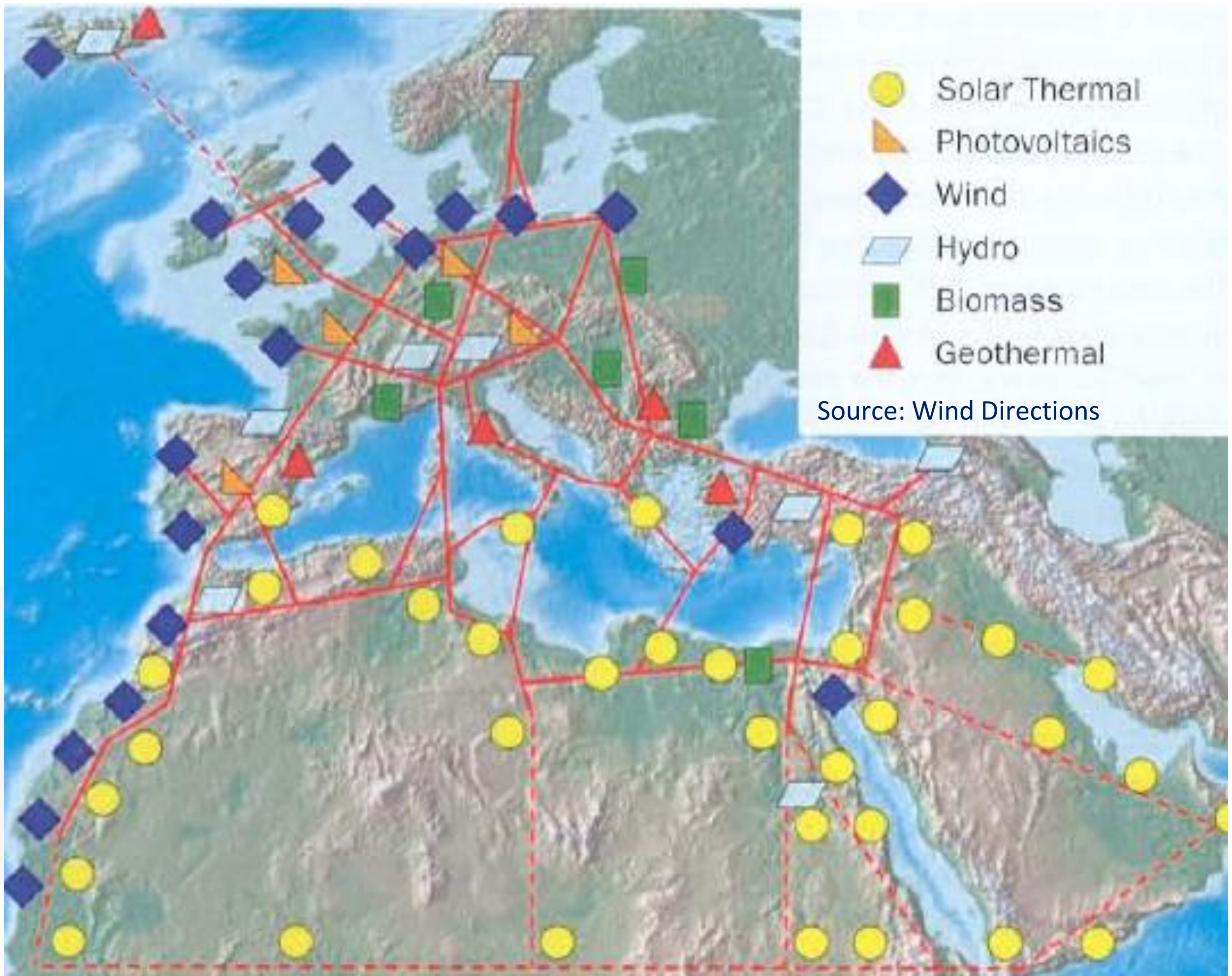
The European “Supergrid”

A possible way to cope with both the growing deployment of offshore wind and limited grid capacity onshore is to plan an offshore super grid interconnecting most relevant systems.

Fonte: www.airtricity.com

That will solve most of the Northern Europe congestions…

...but it is in Southern Europe, the Mediterranean and the Arabian Peninsula that the concept acquires its real dimension!



The large wind variability smoothes out when grids and power systems are aggregated in large scales, thus enabling to increase not only the wind, but also the solar power penetration (e.g. CSP and large PV).

Synthesis

- The wind industry has experienced a remarkable increase in its power system interface and performance in the past recent years.
- Technical studies to assess the full impact of very 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, F), DSM, H2 generation, PHS;
  - Electric vehicles and distributed storage (SmartGrid concepts);
  - Large scale transmission networks interconnection;

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Open questions for 2020:

- When, where and under what circumstances should the wind power stations be deloaded or ramped?" to provide primary frequency control".
- Which power plants will be retrofitted to allow added control and more wind integration at lower overall costs?
- How to select the best aggregation agent (virtual power plant operator) for our wind power plant?
- Will the actual energy markets' model survive? How will markets be organized in the future to allow the participation of large shares of non-dispatchable power plants?

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Final notes: the Portuguese very High Wind Penetration Experience

- The principles that conducted the Portuguese power system design for very high wind penetration proved, so far, to be entirely adequate.
  - The quality of service, so far, was not compromised;
- Portugal had the lowest costs for added transmission;
- The "wind dispatch centres" are a valuable tool and were financed by private investors
  - in order to be granted grid connection and give a noticeable contribution for the system security of operation;
- Added storage at PHS is being deployed up to 2020 by retrofitting of old hydro stations (1950-60)
  - that have low investment costs (~1000 Euro/kW installed);
- No major technical incidents were reported by the TSO,
  - but additional FRT capability, voltage control and primary frequency regulation (of distributed generation) is desirable.
- Curtailment of excess renewable generation (not only wind) has to be fully implemented.

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