Integrating renewable energy into the Spanish energy networks – Technology challenges

September 15th, 2010
Gumersindo Queijo
Index

- Renewable Energy in Spain Today
- System Development and Access & Connection Issues
- Operational Challenges for RES Integration
- Wind Power Production Forecast
- Wind Energy Variability
- Network Congestions
- Influence of Renewable Energy on Generation Reserves
- Power Balance Feasibility
- Voltage Control
- CECRE: Control Centre for Renewable Generation
- Real Time Production Control (GEMAS)
- Final Remarks
Renewable Energy in Spain Today
Two types of regulatory regimes for Generation

Special Regime

- Production $P \leq 50$ MW that use:
  - Co-generation
  - Renewable Energy Sources
  - Urban solid residues

- Priority Access (right to sell all their production except security constraints)

- Retribution:
  - Regulated in feed tariff
  - Market Price + Prime with Cap & Floor

Ordinary Regime

- All other power plants

- Obligation to participate in the market $P > 50$ MW

- Retribution:
  - Market Price
Success of the feed-in tariff model: Evolution of wind power installed capacity (MW)

Regulation has allowed to achieve the goals of the Spanish Regulator and Government
Spain and REE in the World

- Installed wind capacity and other data from 2009
- Spain ranks 4th country in the world in terms of wind power installed capacity.
- In terms of % of electricity consumption ranks 2nd after Denmark.
- REE is the first TSO in the World in terms of amount of wind power in its system.

<table>
<thead>
<tr>
<th>Country</th>
<th>Installed Wind Capacity (MW)</th>
<th>% of Energy Consumed</th>
<th>% of Total Installed Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>35 159</td>
<td>1%</td>
<td>3,2</td>
</tr>
<tr>
<td>Germany</td>
<td>25 777</td>
<td>9%</td>
<td>19,1</td>
</tr>
<tr>
<td>Spain</td>
<td>19 149</td>
<td>14%</td>
<td>20</td>
</tr>
<tr>
<td>China</td>
<td>26 010</td>
<td>&lt;1%</td>
<td>1,8</td>
</tr>
<tr>
<td>India</td>
<td>10 925</td>
<td>2%</td>
<td>6,1</td>
</tr>
<tr>
<td>Denmark</td>
<td>3 497</td>
<td>20%</td>
<td>24,1</td>
</tr>
</tbody>
</table>
Installed power in December 2009

<table>
<thead>
<tr>
<th>Technology</th>
<th>MW</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro-power</td>
<td>16.657</td>
<td>17,8</td>
</tr>
<tr>
<td>Nuclear</td>
<td>7.716</td>
<td>8,2</td>
</tr>
<tr>
<td>Coal</td>
<td>11.357</td>
<td>12,1</td>
</tr>
<tr>
<td>Fuel-Gas</td>
<td>3.008</td>
<td>3,2</td>
</tr>
<tr>
<td>Combined cycles</td>
<td>23.066</td>
<td>24,6</td>
</tr>
<tr>
<td>Total (ordinary regime)</td>
<td>61.806</td>
<td>65,9</td>
</tr>
<tr>
<td>Wind power generation</td>
<td>18.719</td>
<td>20,0</td>
</tr>
<tr>
<td>Rest of special regime</td>
<td>13.185</td>
<td>14,1</td>
</tr>
<tr>
<td>Total (special regime)</td>
<td>31.924</td>
<td>34,1</td>
</tr>
<tr>
<td>Total</td>
<td>93.729</td>
<td></td>
</tr>
</tbody>
</table>

Demand coverage in 2008

- Hydro-power: 9%
- Nuclear: 19%
- Coal: 12%
- Fuel-Gas: 12%
- Combined cycle: 30%
- Rest special regime: 16%
- Wind power: 13%

Special Regime includes solar PV, solar thermal, biomass, CHP, mini-hydro, waste treatment...
**Installed Power Special Regime**

<table>
<thead>
<tr>
<th>Technology</th>
<th>MW</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>18.719</td>
<td>56.9</td>
</tr>
<tr>
<td>Solar</td>
<td>3.497</td>
<td>11.0</td>
</tr>
<tr>
<td>Other Renewables</td>
<td>2.555</td>
<td>8.4</td>
</tr>
<tr>
<td>Cogeneration (CHP)</td>
<td>6.750</td>
<td>20.1</td>
</tr>
<tr>
<td>Waste-Treatment</td>
<td>579</td>
<td>1.9</td>
</tr>
<tr>
<td>Solid Urban Waste</td>
<td>494</td>
<td>1.6</td>
</tr>
<tr>
<td>Total Special Regime</td>
<td>31.924</td>
<td></td>
</tr>
</tbody>
</table>

**Energy produced in 2009**

<table>
<thead>
<tr>
<th>Technology</th>
<th>GWh</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>31.393</td>
<td>47.7</td>
</tr>
<tr>
<td>Solar</td>
<td>2.428</td>
<td>3.7</td>
</tr>
<tr>
<td>Other Renewables</td>
<td>5.817</td>
<td>8.8</td>
</tr>
<tr>
<td>Cogeneration (CHP)</td>
<td>20.591</td>
<td>31.3</td>
</tr>
<tr>
<td>Waste-Treatment</td>
<td>3.142</td>
<td>4.8</td>
</tr>
<tr>
<td>Solid Urban Waste</td>
<td>2.381</td>
<td>3.6</td>
</tr>
<tr>
<td>Total Special Regime</td>
<td>66.298</td>
<td></td>
</tr>
</tbody>
</table>

Official Network Planning for 2016 contemplates ~29,000 MW.

Further increase expected for compliance with proposed EC initiatives (20% of primary energy must come from renewables).
Wind Power capacity installed in European countries (2009)

Source “Wind in Power 2009” EWEA
Wind Power installed capacity estimation for 2015
Wind Power penetration with respect to peak load
Wind Power penetration with respect to minimum load
The Iberian System has the highest wind penetration

- For Spain and Portugal, due to the weak interconnection Spain – France, the relevant system for wind penetration is the Iberian System.

- For Germany, Austria... given the strong interconnections, the relevant region for wind penetration is the whole central Europe: Germany, France, Switzerland, Italy, Netherlands, Belgium, Austria,. Czech Rep., Slovak Rep., Hungary and Poland.

- Wind Penetration Central European System:
  - 2008: 11%; 2015: 22%

  Values referred to peak demand 2008

- Wind Penetration Iberian System:
  - 2008: 31%; 2015: 64%

But with respect to minimum load, wind penetration in 2015 will be 160% !!!
Installed wind power capacity is distributed over very wide areas, almost all over the country.

Installed Power: 19436.5 MW

Some records:
- 12.948 MW  24/02/10 11:21 h
- 12.843 MWh 24/02/10 11-12 h
- 278.507 MWh 4/05/10
Maximizing renewable power integration

REE works to maximize renewable energy integration in secure conditions. Several work areas:

- Access and connection procedures, network planning and development
  - Assessment of maximum generation capacity (zonal and national)
  - Identification of technical requirements for generation (grid code improvement)
- Improving “dispatchability”:
  - Tool for wind power production forecast (SIPREÓLICO)
  - Control of wind generation via dispatch (orders to reduce generation when needed because of system security reasons)
- Regulatory proposals based on acquired knowledge and experience
## Renewable Generation Prospects

Very ambitious objectives in renewable energy:

- **in 2010:** 12% in Primary Energy (≈30% in electric energy)
- **in 2020:** 20% in Final Energy (≈40% in electric energy)

### Renewable Source of Generation

<table>
<thead>
<tr>
<th>Renewable Source of Generation</th>
<th>FORESEEN [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>Wind Power: the most significant source, but in Spain not the only one. Very good social support (at least up to now)</td>
<td>19,325</td>
</tr>
<tr>
<td>Solar-Thermoelectric: quite certain and likely to increase</td>
<td>861</td>
</tr>
<tr>
<td>Solar Photovoltaic: boom in 2008 due to expected primes</td>
<td>4400</td>
</tr>
<tr>
<td>Biomass: very uncertain</td>
<td>350</td>
</tr>
</tbody>
</table>

**Total (2010): 24,906 MW**
Renewable Generation Prospects

Calendar for renewable energy approved by the Government
Press Note of the Industry Ministry dated November 16\textsuperscript{th}, 2009

<table>
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<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Eólica</td>
<td>1.524</td>
<td>1.595</td>
<td>3.508</td>
<td>1.609</td>
<td>1.864</td>
<td>1.855</td>
<td>1.700</td>
<td>1.700</td>
<td></td>
</tr>
<tr>
<td>Termoeléctrica</td>
<td></td>
<td>11</td>
<td>0</td>
<td>350</td>
<td></td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>540</td>
</tr>
<tr>
<td>Fotovoltaica**</td>
<td>25</td>
<td>98</td>
<td>550</td>
<td>2.748</td>
<td>473</td>
<td>500</td>
<td>484</td>
<td>532</td>
<td></td>
</tr>
<tr>
<td>Minihidroeléctrica</td>
<td>57</td>
<td>130</td>
<td>7</td>
<td>45</td>
<td>112</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Biomasa</td>
<td>30</td>
<td>41</td>
<td>16</td>
<td>28</td>
<td>65</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>1.635</td>
<td>1.864</td>
<td>4.092</td>
<td>4.429</td>
<td>2.864</td>
<td>3.035</td>
<td>2.864</td>
<td>2.912</td>
<td>540</td>
</tr>
</tbody>
</table>

System Planning and Access & Connection issues
Maximizing RES integration in the Planning stage

RED ELÉCTRICA works to maximize renewable energy integration while preserving system security at the Planning stage:

- Generation Adequacy & System Dynamics Studies (WORD DOCUMENT)
- Network planning and development
  - Assessment of maximum generation capacity (zonal and national) that can be integrated
  - Identification of technical requirements for RES generation (grid code development and improvement)
- Access and connection procedures
  - No difference with conventional generation procedures
- Regulation proposals to assure secure RES Integration
Development and Access to the Network: Current Context

- **Power system Planning**
  - Generation: *not regulated* >> *indicative* planning, with agents decisions depending of incentives
  - Network: *regulated* >> *binding* planning, under National Administration responsibility, with the participation of Regional Autonomous Administrations and developed by REE

- **Access to the Grid:**
  - Regulated: Access and connection procedures
Capacity of the Transmission Network: at the disposal of the agents

- For generators, no grid capacity reserve or preference derives from temporal precedence

Possible production constraints in operation time are to be solved by market mechanisms

- No connection limitation: New comers may degrade the production possibilities of existing or previously foreseen (considered in planning)

- Less barriers but more uncertainty: Practical tendency to over-installing

- Special Regime Generation

  - Priority at dispatch, subject to system security
  - Congestions motivate system development ⇒ ineffective planning
  - Connection limitation according to zonal studies from OS
Access and connection procedures are managed by REE

Main Features

<table>
<thead>
<tr>
<th>Main Perspective</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access</td>
<td>System Operation</td>
</tr>
<tr>
<td>Connection</td>
<td>Transmission</td>
</tr>
<tr>
<td></td>
<td>Engineering and Physical Feasibility</td>
</tr>
</tbody>
</table>

Procedures

- **Access Application**
  - Connection to Transmission >>> SO (REE)
  - Connection to Distribution (> 10 MW.) > DO> SO (REE)

REE issues a report evaluating access feasibility, fulfilling system security criteria

- **Connection Application** >>> Trans.Co.

  Agent submits engineering Project and Programme

  - SO (REE) supervises and issues a report

Agent < TECHNICAL ACCESS CONTRACT> Transmission Company
**Cost Allocation of New Facilities**

- Small efficiency signal: existing vs. new substations
- Very insufficient incentive to geographical energy balance and to promote more efficient locations (with respect to transmission system)

<table>
<thead>
<tr>
<th>Transmission Facilities</th>
<th>Investment Cost</th>
<th>Operation and Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly associated to connection</td>
<td>Agent</td>
<td>System</td>
</tr>
<tr>
<td>Structural Reinforcement</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td>(Agent guarantees 20% of Cost)</td>
<td>Agent</td>
<td>System</td>
</tr>
</tbody>
</table>

### Diagram:
- **Connection Facilities** (no TransGrid)
- **New substation as in/out of existing line**
- **Existing Substation**
- **New bay**
- **TransGrid**

**Connection Facilities**

- Small efficiency signal: existing vs. new substations
- Very insufficient incentive to geographical energy balance and to promote more efficient locations (with respect to transmission system)
In Spain, high presence of wind generation in the transmission grid (contrary to other power systems with high penetration).

<table>
<thead>
<tr>
<th>Conexión a:</th>
<th>MW</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>RdT</td>
<td>8.287,1</td>
<td>60.12%</td>
</tr>
<tr>
<td>RdD</td>
<td>5.497,4</td>
<td>39.88%</td>
</tr>
</tbody>
</table>

**SEPE Ene08: 13.784 MW**

**... and to increase**

<table>
<thead>
<tr>
<th>Nº Tr Nodes</th>
<th>Now</th>
<th>Foreseen</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 kV</td>
<td>12</td>
<td>33</td>
</tr>
<tr>
<td>220 kV</td>
<td>37</td>
<td>70</td>
</tr>
</tbody>
</table>

In addition: off-shore wind power, solar, ...
Increase in Transmission Network required

Transmission Network 2008:
- Km de circuito: 34,322
- Posiciones de subestación: 3,162
- Potencia transformación (MVA): 62,122

Transmission Network planned for 2016:
- Δ Km de circuito: 12,656
- Δ Posiciones de subestación: 3,476
- Δ Potencia transformación (MVA): 52,450
Influence of RES connection on Transmission planning

Transmission Network Plan H2016 is highly ambitious in physical units and economic investment (≈ 8800 M€)

A significant chapter of Plan includes facilities associated to RES for connection and reinforcement for avoiding constrains in operation.
Reinforcement of Spain-France Interconnection is a European Priority Project (with “European Coordinator”) for the Electricity Market: 1st step for Barcelona Summit objective (International Capacity Objective 2005 ≥ 10%InstalledGeneration)

Besides, it is fundamental for maximizing renewable integration in the Iberian System
Operational Challenges for RES Integration
Integration of Wind Energy: Challenges

The particularities of wind generation impose technical and management challenges to the system and to the conventional generation:

• Location far from the load and grid (grid investments needed)
• Wind generators are non-synchronous machines
  ⇒ Different behavior under normal system faults (tripping under voltage dips, no short circuit current, no inertia…)
  ⇒ Different system vulnerability to incidents in the system
  ⇒ Lower voltage control capability (up to now)
• Production Forecasts rather than Production Programs
  ⇒ Lack of firmness and control (Lower Dispatchability)
  ⇒ Need of conventional generation remains the same but will operate less hours per year – Alternatively: storage plants needed
Operational challenges of distributed generation

- Myriad of plants each belonging to different companies with different policies for operation, switching and maintenance and hidden to the System Operator (there are around 575 wind parks installed in the Spanish peninsular system) ⇒ Not acceptable for SO
- Very slow contact in case of emergency production reductions, outages or maintenance planning of the transmission assets next to connection points for generation ⇒ Not acceptable for SO
- SO actions always manual leading to longer execution times ⇒ Not acceptable for SO
- If actions and supervision takes longer and risks are higher, stricter limitations should be in place and planned further in advance reducing RES production and installation ⇒ Not acceptable for wind producers, goals for RES could not be achieved
- A solution was needed
Operational challenges

- Myriad of plants in many cases integrated in the distribution network.
- CECRE: Dedicated control center for supervision and management of special regime generation.
- Legal framework:
  - Royal Decree 661/2007: installations with power installed higher than 10 MW are obliged to be connected to a Special Regime Control Center connected to CECRE.
  - Grid Code: installations higher than 1 MW are obliged to issue real-time production telemeasurements to CECRE.
- Impact of forecast errors in generation reserves.
- Fault-ride-through capabilities mandatory for new generation since 1/1/2008 and adequacy for already installed plants until 1/1/2010.
Operational challenges

- Royal Decree 661/2007. Definition of manageable generation:
  - Non-manageable generation (wind energy, solar...):
    - primary energy source cannot be controlled or storage and production control implies energy spill.
    - production programs are not reliable enough so they should be considered as a forecast.
  - Individual plants can be classified as manageable for the SO if they pass a guideline.

- Balancing mechanisms: only manageable generation is allowed to participate.

- Specific voltage control procedure for special regime generation not yet completely suitable for system operation requirements (work in progress)
Wind Energy Variability
Wind Energy Production Evolution

Records show that wind energy production per year and per MW installed is almost constant: We know how much energy will be produced but we do not know when

- **Absolute Wind Production Evolution**
  - Wind Production Evolution (GWh)
    - Year: 2005 2006 2007 2008
    - Production: 21.239 22.437 26.643 31.135

- **Monotonous curve of relative wind production**

- **Absolute production increases as result of the increase of installed capacity**

- **Relative wind production remains “constant” for long periods of time**
Wind energy production records

- Maximum production: 11.203 MW (05/03/2009)
- Minimum production in one year: 204 MW (30/05/2008)
- 43% of demand coverage by wind energy
Wind Energy Characteristics

- Non manageable primary energy.
- Very variable production output.
- Downward ramps in wind production in the mornings often increase morning ramps of conventional generation.

**Demand vs. Wind Production**

**Wind Production during a Year (May to May)**
There are monthly patterns (March, April, November… have had the highest production) and reduction in the mornings.

- **Data corresponds to one year (20/05/2007-19/05/2008)**
- **Largest wind production do not coincide with largest demand requirements (in winter and summer). Discrepancy specially important in summer.**
Wind production variability

- Increase of 586 MW in 30 min. Gradient: 1172 MW/h
- Decrease of 1110 MW in 1 h 25 min. Gradient: -785 MW/h

Wind turbines technology

- Wind generation tripping if wind speed higher than 25 m/s.
- Wind power variation on this day: 1800 MW reduction in 2 hours
- Large number of wind farms tripping because of too high wind speed and then recovering production after some hours.
Wind Power Production Forecast
REE wind power prediction tool in operation since 2002

Real time wind generation

Meteorological forecast

System operation

REE. Cecre (setpoints)
Classification of wind power production forecast tools

- According to the scope of the forecast
  - Single wind farm forecast
  - Multi-wind farm forecast
  - Wide area forecast – Country (control area) forecast
    As geographic dispersion increases relative forecasting errors decrease as a consequence of statistical compensation of combined errors (portfolio effect)

- According to the time horizon of the forecast
  - Long term forecast: Normally used to estimate wind power energy outcome during long periods of time
  - Short term forecast: From 1 hour to several days, Day Ahead being the most important time horizon
  - Very short term forecast: Less than 1 hour

Different tools and methods are used for each case
SIPREOLICO: wind power prediction tool up to 48 hours

- Running since 2002
- Method:
  - Used presently: Time series self-adaptative
  - Being tested: neural networks
- Input data:
  - Wind power production: 15 minutes mean values
  - Meteorological forecasts up to 48 hours (wind forecast: speed and direction)
  - Wind power prediction for the whole system
  - Ensembles
- Results:
  - Detailed hourly forecasts up to 48 hours updated every 20 minutes
  - Probabilistic output with confidence intervals (useful for reserves)
Tool description

Real time wind power

- Data processing
- Forecasts treatment

Meteorological Forecasts

National WPP

New wind farms

- Wind farms database
- Prediction algorithm

Results processing

- Report 1
- Report 2
- Report N

Real P-w curves

Statistical corrections

Turbines database

Historical data

Result graphs
Use of historical wind power production data series

- Past data of weather variables and power output is used for statistical wind power forecasting.
  - Find weather situations in the past similar to those predicted in the future and retrieves the past power output.
  - May be used as a model itself or as a correction of a physical model.
Meteorological forecast models

- NWP spatial resolution is normally several km and may not be sufficient for wind farm production forecasting.
  - Results for grid points must be extrapolated to the physical location of the wind farm.
  - In mountainous areas weather variables change locally whereas in flat terrain these variables are geographically more constant.

- Physical models may be considered downscaling NWP results:
  - Terrain consideration such as roughness or shape included.
  - Hub height could be considered to improve results

- At least a value of wind speed and wind direction is obtained for a certain wind farm. Some tools may also use temperature, pressure or humidity.
Probabilistic forecast and ensemble models

- Probabilistic weather forecasting can be introduced by the use of ensemble models.

- Ensemble models provide multiple forecasts which are generated altering slightly the initial conditions of the prediction or the forecast model itself.

- By entering the different weather variable results multiple wind forecasts are obtained.

- Ensemble weather models can also be combined with statistical output predictions depending on similar weather situations.
Combination of different models

- Depending on the weather variables that are forecasted at a given moment, an intelligent algorithm could choose which forecast method or model to use depending on the past accuracy for the predicted weather scenario.

```
1-FORECAST MANAGER

2-COMBINATION

3-UNCERTAINTY
Wind
Power and
Intervals

4-DIAGNOSIS
Diagnosis
Report
```
Combination of different models

- A well tuned combination of different models gives at least better results than the best model used.
- Detailed error analysis of the different models’ results must be carried out in order to determine under which situations a certain model is better than the others.

Example of Combination Criteria:

Step 1:
- Combination of forecasts using the **optimal average method**.
- Combination of forecasts using the **minimal risk method**.

Step 2:
- Combination of Step 1 combinations using the **minimal risk method**.
Error analysis

- Root mean square errors can be normalized in percentage relative to production or relative to installed capacity.
- An error of 5% relative to installed capacity is equivalent to a 20% error relative to production!
Wind Power Production forecast errors have improved significantly in REE due to continuous development of the forecasting tools used in Siprélico.

Further improvements seem to be limited by weather prediction models.
Mean error distribution up to 4 and 40 hours normalized by wind power installed in 2007
Error density functions normally resemble a Weibull distribution.

Standard deviation is less when errors are large relative to the production.
Operating Reserve Margin

- Appropriate reserve requirements for load frequency regulation allows the TSO to overcome generation-load unbalances, but minimizing system costs and the generation ecological footprint.

- The required reserve levels at every moment are determined in the case of Spanish Power System mainly by the following variables:
  - Demand Forecast Error.
  - Wind Power Forecast Error.
  - Failure of the thermal generation units.

- Therefore, a deterministic reserve requirement level should be:

\[
\text{Reserve}(t) = \text{Demand.Forec.Err}(t) + \text{Wind.Forec.Err}(t) + \text{Failure}(t)
\]
Probabilistic running reserve level calculation

- The previous variables, analyzed in a time range large enough, has an Stochastic behavior (i.e. random variable). Therefore is possible to calculate its probability density function.
- So, the previous deterministic equation:
  \[ \text{Reserve}(t) = \text{Demand.Forec.Err}(t) + \text{Wind.Forec.Err}(t) + \text{Failure}(t) \]
  result in the following probabilistic equation:
  \[ \text{pdf}_{\text{Reser}}(x,y,z) = \text{pdf}_{\text{Err}.\text{Forec.Demand}}(x) * \text{pdf}_{\text{Err}.\text{Forec.Wind}}(y) * \text{failure}(z) \]

Where * represents the convolution between the different probability density functions that set the reserve levels.
Probability density functions

Probability density function of the Demand Forecast Error

Probability density function of the Wind Forecast Error

Probability density function of the Non availability units generation
Combined probability density function

- The convolutions of the previous probability density functions leads to a new probability density function that represents the probability distribution for different time horizons.
Combined probability density function

- With the help of the combined probability density function, the required reserve levels at different time horizons and with different confidence intervals can be calculated.
REE has developed a tool to forecast the production of all wind parks: SIPREÓLICO

- Wind speed forecasts are available and more reliable than other aspects of weather.
- Hourly forecasts of the next 48 hours by region or transmission system node (update every 15 minutes).
- Total hourly forecast of the next 10 days (update each hour).
- Hourly stochastic forecast of total production: percentiles 15, 50, and 85.
- Much better than wind programs in the daily market (this is the best forecast of the owners).
Evolution of absolute error (forecasted energy/real production)

- Critical time horizons are 24 or 32 hours in advance for day ahead power reserve evaluation and 5 hours for real-time evaluation.
- Positive evolution in forecast error in the last years has resulted in fewer need for reserves to cover wind forecast errors, specially in day ahead processes.
Wind Production within 15% - 85% probability function of forecasted wind production

Prediction intervals (Oct. 2007)

- PR_0.15
- PR_50%
- PR_0.85
- Wind production

MW

0 2000 4000 6000 8000

Hours

1 73 145 217 289 361 433 505 577 649 721
Use of Wind Production Forecasts

Day Ahead wind Production forecast is used for “hot” power reserve constraint evaluation in day ahead constraint resolution

- At 11:00 h in D-1 after market results are received, REE checks if there are enough available “hot reserves” for the next day:
  - Power Reserve in all connected thermal plants
  - Hydro power reserves with 4-hour maximum output
  - Hydro pumping storage reserves

- Constraint used: “Hot reserves” must be larger than some MW value computed taking into account possible generator trips, load uncertainty… and now wind production uncertainty

- If needed, additional conventional generators must be started up

Wind forecast tools are probabilistic. Percentile 85 of wind production greater than best forecast is used. Still it means that there is a 15% possibility that wind production could be for example 630 MW lower than best forecast. These uncertainty must be translated into bigger running reserves than with conventional generation
Programming of Construction and Maintenance works

- Weekly and short term work planning is done in REE’s transmission network.
  - 10 day wind forecast: used for weekly programming in some areas
  - 48 hour wind forecast: used for short term programming in some areas
- 73% of installed wind capacity is connected directly to the transmission network or to observable levels. Visibility in EMS and state estimator.
- Rest can be modeled in state estimator on its closest transmission system mode using PSS/E. Thanks to data provided to the CECRE.
- Forecast by transmission system node can be modeled for future scenarios in PSS.

Future scenario with modeled wind forecast

Nodal SIPREÓLICO
Probability density functions of errors (II)

- With the help of the probability density function of the wind power forecast error we can calculate how much additional running reserve is needed in the system to compensate for the wind forecast error uncertainty.

- Running reserve needs could also be sized depending on the combination of demand forecast error, wind forecast error, failure of conventional generation and other possible events.
Use of wind production forecast in system operation

- Long term wind energy production estimation is used for generation adequacy studies
  - but has very limited use for system planning

- Wind Power Production Forecast is important for Short term System Operation Planning
  - Maintenance Planning of wind in-feeders or lines in areas where wind production affects flows significantly

- Wind Power Production Forecast is very important for Day ahead Generation Programming
  - Calculation of needed running (or hot) reserve

- Very short term (less than one hour) Wind Power Production forecast is important for real time operation
  - Is used to monitor continuously Wind Power Production and detect potential sudden changes. Need to assure that fast generation reserves available will be enough to cope with them
Use of Wind Power Prediction to evaluate Tertiary Reserves needs

Need to manage fast changes like the one shown in the picture

Need to update Tertiary Reserve needs evaluation

Calculations every 15 minutes (current error 2%).
Use of wind forecast for evaluation of running reserve needs

Starting time of thermal units can be 3 or 4 hours
Thermal units must be programmed the day before operation

The system needs to have running (or hot) reserve to cope with all possible needs to increase production in less than 3 or 4 hours with respect to the generation program:

- Potential Generator Failures (n-1: largest unit used)
- Errors in demand prediction (demand 1% higher is used)
- Error in wind power prediction

.....

The generation program for tomorrow must have running reserves larger than the requirement. If not, new thermal units must be committed in the day ahead program.

Need to use a safe value of predicted wind power production: a minimum expected value for wind production. Need to use a probabilistic wind production forecast tool which gives that value with certain confidence interval (80%, 90%, 95%....)
Use of wind forecast for evaluation of running reserve needs

Available downward reserve can also be an important issue: An example later
Technical constraints in day ahead market

- In the DAY AHEAD Generation Programming process, REE compares the PBF (wind farms forecast) with Sipreólico (more accurate).

- The differences are solved connecting or disconnecting conventional generation when needed. So, this affects the units that are going to be running.

- Since 2005, most of the wind farms are participating directly in the market (in October 2009 98% of them) so their forecast are becoming better as they have penalties in case of deviations.

- However, Sipreólico still presents better results (16-18% between 24-48 hours) and the difference is evaluated and decisions are taken as described before.
On the morning of Sunday November 2nd at 8:00 h with one of the lowest demands of the year (~20 000 MW), wind prediction error hit 3200 MW.

The increase in wind forecast error from 5:00 to 7:00 h was too fast to have time to shut down thermal plants.

Spanish system ran out of downward reserves very rapidly and the only solution to balance the system was to decrease wind production from 7:22 to 9:30 h.
On January 23rd and 24th 2009 the storm Klaus hit the Iberian peninsula. Some wind parks recorded winds up to 220 km/h.

Most turbines in the north of Spain shut down due to their over-speed protection.

Difference between real and forecasted wind production was greater than 6000 MW on some hours, but since demands were low and thermal plants were connected in real time due to alert situation there was enough upward reserve to deal with these errors.
Good Wind Power Production Forecasts helps dealing with the uncertainties introduced in the system by wind generation and improve significantly the integration of wind energy into the system.

Most Wind Power Production Forecast tools rely firstly on weather prediction models which are used afterwards to estimate wind energy production using:
- Downscaling weather variables to the local areas where wind farms are located
- Historical series
- Complex statistical calculations
- Ensemble models
- Combination of several different models
- …

Wind Power Forecast Errors should be analyzed comparing different methods and models to improve the tools in use.

Wind Power Forecast tools are very important for day ahead generation programming and for fast reserve requirement calculation.

Knowledge of uncertainties due to forecast errors is crucial in systems with high wind power installed capacity.
Network Congestion
Congestions in the transmission network were due to maintenance works or unexpected outages. For example, one 400/132 kV transformer which was out of service from 17/09/2008 to 23/09/2008.

Congestions in the distribution network have appeared mainly due to social and environmental delays in the development of the transmission network and to over-installation of wind parks.
Operational Procedure PO 3.7 and RD661/2007 regulate how these congestions must be managed. Wind parks must adapt their production to the given set-point within 15 minutes.

DSOs may also request limitations to the special regime facilities via SO in order to solve congestions in their networks.
Voltage dip wind power reductions

- 2008: 11 reductions due to voltage dip stability problems in order to avoid congestions in the tie lines with France.
Total of wind energy reduced related to wind production

Only in March 2008 the wind energy curtailed is slightly higher than 1% of the wind energy produced

Average value around 0.3%
Behaviour during voltage dips
Wind generation tripping due to voltage dips.

- The voltage dip which would be generated by a three-phase short circuit in some 400 kV substations affects most of the system.
- From January 1st 2008 all new wind facilities must comply with PO 12.3 (fault-ride-through capability)
- 7 200 MW that had been installed before that are now also compliant with the new code. Only 3 900 MW remain without fault-ride-through capabilities for faults shorter than 100ms and voltages lower than 85% p.u.
A problem already solved
Wind Generation trips after normal system faults. Example case in North of Spain: Wind Power Disconnections while ordinary generation was not affected
Observation of wind generation trips

- Small number of trips of more than 500 MW
- No critical incident has occurred

New “Grid code” proposed by REE and adopted
Fault-ride-trouch capabilities required

Requirements (Grid Code: PO12.3)

V(t) in the connection point

Voltage (pu)

0.2 0.5 1

Time (sec)

start of disturbance

Situations where generators must remain connected

0.6 2 ph isolated

Fault length

Clearance of the fault

Limits of consumption (P, Q) during fault and recovery

0.8 0.95 pu
Influence of Renewable Energy on Generation Reserve
## System Balancing Reserves

<table>
<thead>
<tr>
<th>Type</th>
<th>Definition</th>
<th>Influence of Wind Power on Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Regulation</td>
<td>Action of speed regulators from generator units responding to changes in system frequency (&lt;30 s to 15 minutes)</td>
<td>Not influenced by wind power but other generators must provide the primary reserve that wind generators do not provide</td>
</tr>
<tr>
<td>Secondary Regulation</td>
<td>Automatic action of central algorithm and AGCs in the generation units that provide this service responding to changes in system frequency and power deviations with respect to France. (≤100 s to 15 minutes)</td>
<td>Only slightly affected by wind generation ramps when these ramps are opposite to system demand. Presently, no need to contract further reserve bands.</td>
</tr>
<tr>
<td>Tertiary Regulation</td>
<td>Manual power variation with respect to a previous program in less than 15 minutes. (&lt;15 min to 2 hours)</td>
<td>Only slightly affected by wind generation ramps when these ramps are opposite to system demand.</td>
</tr>
<tr>
<td>Running Reserves or Hot Reserves</td>
<td>Manageable generation reserves that can be called upon within 15 minutes to approximately 2 hours. Include tertiary reserves and consist of the running reserves of connected thermal units and hydro and hydro pump storage reserves. (15 min - 2 hours to 4 - 5 hours)</td>
<td>Significant influence of wind power. Reserve provision must be increased to take into account wind power forecast errors. Reserves are checked from day D-1 once market results are received until real time.</td>
</tr>
</tbody>
</table>
System Balancing Reserves

Wind Power Capacity Vs. Tertiary Energy scheduled

- Mean Value of Upward Tertiary Energy scheduled
- Mean value of Downward Tertiary Energy scheduled
- Wind Power Capacity
What needs to be produced by the remaining generators: Demand – Wind Generation

By definition Load Ratio is always lower than Requirement Ratio

Load Ratio = 1.7

Requirement Ratio = 2.2

Increased Requirement for Conventional Generation

Steeper slopes from off-peak hours to peak hours
Requirement for Manageable Generation (II)

Requirement for March the 5th, 2009

Demand ratio = 1.63

Requirement ratio = 2.11

Demand
Wind Production
Requirement
Consequences of higher requirement ratios: Off Peak Situations

- Since there is a minimum production value for part of the non-wind generation (technical minimum power production of thermal units, nuclear and flowing hydro power plants...) there is a requirement value under which it is necessary to shut down conventional power generation during off-peak hours to start them up again several hours later (this has happened several times since 2006). Shut down conventional generation in off-peak hours to start them up again.

- Due to the need of keeping connected power plants during off-peak periods that are necessary for the daily peak loads (longer start up times) and to deliver ancillary services there is also a ratio above which wind power reduction is unavoidable. Reduce wind power production in off-peak situations when it is not possible to shut down more conventional plants.
Requirement for Manageable Generation (I)

Monotonous curve for demand and requirement ratio in 2008
Requirement for Manageable Generation (III)

- Since there is a minimum value for manageable generation (technical minimum power output of generating units, flowing hydro power plants…) there is a ratio over which it is necessary to shut down conventional power generation during off-peak hours to connect it back several hours later in real time (8 times since 2006).

- Due to the need of keeping connected power plants during off-peak periods that are necessary for the daily peak loads (longer start up times) and to deliver ancillary services there is also a ratio above which wind power reduction is unavoidable.
Demand-generation balance: 2/11/2008

- Low demand (~20 000 MW) and high forecasted errors (~3 200 MW)
- Running out of downward reserves:
  - Shut down in real time of combined cycles.
  - As last resource, wind power reduction from 7:22 to 9:30 h.
- **2004-2007**: Only few days with requirement ratio > 2
- **2011 (20,000 MW of wind capacity installed)**: 10% of the time requirement ratio > 2
- **Possible solutions**: Storage plants (pumping), wind generation providing frequency control under certain system conditions, gas turbines for peaks…
Increased Ramp Requirements

Maximum increase/decrease ramps (transition off-peak \(\Rightarrow\) peak) and off-peak situation impose additional requirements on conventional generation:

- Additional Need of Fast Response generation

Demand. Winter week profile
Ramps \(\sim +/\text{-} 4.500\) MW/h

Wind \(\sim +/\text{-} 1.000\) MW/h

Will speed of response be a limiting factor???
Demand + Wind: \(\sim +/\text{-} 5.500\) MW/h
(with \(\approx 10.000\) MW inst of WP) + forecast error
Voltage Control
Voltage Control

- RD 661/2007 Art. 29: Reactive power bonus or penalization.
  From +8 to -4% of 7.8441 c€/kWh depending on the power factor.
  Periods do not distinguish between labor days or holidays so producers might behave contrary to system requirements.
- In reality it leads to simultaneous connection/disconnection of capacitors.

### Reactive Power Bonus

<table>
<thead>
<tr>
<th>Type of</th>
<th>Power Factor</th>
<th>Bonus (%)</th>
<th>Power Factor</th>
<th>Bonus (%)</th>
<th>Power Factor</th>
<th>Bonus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Peak</td>
<td>Inter</td>
<td>Off-Peak</td>
<td>Peak</td>
<td>Inter</td>
</tr>
<tr>
<td>Inductive</td>
<td>&lt; 0,95</td>
<td>-4</td>
<td>-4</td>
<td>8</td>
<td>&lt; 0,95</td>
<td>-4</td>
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<tr>
<td></td>
<td>&lt; 0,96 y ≥ 0,95</td>
<td>-3</td>
<td>0</td>
<td>6</td>
<td>&lt; 0,96 y ≥ 0,95</td>
<td>-3</td>
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<tr>
<td></td>
<td>&lt; 0,97 y ≥ 0,96</td>
<td>-2</td>
<td>0</td>
<td>4</td>
<td>&lt; 0,97 y ≥ 0,96</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>&lt; 0,98 y ≥ 0,97</td>
<td>-1</td>
<td>0</td>
<td>2</td>
<td>&lt; 0,98 y ≥ 0,97</td>
<td>-1</td>
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<tr>
<td></td>
<td>&lt; 1 y ≥ 0,98</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>&lt; 1 y ≥ 0,98</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Capacitive</td>
<td>&lt; 1 y ≥ 0,98</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>&lt; 1 y ≥ 0,98</td>
<td>0</td>
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<td>&lt; 0,98 y ≥ 0,97</td>
<td>2</td>
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<td>-4</td>
<td>-4</td>
<td>&lt; 0,95</td>
<td>8</td>
</tr>
</tbody>
</table>
Voltage Control

- Voltage variations during off peak to peak periods (9/3/2009)
- Voltage variation during intermediate to peak periods. (7/2/2009)
Voltage control

- CECRE may issue instructions to modify these table values if voltage problems are detected in the transmission or distribution network.
- Before 1/4/2009, OS issue particular instructions for solving problems in certain nodes of the system.
- From 1/4/2009, all the special regime installations higher than 10 MW are obliged to maintain an inductive power factor between 0.98 and 0.99.
  - In order to eliminate sudden changes in the voltage profile corresponding to the transitions off peak-intermediate-peak periods.
  - In order to avoid high voltage problems in the system.

Voltage profile in 2008 and 2009 Easter Holiday
- 12/4/2009. Minimum demand: 17 666 MW. Wind production (8:00 h): 5 460 MW
- Effectiveness of the measure. The sudden change in the voltage profile disappear.

- Final Solution (to be implemented) : Continuous Auntomatic Voltage Control through the CECRE.
CECRE: Control Center for Renewable Generation
CECRE: Control Center for Renewable Generation
CECRE: Implemented in June 06 by REE within the Control Structure

CECRE is the First RES Control Centre in the world

EBAE Award European Product for Sustainable Development
CECRE
European Business Awards
for the Environment

DIPLOMA as one of three best
European Product for the
Sustainable Development
2008

Premios Europeos de Medio Ambiente a la Empresa
Sección Española, Convocatoria 2007/08

Premio al Servicio para el Desarrollo Sostenible
Centro de Control para el Régimen Especial (CECRE)

RED ELÉCTRICA DE ESPAÑA

Madrid, 13 de marzo de 2008
CECRE Purpose and targets

- Facilitate the maximum RES generation integration in the system without compromising system security
  - Control and supervision of RES Generation
    - Receive all relevant RES production information in real time, treat it and send data needed to the REE’s National Control Centre
    - Analyse system security with respect to RES production
    - Send orders to RES generation when needed
    - These reduction of production orders are followed reasonably well
CECRE: purpose and targets

- **Target:** achieve a greater level of integration for renewable energy sources without compromising system security.
- **Main function:** Organise special regime electric production according to the needs of the electric system.
  - Be the only real time communication channel with CECOEL and with the Control Centres (RESCC), which would be the entities in charge of switching operations in the facilities.
  - Receive the relevant production information of generation units in real time and send it to CECOEL.
  - Coordinate, control and supervise all generation units by means of grouping them in Control Centres.
  - Contribute with security and effectiveness in System Operation.
  - Change zone simultaneous production hypothesis and preventive criteria (conservative) by real-time production control and therefore allowing:
    - Higher energy production
    - Higher installed power (agent decision)
CECRE is a control centre devoted to RES generation, (specially Wind Generation):

- Integrated in REE’s Control Centre Structure
- Communication with Generation Control Centres for supervision and control instructions.
- According to RD661/2007 all RES facilities >10 MW must be connected to a RESCC.
- When needed CECRE sends orders to reduce RES generation through the SCADA system to the RESCC.

**CECRE**

**CECOEL / CECORE**

**CC\textsubscript{CONV}**

**RES\textsubscript{CC1}** ...

**RES\textsubscript{CCn}**

**RESCC**: Renewable Energy Source Control Centre

**CC\textsubscript{CONV}**: Control Centre for conventional generation
RES power connected to the CECRE via RESCC

- According to RD661/2007 all special regime facilities >10 MW must be connected to a RESCC.
- Facilities that don’t comply with this requirement lose the Special Regime status regarding the prime received.
- In practice, today all RES are connected to CECRE
Real Time Production Control
Generation control enables maximize production by avoiding preventive restrictions and delay upto real time.

Generation Control by REE involves:

- WP ⇒ REE.- Capability of REE for receiving real time info from all WP (production, voltage, connectivity, wind speed, …).

- REE ⇒ WP.- Capability of WP for receiving and executing REE’s instructions:
  - production control
  - provision of system services (regulation, reactive)

For security and efficiency, this interlocution between REE and plants is not individual (> 500 wind farms now) but via Generation Dispatch Centers with control over a number of plants:

- Human and technical resources (24 h)
- Secure and redundant Connection Dispatching Centre <> REE CC (computer<>computer, telephone)
- Connection Dispatching Centre <> Wind Farms-Generators, connected to a specific section of REE Control Centre (CECRE)
**GEMAS: Functional Scheme**

- Real time wind power production
- Snapshot (PSS/E)
- Wind farms Info.

GEMAS

Maximization of the Wind Power production compatible to the interconnected power system security

Wind farm, Trans. Network bus, RESCC and Technology Set points

RED ELÉCTRICA DE ESPAÑA
GEMAS: Wind Power Loss Simulation

Duration of the fault 100 ms

Generation tripping in this case $P_{\text{Loss}} = 208$ MW

Method allows calculations in real time

Three-phase dead short circuits are simulated (switching studies with PSS/E) in 70 different substations.

Admissible generation disconnection is calculated in order to prevent overloads in the tie lines with France or inadmissible voltage drops in the system.
Real Time Simulations (switching studies):
three phases dead faults

Wind generation loss > Maximum admissible loss

1st Optimization problem:
Maximize wind generation within security limits

2nd Optimization problem:
Maximize the system security

Filters for the solutions
Set points added by
- Control Center
- Transmission Network substation
- Wind farm Technology

**GEMAS: Flowchart**

Max $\Sigma P_{\text{wind farm}}$
Restrained to:

Gen. loss critical contingency $i \leq$ Maximum admissible loss

$0 \leq P_{\text{wind farm}} \leq P_{\text{current wind farm}}$

Max $\Sigma P_{\text{wind farm}}$
Restrained to:

Gen. loss critical contingency $i \leq$ Maximum admissible loss

$0 \leq P_{\text{wind farm}} \leq P_{\text{current wind farm}}$

Filters for the solutions
Set points added by
- Control Center
- Transmission Network substation
- Wind farm Technology

Maximum wind generation admissible in the system
CECRE can also issue set-points automatically

- CECRE checks with the application GEMAS if with the real-time wind scenario the System is safe due to voltage dips or congestions.
- If not, wind generation set-points are calculated.
- Presently only done for wind generation, but a similar methodology can also be applied for all renewable energy sources.

![Diagram](image-url)

- **CECRE** checks with the application **GEMAS** if with the real-time wind scenario the System is safe due to voltage dips or congestions.
- If not, wind generation set-points are calculated.
- Presently only done for wind generation, but a similar methodology can also be applied for all renewable energy sources.

**GEMAS**: Generación Eólica Máxima Admisible en el Sistema  
**RESCC**: Renewable Energy Source Control Centre
Wind power reduction due to risk of generation trip 27/03/2008

- The reduction was instructed due to the risk of losing the interconnection with France if certain faults occurred, which would cause a sudden wind generation loss even if the fault was correctly isolated by the protection equipment.
- Set-points were recalculated each hour to adapt to changing conditions in the wind generation.
Several reductions ordered, generally to avoid Fr-Sp tripping risk.

04/03/08
- Reduction of 500 MW affecting 112 WP (additionally, limitation of 45 WP)
- Additional reduction due to machine stop for wind and ice.

10.032 MW Record
15:47 h reduction instruction starts
19:10 h reduction instruction ends
Other RES
New regulation by which promoters apply to Ministry, which requires zonal study from REE.
The Solar Thermoelectric generation, expected to be an important chapter in the Spanish power system, brings some positive features:

- Synchronous generators
  - contribution to system inertia and P-f regulation
  - robust to grid perturbations (voltage dips)
- Relevant contribution at summer peak
- Energy storage (4 to 12 hours, avoids energy spilling)
- Complementary source (support with gas, which enables power output ≈ 30% of rated power)
  - higher production equivalent time (>3500 h)
  - compensate for fluctuations of primary source and contribute to firm power delivery, with high reliability:
    - 24 h: 90%  ⇒  6 h: 95%
    - power programmes more than forecasts
Solar Thermoelectric (June 2008)

Applications in REE: 10.271 MW
Total Transmission: 8.183 MW
Total Distribution: 2.089 MW
Some help from EV?
Integration of electric vehicles in the electric system

*Impact in the annual demand: Quite LOW*

One million electric vehicles in 2014 would increase the electricity demand in Spain ~ +1%.

(~10 millions ↔ ~ +7.5% de la energy annual in 2030)

- 1 wind generator 1.5 MW
  - ~ 3,300 MWh/year
  - 700 - 1,300 vehicles (Hypothesis: 25,000 km/year)

- Photovoltaic Plant 10 MW
  - ~ 20,000 MWh/year
  - 4,000 - 8,000 vehicles

- Nuclear Unit 1,000 MW
  - ~ 8,500,000 MWh/year
  - 1,700,000 - 3,500,000 vehicles
Integration of electric vehicles in the electric system

However, for the electrical system planning and operation there are several factors in the charging process that are crucial:

- **¿How much power?**
  - Power <> charging time

- **¿When it is done?**
  - Peak or off peak

- **¿How it is done?**
  - simultaneously intelligent system – Smart Grid
Integration of electric vehicles in the electric system

Example: 1 million vehicles electric in 2014

<table>
<thead>
<tr>
<th>Charging Time</th>
<th>Simultaneity of users</th>
<th>Needed power</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 20 min</td>
<td>100 %</td>
<td>~ 60.000 MW</td>
</tr>
<tr>
<td>~ 20 min</td>
<td>100 % a lo largo de 3 horas</td>
<td>~7.000 MW</td>
</tr>
<tr>
<td>4-8 hours</td>
<td>100 %</td>
<td>~5.000-2.500 MW</td>
</tr>
</tbody>
</table>
Integration of electric vehicles in the electric system

Perfil de demanda para una penetración de un millón de vehículos eléctricos en 2014, recarga 20min del 100% del parque de 19 a 22h (día tipo de invierno)

¿When? In Peak Hours
¿How long? 20 minutes
Example:
Charging time: 20 minutes
At home arrival
Winter peak
No Smart Grid

Increase in Peak Demand ~ 7.000 MW
⇒ Need of more infrastructures (Generation, Transmission and Distr.
⇒ Inefficiencies in Generation
Integration of electric vehicles in the electric system

Perfil de demanda para una penetración de un millón de vehículos eléctricos en 2014, recarga simultánea 4 horas (día tipo de invierno)

- **¿When?**
  - In Off Peak Hours

- **¿How long?**
  - 4 hours

**Example:**
Charging time: 4 hours
Off peak hours
No Smart Grid

No Increase in Peak Demand
⇒ No Need of more infrastructures (Generation, Transmission and Distr.)
⇒ More Efficiencies in Generation
Integration of electric vehicles in the electric system

SMART
Integration of electric vehicles in the electric system

SMART : maximum scenario

6-7 million of electric vehicles could be integrated without needing any investment in generation nor transmission
Conclusions

- Wind energy in particular and RES in Spain have reached high penetration levels and they will continue to increase. The system would be unmanageable without controlling RES production. In Spain Control and supervision of RES is an absolute need. The control centers CECRE and RESCC are the means to fulfill this need.

- CECRE improves the integration of RES making them compatible with security of supply. Better and safer RES integration means that more RES energy can be integrated.

- CECRE and GEMAS complement complex off-line security analysis including transient studies with faster and easier static studies making real time simulations possible maximizing RES generation while keeping the system security.

- Wind Production Forecasts are also a need. Tools for this can be tuned and improved only when RES production is monitored.

- Future challenges: balance feasibility, requirements for conventional generation, continuous voltage control, ancillary services requirements...
Outlook into the future

- Challenges 2011: 20 000 MW wind installed capacity:
  - Balance feasibility in off-peak hours could be an issue now.
  - Voltage control: more nodes will need to have modified power factors.
  - Voltage dip trippings should no longer be a problem due to compliance with the grid code.

- Challenges beyond 2011: up to 40 000 MW wind installed capacity. Safe integration will depend on several factors:
  - Capability both technical and economical for wind generation to provide frequency control (primary reserve, inertia emulation?...).
  - Voltage control with set-points issued by the CECRE and dynamic voltage support.
  - Amount of storage such as hydro-pump units and very fast thermal plants.
  - Correlation between wind and solar production.
  - Evolution of wind forecast.
  - Flexible market mechanisms and international exchange capacity.
RES production will develop quickly if a stable and attractive enough economic regulation is in place. Feed-in tariffs are a very good model to achieve this. Incentives added to the market price with cap & floor are also a very good alternative. The Regulator can design the system so as to achieve whatever desired goals. Wind technology is mature and in the next future will require less and less support. An independent TSO is also probably required.

- Introduce mandatorily Control and Supervision of RES as soon as possible. The scheme used in Spain could be a model to follow.
  - Require RES plants to send real time production measurements to the TSO as well and other signals (wind speed, availability data...)
  - Require RES plants to be able to follow reduction of production orders
- Develop Wind Production Forecast tools adapted to your RES generation exact location and characteristics, Check continuously forecasts with real production data until forecast errors are minimized.
- Require fault-ride-tough capability (now is normal)
- Require Voltage Control Capabilities
- Cooperate with neighbour TSOs and within TSO associations.
Thanks for your attention!
Thanks fc