The Spanish experience in the integration of the electricity from wind power plants into the electrical system.

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Abstract—Wind power in Spain has grown in recently to become the fourth technology in electricity generation. This has forced wind power and the electricity system operator to work jointly to develop methods for reducing the impact on system regulation and to help increase system security. Among these methods are control centres for wind farms, the widespread use of power forecast, voltage dip ride through capabilities and reactive power management. The use of these different solutions, as well as the continued work of the whole of the wind sector with the system operator drives Spain wind power to attain high penetration despite limited grid interconnection with the neighbouring grids comparing other wind power producing countries.

Index Terms—Control Centre, Forecast, Reactive Power, Voltage Dip Ride Through (VDRT).

I. INTRODUCTION

Wind Power has developed in the last few years as one of the main players of the electrical system in a few pioneering countries. Initially, its input was counted as a variation of electricity demand and it was required therefore no participation in energy regulation. Thus, wind power grew with smaller technological constraints, focusing mainly in the fast increase in unitary power and efficiency. Over just a few years, wind power grew exponentially reaching up to levels that were previously thought unattainable. This brought up new questions on balancing power and grid stability of the grid that was designed to accept the production of the common synchronous machines, as opposed to the “rigid” asynchronous wind turbine generators (WTGs) or to manage programmable conventional power plants in comparison to variable sources of generation like wind.

As soon as wind power reached a significant penetration in the coverage of the electricity demand, there arose the need for a certain control of the wind farms that helped the system operator to introduce safely vast amounts of power in the grid in a controlled manner transforming wind energy from demand forecast deviation to a full rights energy producer.

Spain, along with Denmark and Germany is one of those pioneering countries that believed in wind energy from the start. Soon, installed capacity reached 1000 MW/year, all previous plans for growth were dwarfed as previsions changed from over 8974 MW (Renewable Energies Plan 1999) to 13000 MW (Infrastructures Plan 2002) to 20155 MW (Renewable Energies Plan 2004) for the years 2010/2011. Today wind power amounts to over 9% of total electricity generation in Spain, with peaks of 41%, becoming the fourth technology in electricity generation, just over hydroelectric power.

This huge numbers and the limited interconnection of the Spanish grid has conveyed big challenges for both the wind power sector, through AEE, and the System Operator (REE), that have led them to work together in a leading experience allowing the continuous growth with the maximum attainable security.

II. CONTROL CENTRES, FORECAST, REACTIVE POWER AND VOLTAGE DIP RIDE THROUGH (VDRT)

Production peaks of 10,800 MW and valleys of a few hundred MW can be integrated in the electrical system, but changes in production have to be known in advance in order to reduce the demand/generation deviations and tertiary ancillary services to a minimum and allow for precise planning of the resources. Section II explains the Spanish solution for wind power forecast and its implementations and experiences.

Vast amounts of wind power introduced at low demand periods, problems of overload in some specific grids or potential instability risks mark situations when wind power production must be curtailed for security reasons to a controlled production that does not reach a given level. Section III describes control centres and its capabilities.

Demand variation affects voltage levels and a certain reactive power control helps level the effect. Section IV describes reactive power allocation in Spain.

Short circuits and other grid faults, happen occasionally, producing disturbances that have to be withstood in order to allow and help the system to recover instead of deepening the fault and spreading the problem through the grid. Section V shows how wind power in Spain deals with voltage dips and the verification procedure with which a wind farm certifies its compliance with the requirements.

Finally, Section VI details the conclusions and further work needed to secure a continued development and security.
II. WIND POWER FORECAST

The electricity system depends on precise forecasting of the energy demand as well as knowledge of the production capabilities, in order to balance accurately power production and prevent risks of blackout that could happen if the frequency or the voltage went out of security limits because of high power imbalances. With wind power covering up to one third of electricity demand, its contribution to the power demand must be precisely known in advance.

In Spain, remuneration of wind energy is based on the feed-in tariff scheme under two approaches: regulated tariff, fix and known price throughout the whole plant life, or pool price plus a premium, if the electricity is sold in the electricity market.

Wind power inscribed in regulated tariff is obliged to make a prediction [1] and [2] specifying the amount of power to be produced a day in advance, one hour before the market closing time. Deviations from the prediction are penalized according to the amount of electricity deviated multiplied by an unitary price fixed by the regulation, thus encouraging the producers to achieve better predictions to increase incomes.

In the case of the wind power selling the energy output through the electricity market, which is by large the most common election (around of 90% of the total wind production), it is the market itself which regulates the reliability of the forecasts and penalizes deviations.

Several methods can be used predicting wind energy output, which vary from statistical to physical models to a combination of both. As well prediction could be based on integrating the output of many wind farms together using several predictions, to better optimize the foreknowledge of a single wind farm. Still, while many solutions are available, there has been misunderstandings and doubts about the actual possibilities of prediction and factors that affect the accuracy of the forecasts.

For that reason, the Spanish Wind Energy Association (AEE) led in a coordinated effort from the whole wind sector the Prediction Exercise in which those questions where addressed. The project supported by the Spanish Ministry for Science it has had an important impact on improving the forecasting tools as well as on learning more about the possibilities of these technologies, being more fruitful than other initiatives over granted by multinational programmes.

The Prediction Exercise, seven wind farms placed in different terrains and with different turbine characteristics where chosen throughout Spain making a characteristic sample of the whole system. Also, six predicting companies – which later expanded to nine, given the interest awakened by the Exercise – were chosen representing several ways of making predictions: from purely statistical, using only historical weather and power output data to mostly physical, using different levels of downscaling and a model of the wind farms including the WTG power curve. The starting point was simple: at least one predictor would predict for the seven wind farms and at least one wind farm would receive predictions from all the companies. This way the effect of terrain and prediction type could be accurately assessed.

A. Definition of error: EMAP

One of the key points found while preparing the exercise was the often overlooked definition of prediction error. Looking for simplicity and significance, the definition settled for one that gives the most meaning: EMAP, the mean absolute production error, more clear than the RMSE, root mean square error, very academic and extensively used. This way, if over a month a 50 MW wind farm produced 10,000 MW/h and the sum of the deviations for each hour is 3,000 MW/h, the EMAM will be a 30% for that month.

\[
EMAP = \frac{\sum_{i=1}^{n} |P_{prod, i} - P_{pred, i}|}{\sum_{i=1}^{n} P_{prod, i}} \times 100
\]

Since the penalizing for deviations is calculated in absolute terms, a characteristic EMAP gives also an idea of possible returns for an installation for a given period very quickly.

B. Forecast error vs. Capacity factor

The expected EMAP for any given wind farm can be expected to be around 35% and as low as a little under 30% in average for a prediction of one wind farm. For individual months, and depending on the capacity factor, values of EMAP as low as 20% and higher than 60% can be obtained.

EMAP depends highly on capacity factor, see Fig. 1, which is understandable, since for very low productions, little errors are high on percentage. Therefore, in order to ascertain the accuracy of a given predictor, a certain time is needed. We have used typically a month.

If lower times are used, the accuracy and dispersion of a given predictor can be found as shown in Fig. 2.
The figures show the difference in tendencies of two of the predicting companies and the scattering of the EMAP, which gives an idea of the range that can be expected.

C. Influence of Terrain

It is a common assumption that the complexity of the terrain a certain wind farm is set in has an effect on the accuracy of the predictions. In order to determine the magnitude of the effect, the seven wind farms were chosen in locations with complexity index ranging from island, plain to mountain. Also the prediction of all of the wind farms by some of the companies gives the perfect frame for an objective calculation. The results show that contrary to the assumption, terrain complexity has little to no effect on prediction accuracy being equally hard to predict wind power production on plains or mountain territory. Also, physical prediction models show no reduction of accuracy for increased complexity, behaving like statistical models which do not model the wind farm terrain.

Once isolated the data in order to reduce the effects of power production, the tendencies of most of the predictions were to improve with the complexity, as seen in Fig. 3. Further selection of the data, using only the most representative wind directions and the complexity index for each direction tendencies show almost random.

D. Effect of wind farm aggregation

As explained in point B regarding error levels, the lowest EMAP which can be expected for a single wind farm in a windy month is around 20%. This value, though small in power for a single wind farm, would be very high for the whole of the 15,000 plus MW installed in Spain. Also, market rules allow for the coupling of several production units under the same offer, in our case, the production predicted for more than one wind farm.

The experience obtained in the Prediction Exercise shows that in fact, the result of adding the predictions of several wind farms improves considerably the accuracy. Table I shows how the EMAP decreases with the coupling of any two wind farms in a significant way.
TABLE I
DECREASE IN THE EMAP WHEN COUPLING ANY TWO OF THE WIND FARMS OF THE EXERCISE

<table>
<thead>
<tr>
<th>Wind farm</th>
<th>Wind farm 1</th>
<th>Wind farm 2</th>
<th>Wind farm 3</th>
<th>Wind farm 4</th>
<th>Wind farm 5</th>
<th>Wind farm 6</th>
<th>Wind farm 7</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind farm 1</td>
<td>7.0%</td>
<td>7.7%</td>
<td>7.9%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.5%</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>Wind farm 2</td>
<td>10.5%</td>
<td>--</td>
<td>11.2%</td>
<td>12.7%</td>
<td>11.1%</td>
<td>11.8%</td>
<td>12.4%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Wind farm 3</td>
<td>9.0%</td>
<td>--</td>
<td>10.9%</td>
<td>10.3%</td>
<td>9.9%</td>
<td>11.2%</td>
<td>0.9%</td>
<td></td>
</tr>
<tr>
<td>Wind farm 4</td>
<td>10.6%</td>
<td>11.1%</td>
<td>12.8%</td>
<td>--</td>
<td>10.6%</td>
<td>11.3%</td>
<td>11.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Wind farm 5</td>
<td>9.1%</td>
<td>8.3%</td>
<td>9.6%</td>
<td>8.6%</td>
<td>--</td>
<td>8.0%</td>
<td>8.3%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Wind farm 6</td>
<td>9.1%</td>
<td>8.4%</td>
<td>9.7%</td>
<td>9.8%</td>
<td>8.1%</td>
<td>--</td>
<td>10.5%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Wind farm 7</td>
<td>10.5%</td>
<td>9.5%</td>
<td>11.4%</td>
<td>9.6%</td>
<td>8.6%</td>
<td>10.3%</td>
<td>--</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

When we couple the predictions of all of the wind farms used in the exercise the results are much more impressive, halving the EMAP of each wind farm as seen in Fig. 4. These results are continuous throughout the exercise showing that the high reduction is a property of coupling the predictions.

The previous results are taken for a single predictor predicting for all of the wind farms, but the results are very similar for different predictors as can be seen in Fig. 4.

Adding predictions for wind farms make errors generally compensate and while single error values for a given hour might increase, the total amount of the errors is considerably lower.

When extrapolated to the whole of the Spanish electrical system, the resulting error is low enough to allow the system operator to maintain the tertiary services at a very low level, which according to AEE estimations was less of 30% of the values estimated at the beginning of the wind energy growth.

The Prediction Exercise shown the importance of improving the source of information, either global data or the output of mesoscale models, as well the good results obtained with statistical tools.

III. CONTROL CENTRES

The operation of the electricity system requires the ability of controlling generation in order to meet demand and to avoid potential security risks. Wind power has a priority of access to the grid, which can only be restricted by those security reasons, while the remaining thermal and hydraulic plants regulate their production in order to provide the necessary ancillary services besides their supply of active power.

Still, while desirable, it is not always possible to introduce all of the produced wind power into the grid, for system specifications. Also, as the system grows and wind power takes a still larger role in electricity production, absorbing all of the produced power in certain nodes could not be possible due to over-installation, forcing wind farms to reduce their energy output in order to meet the capacity of the lines to distribute the power.

For those reasons Spain has made an effort to have all of its wind farms connected to control centres sending in real time all necessary information and allowing the control centre, on request by the system operator to regulate the amount of energy shed into the grid.

The Operational Procedure 9 [4] states that every power plant must provide information about its structure, information about real time situation and other information for the correct
Furthermore, O.P. 3.7 [5] states that every wind farm has to be connected to a Control Centre which in turn is connected through a point to point communication line or a dedicated ADSL line to the Renewable Energies Control Centre (CECRE in its Spanish initials). This allows for real time communication detailing necessary information for the optimization of the system operation, as well as other relevant data. The scheme is shown in Fig. 5.

The data transferred by the wind farms to the control centres is the following:

- Active power
- Reactive power
- State of the wind farm connection to the transmission - distribution grid (connected/disconnected)

And if available:

- Voltage level
- Wind speed and direction
- Temperature

This information is to be updated in real time and sent to the CECRE by the control centres at least 12s.

Once this information is available by the system operator, it allows for fast and reliable control using the same control centres as feedback method with orders of power reduction in those cases where system security makes it necessary. The control centre has thus the following capacities:

- Receive a maximum power output level for a wind farm. A code explaining curtailment reasons is included.
- Receive at least once a minute curtailment instructions, check for variations and process.
- Curtail production beneath said levels in at most 15 minutes and be able to receive further curtailment levels in the meantime.
- If levels are infringed more than 10% for periods over 5 minutes shut down the whole wind farm informing the CECRE and keep the wind farm down for at least half an hour. Reconnection of the wind farm can only be carried out if compliance with the instructions can be guaranteed.
- Keep the current level until new instructions are received.
- If connection with the CECRE is lost, automatically put the wind farm to 85% of the last level.

In Fig. 6, the operative structure of the whole system is depicted. This arrangement allowing the system operator to control dynamically the power output of the wind farms permits maximum levels of wind power penetration, since system security is not compromised. Direct connection from a wind farm to the CECRE has not been applied due mainly to high costs reasons.

Throughout March 2008, the high winds registered in Spain have caused the perfect situation for trying the system in depth and it has shown a perfect response, lowering production in the necessary wind farms to maintain grid security and returning to normal working levels. Fig. 7 is an example of how the system responds on time during power reductions and regains production once the system is able to absorb it.

It is important to indicate that in case of real time curtailments, the most common, loss of profits are not covered and only in case of programmed reductions, 15% of the hourly price could be recovered applied or the programmed production finally curtailed.
Fig. 7. Example of a real wind power cut March 4th, 2008 where a new wind production record was attained. The order is sent just before the peak, and before 15 minutes the limits are met and kept until the order is lifted several hours later. (Source: REE)

The program GEMAS used by the system operator calculates in real time the possible loss of wind power generation caused by a voltage dip in any node of the system, compares the vulnerability of the system and especially the possible loss of the interconnection with France because of loss of synchronization and if the limit is reached, calculates the best possible solution for minimizing the amount of wind power shed maintaining secure operation. Then, the order is given for certain wind farms connected to certain nodes and controlled by a control centre to adjust its production to limit to secure levels.

Also, the infrastructure that is already working in the vast majority of the Spanish system will allow in case of necessity for future communications between system operator and wind farms, adjusting rapidly to new challenges.

IV. REACTIVE POWER ALLOCATION

Initially, wind turbines were simple asynchronous generators capable of producing only active power but needing reactive power in order to work. Later developments have made wind turbines consume no reactive power, but installed capacity, as in the previous cases, has made wind farms important contributors to maintain voltage levels within normal operation values.

As demand varies, the voltage levels in the grid vary accordingly and power plants must adapt their production to keep voltage levels. This is achieved through the variation of reactive power generation, as generating reactive power increases the voltage while reactive power consumption lowers it.

Current regulation divides operation times throughout the day in three zones: peak, valley and plain, each corresponding to certain demand levels. Synchronizing with said demand levels, wind power must adjust its production to regulate voltage. To promote the adequate generation of reactive power, regulations [2] set an incentive for compliance and penalizes other behaviour. The result is shown in table II.

<table>
<thead>
<tr>
<th>type</th>
<th>Peak</th>
<th>Plain</th>
<th>Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fp &lt; 0.95</td>
<td>-4</td>
<td>-4</td>
<td>8</td>
</tr>
<tr>
<td>0.96 &gt; Fp &gt; 0.95</td>
<td>-3</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>0.97 &gt; Fp &gt; 0.96</td>
<td>-2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>0.98 &gt; Fp &gt; 0.97</td>
<td>-1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1,00 &gt; Fp &gt; 0.98</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Capacitive</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>1,00 &gt; Fp &gt; 0.98</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>0.98 &gt; Fp &gt; 0.97</td>
<td>2</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>0.97 &gt; Fp &gt; 0.96</td>
<td>4</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td>0.96 &gt; Fp &gt; 0.95</td>
<td>6</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>Fp &lt; 0.95</td>
<td>8</td>
<td>-4</td>
<td>-4</td>
</tr>
</tbody>
</table>

The table shows how during peak hours, wind farms must help to rise voltage levels, during valley hours help lower voltage level and not affect during plain hours.

Recently, the high number of wind farms installed in certain nodes has caused peaks in voltage levels just at the beginning of peak hours caused by the simultaneous connection of many reactive power controls all producing reactive power. As soon as the problem was discovered and thanks to the Control Centres to which all wind farms are connected, simple time shift instructions were given, solving the problem with the always positive contribution of the wind producers sector and opening the door to voltage control in the future.

Nowadays, limitations on the amount of wind power that can be connected to a certain node [6], prevents wind farms from having great effect in voltage control, but as time goes on and barriers are lifted, wind farms are already equipped with the necessary tools for voltage control, based on grid voltage levels or reactive power generation instructions from the system operator.

This type of control is already being tested and it is demonstrated that works according to expectations and that if needed could be implemented swiftly in most of the existing wind farms and any new installation.

V. VOLTAGE DIPS

One of the main fears of any system operator is that of transient stability. The possibility that large amounts of generation are lost due to singular grid disturbances, which propagate through the system is a severe problem for the transmissions system operator which must be addressed with a strong focus on security.

Recent events, like the incident on November 4, 2006 [7] – although this was caused by frequency shifts – pointed out
clearly the necessity of securing transient stability to avoid shedding load in case of a disturbance and ultimately a blackout.

Wind turbines have been traditionally weak to grid variations, and once again, while penetration was low, the system preferred wind turbines to disconnect in case of disturbances instead of introducing variations which could in some cases further hinder the recuperation of the voltage levels. That case is no longer valid, since the simultaneous disconnection of some thousand megawatts wind power would cause important problems in covering demand and thus deepen the problem.

For these reasons, for the past years, a strong cooperation between the system operator and the whole of the wind power sector has struggled to find the best possible way to ensure grid security and develop technological solutions for the new challenges presented. This joint work has brought both the Operational Procedure 12.3 [8] stating the appropriate response of the wind farms to voltage dips, as well as the Verification, Validation and Certification Procedure (PVVC) for checking compliance of the wind farms with the O.P. [9].

A. The O.P. 12.3

The first step is defining a voltage dip. The standard dip in Spain as defined by the system operator is shown in Fig. 8, with an initial voltage fall to 0.2 p.u., a duration of up to 500 ms, a recovery to 0.8 p.u. in 1s after the beginning of the dip and a slower recovery over time to normal operation levels. In the case of a two-phase fault, the voltage drop for the phases in fault is down to 0.6 p.u.

Fig. 8. Spanish three-phase voltage dip as defined by the system operator.

The shaded zone in Fig. 8 depicts all the possible situations in which a wind farm must remain connected to the grid. Thus, wind farms can only disconnect if the dip is lower or longer than described.

But not only must wind farms remain connected during faults, they also have to help the system recover after one. Thus, O.P. 12.3 sets a limit to the consumption of active as well as reactive power during the fault and sets a working point for the wind farms during the voltage dip as seen in Fig. 9. The specific requirements a wind farm must meet are:

Three phase faults:

- Wind farms must also remain connected during overvoltages produced just after voltage dip recovery.
- No reactive power consumption during the fault except for the 150ms after the beginning of the fault and after the beginning of fault clearance.
- Reactive power consumption in those periods must be lower than 60% of nominal power for each cycle at the beginning of the fault.
- Reactive power consumption after fault clearance must be lower than 60% of nominal power for the whole period and net reactive current for each cycle must be lower than 1.5 nominal current.
- No active power can be consumed during the fault except for the 150ms after the beginning of the fault and after the beginning of fault clearance. Active power consumption during the rest of the fault and fault clearance can be no higher than 10% of nominal power.
- During fault and fault recovery the system must provide the maximum possible current, always inside the operation point described in Fig. 9.

For two-phase faults, the requirements are very similar, though active and reactive power consumption during the fault are more restricted.

As we can see, very hard the restrictions are set for the wind farms in the case of voltage dips, all aimed to make wind power not only comply with current necessities, but also to ensure future developments where wind power will be a key factor for providing system stability.

B. The Verification Procedure

Once settled the requirements for a wind farm in the case of a voltage dip, it becomes necessary to devise a method for proving the real response of the wind farms and decide if they in fact comply with said requirements. This method is the “Procedure for Verification Validation and Certification of the Requirements of the P.O. 12.3 on the Response of Wind Farms in the event of Voltage Dips” which has also been
written by the wind power sector in close collaboration with the system operator. This Procedure is continuously under revision in order to keep it up to date with new necessities that may arise as little foreknowledge was at hand.

The procedure states that in order to prove that a certain wind farm complies with the requirements, its WTGs must be tested in field for voltage dips, a model of the WTG must be validated and finally a model of the whole wind farm must be simulated showing that the requirements are met, before a certificate is issued.

Since a voltage dip will be harsher at the grid connecting point of the wind farm than at the WTGs connecting point, in case a wind turbine is able to comply individually with the requirements of the O.P. 12.3, a wind farm consisting in several of those WTGs can be certified as complying.

On the other side, if other elements as FACTS affecting the response of the wind farm in voltage dips is installed in the wind farm, those must also be tested in field – with certain limitations – and their models have to be validated so that the model of the wind farm is as accurate as possible for the results of the simulations to be valid and reflect the actual response of the wind farm.

These two possible paths to certifying a wind farm are detailed in the Procedure as “Particular Procedure”, when only the WTG is tested in field and “General Procedure”, when the whole process must be carried out. The diagram in Fig. 10 shows the process flow for obtaining a certificate.

The existence of the particular procedure allows for a fast and reliable certification of all the new wind farms, since its elements withstand the voltage dips in full, while the general procedure provides a secure method for assessing the response of the remaining wind farms

A. Verification of the WTG response

Since the purpose of the field test for each of the procedures is different: in the particular procedure full compliance instead of just response assessment in the general procedure; the voltage dips to which they are subjected are therefore different.

In the first case, the full voltage dip is applied, while in the second, the voltage dip must only be more severe than the one the WTG sees, so that compliance is assured by real tests.

The voltage dip in the field tests is induced through a dip generator as shown in Fig. 11, so that the slopes for dip start and dip end are determined by the switch.

![Fig. 11. Voltage dip generation equipment](image)

The field tests are both for three-phase and two-phase dips and in situations of full load and partial load. To prove that the result is an actual behaviour of the machine not produced by chance three tests are carried out showing that the machine responds as expected. If a machine which is tested for the particular procedure does not respond satisfactorily in one of the tests, it must pass the next four tests or else will receive a negative report and need to be readjusted or else go through the general procedure, where the wind farm simulation will show if the whole farm complies or not.

For FACTS, the field test are different, since in many cases the necessary power values to make an on-load test are comparable to testing a full wind farm. Therefore, only a partial test is carried out, enough to validate the necessary model later on.

In the case that a particular solution is implemented at WTG scale, the WTG with the solution can be tested as a unitary power producing system and follow the particular procedure for the certification of the wind farm.

B. Model Validation

If the particular procedure is carried out, only the previous test is necessary, and if satisfactory, a certificate for the wind farm is obtained. If the certification follows the general procedure instead, after the necessary field tests come the
validation of the models.

The models for the wind turbines as well as the FACTS are provided by their own manufacturers, who provide their profound knowledge of the machine. Still, there might be cases where the solution installed makes the dip disappear to the WTG; in those cases, a library model can be used with the parameters adjusted to fit the particular WTG.

The models are tested, using the same voltage dip used in the field test, in order to prove that the response of the model to the dip equals that of the physical machine. There is a certain threshold for similarity and if the data for the simulations differs in more than a 4% for 10% of the data, the model is deemed incorrect and a new one closer to the physical machine must be made for the procedure to continue.

C. Wind Farm Simulation

The previous steps are designed so that the actual simulation of the wind farm is as close to reality as possible. The remaining passive components of the wind farm use library models since the response is well known. Still, the real data as to the type and length of the lines, the characteristics of the transformer, the switches and remaining components is used in the model of the wind farm.

Basing a certification on a simulation can be risky, since computer simulations are close to reality, but the differences can mean uncertainties difficult to assume by the system operator, which relies on the fidelity of the data to adjust the system efficiently and securely. The steps precious to the wind farm simulation have been designed to provide the necessary certainty for the system operator as well as the wind farm owners of the reliable behaviour of the wind farm.

The simulations are carried out by the same laboratories accredited to perform the model validations and the wind farm models are tested extensively to assure that all the requisites set in the O.P. 12.3 are met.

A wind farm which satisfactorily passes all the steps receives a certification stating compliance with voltage dip ride through requirements.

D. The Technical Verification Committee

As was mentioned before, the procedure is being checked and modified as more knowledge is gained from experience. In order to make the changes in a comprehensive way, already at the first draft of the procedure a correction mechanism was included. Said mechanism consisted in a Technical Verification Committee, formed by experts of the WTGs and FACTS manufacturers, wind energy producers and the system operator, assisted by the laboratories and certification bodies accredited to perform the different steps of the procedure.

This committee meets regularly and discusses the development of the procedure as it is put to work, introducing changes continually that allow for an improved security of the whole procedure as well as simplify or detail aspects that become clear as experience is acquired. These changes are applied swiftly and communicated to the accrediting bodies and ministry involved, so that they are put to use as soon as possible.

Although changes are introduced regularly, they are not retroactive, allowing the initial wind farms and WTGs undergoing tests and obtaining certificates, to maintain their results, thus enhancing the use of the procedure by including feedback.

II. CONCLUSIONS

As we have seen in the article, Spain has developed in recent years not only and impressive number of wind farms, but also solid means to integrate them and many future ones into the grid in a secure way, allowing Spain to attain higher energy independence levels and to accomplish its goals in carbon and other greenhouse gases emissions without endangering the system.

Important problems have been tackled, finishing with some of the initial myths of wind power, as are unpredictability or uncontrollability, growing steadily from a small variation in demand to currently being the fourth technology in electricity generation and the third in installed power. Still much work lies ahead to reach and surpass the ambitious goals that have been set for wind power, destined to be the leading renewable energy in Spain for many years. But the experience obtained during these last years make us confident that new challenges will be addressed swiftly, long before they become security problems.

In fact some of the problems are already being addressed. Voltage regulation, necessary once the limitations on installed wind power are lifted, is already under work; better prediction is being worked over and its use by the system regulator is just a matter of time; tougher dips are being studied for the feasibility of ride through capabilities and the control system already being used will be a tool in the future for regulating many aspects of generation that future developments will allow.

Continuous research is being done that will allow for a better use of the wind potential, as much for turbines on land as off-shore developments; storage systems for short and medium time electricity storage; better sensors and wind measurements tools, certificates for wind farm projects... all of these improvements are being currently studied and they will come paired with the means to introduce the produced energy painlessly in the system.

It can be said without doubt, that wind power has a bright future ahead.

III. REFERENCES

[5] Resolución de 04-10-2006,”P.O. 3.7 Pro grammación de la generación renovable no gobernable”, BOE 24/10/06.
IV. BIOGRAPHIES

Alberto Ceña Lázaro. Aeronautical engineer, it is now technical Director of ASOCIACION EMPRESARIAL EOLICA, AEE, (Association of promoters, manufacturers and financial entities) which represents the 85% of the total installed power in Spain. Previously, he served as Commercial Director of the Energy Services Company of the ACCIONA Group that promotes, operates and constructs projects of cogeneration and renewable energy (biomass and wind, second producer in Spain). He was also President of GEDEON S.COOP., wind turbines manufacturers, as well as he hold different positions in the European Commission and the Spanish Ministry for Industry and Energy.

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