Ancillary Services – The Current Situation in the Iberian Electricity Market and Future Possible Developments

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***Abstract* — This paper analyses and discusses the current situation in Portugal and in Spain regarding the procurement and the supply of the ancillary services considered in the Codes for the Operation of these two power systems. This is relevant because Portugal and Spain share a common day ahead and bilateral contract electricity market since 2007. However, several technical activities as the procurement and the provision of Ancillary Services are not yet entirely harmonized and fully integrated and continue to be provided within the control area of each country. Accordingly, this paper discusses three possible approaches that the two TSO's can adopt to further enlarge this integration. Then, tertiary reserve is taken as an example to illustrate the advantages that can be obtained if it is used a common list of bids from the two countries. The Case Study analyses four situations including the present mechanisms used to procure tertiary reserve, as well as the use of a common bid list admitting different values for the capacity of the interconnection lines between the two countries. Based on these results, the paper provides a discussion on the mentioned three integration models addressing their advantages and practical difficulties.**

Index Terms— Ancillary Services, Iberian Electricity Market, primary reserve, secondary reserve, tertiary reserve.

I. Introduction

In the last twenty years the structure and the operation of power systems evolved from vertically integrated companies till the separation of the industry in several activities and the development of competition in some of them. More than two decades after the beginning of this restructuring process, there are some relevant guidelines common to the experiences in several countries. In a first move, traditional vertically integrated companies were decoupled in generation, transmission and distribution, Then, in a second phase conducted in a gradual way, distribution was separated from retailing while eligibility was extended to all consumers. In several countries traditional companies, or at least parts of them, were privatized, and transmission and distribution network companies originated independent transmission and distribution providers most of the times also being responsible for the operation and monitoring the systems, corresponding to TSO's, Transmission System Operators, and DSO's, Distribution System Operators. As a result of this process, the activities in the two extreme sides of the electricity value chain, generation and retailing, are now typically run under competition while transmission and distribution network activities remain monopolies regulated by independent regulatory agencies. Regulatory agencies are just one of the new types of agents in the sector. Finally, the relation between the generation and the demand is now performed via the Market Operator or establishing bilateral contracts, either physical or financial, having different time spans.

When talking about electricity markets, one is usually addressing day-ahead markets that receive buying and selling bids each day to plan the operation of the system for the next day. The economic schedules obtained for each hour of the next day will have to be validated together with the relevant bilateral contracts by the System Operator. If congestion happens, these schedules have to be changed in order to enforce technical constraints. When addressing these markets, we are in fact talking about active power. As we know, this just corresponds to part of the problem because the safe and reliable operation of power systems requires a number of other services, usually known as Ancillary Services. The definition, the scope and the way used to schedule and contract these services is not harmonized in different countries, namely in Western Europe or even in countries that developed common electricity markets, as for instance Portugal and Spain. In any case, the focus on active power can be explained for two main reasons. The price of generating active power together with the regulated transmission and distribution costs correspond to more than 90 % of the final end user tariff which means that outside readers may consider that a reduced impact of Ancillary Services in the final price just reflects their lack of relevance. Secondly, Ancillary Services have a much more technical accent which means that their need is in general more difficult to explain to non-engineers. As a result, this is a much less mediated topic if compared with active power markets.

Despite their reduced impact in terms of cost, Ancillary Services are crucial from a technical point of view. Having in mind these general ideas and concerns, in Section II this paper reviews several concepts associated to Ancillary Services with a particular emphasis on reserves (including primary, secondary and tertiary reserves) together with methodologies in the literature to allocate some of these services. In Section III this paper reviews the procedures adopted in Portugal and in Spain to allocate and contract these services considering that some of them are mandatory and non-remunerated while others are voluntary and subjected to auctions in which it is

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defined the associated marginal price. Section IV describes three possible strategies that the TSO's can adopt to harmonize and integrate the national markets for some of these services. Section V will then present the results obtained with a Case Study based on realistic data for the tertiary reserves contracted in Portugal and in Spain. In this Case Study we analyse the existence of individual tertiary reserve bid lists, the existence of a common list for up and down tertiary reserve admitting that the capacity of the interconnection lines is unlimited, the existence of a common tertiary reserve bid list considering the current interconnection capacity and, finally, a common tertiary reserve bid list considering that the current interconnection capacity is increased by 300 MW. As a result, we obtained the up and down tertiary reserve prices, the amount of used energy, the value paid by the TSO regarding this energy and the number of hours the interconnection lines were congested eventually preventing buying tertiary reserve where it is cheaper. Finally, Section VI draws the most relevant conclusions of this work.

II. General Issues on Ancillary Services

As mentioned above, when talking about Ancillary Services there is not a commonly accepted definition for them. Apart from that, when going from one country to another or from Europe to North America the classification of these services is also not common. In any case and in very general terms, Ancillary Services can be defined as the services required to operate a power system under adequate levels of security, stability and quality of service. For instance, in [1] Ancillary Services are defined as "the set of products separated from the energy production, which are related to the security and the reliability of a power system" while [2] quotes the definition of FERC indicating that Ancillary Services are "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected power system". This reference also indicates that Ancillary Services can be provided by generation, transmission, system control and distribution system equipment, as well as by qualified consumers that, for instance, accept doing load shedding as long as they are paid a specified amount.

Regarding the types of services, reference [1] organizes Ancillary Services in active power ancillary services (as load-frequency control including primary, secondary / AGC, tertiary control, balancing service and black start) and reactive power ancillary services, as voltage control. Reference [2] enumerates the Ancillary Services identified by FERC, namely reactive power/voltage control, loss compensation, scheduling and dispatch, load following, system protection and energy imbalance. Curiously, this paper mentions that an earlier work of the same authors identified 19 ancillary services, just illustrating the lack of uniformity associated to this topic.

The evolution of power systems in recent years originated the progressive creation of transnational electricity markets, namely sharing common trading platforms, for instance Market Operators common to several countries. The NordPool and the Common Iberian Electricity Market, MIBEL, are just two examples of this kind of structures. However, when looking at the way Ancillary Services and allocated and paid, this harmonization and convergence is far more difficult although it could be interesting and promising in terms, for instance, of reducing the cost of reserves if it was possible to contract at least some of these services in a wider geographical area.

In any case, and apart from these classification and enumeration difficulties, it is clear that we can talk about active power oriented services and reactive power ones. In terms of active power reserves, they are typically divided according to the time after which they should be in operation leading to services as:

- primary reserves to be provided by the speed-droop of the generators in order to provide automatic adjustments of generation to balance the demand;
- secondary reserves typically associated to the Automatic Generation Control, AGC, that equips several generators in order to control frequency and to ensure that it comes back inside a narrow band around the nominal value, in the advent of a disturbance;
- tertiary reserves aiming at rebuilding the required levels of secondary reserve and typically having a maximum time (for instance of 15 min) to be provided.

Black start corresponds to another service to be provided by machines that can start being energized using autonomous systems, without being connected to the power system. These machines should be reasonably dispersed along the system so that they can be used to start re energizing the whole system after a major black out.

Regarding reactive power services, voltage control is the most typical one. It aims at maintaining voltage magnitudes in the nodes of the grid within specified bands typically indicated in the Operation Codes followed by TSO's. This corresponds typically to a service that is provided in a distributed way from a geographical point of view in the sense that reactive power devices should be spread along the grid to support voltages, to minimize reactive flows and to reduce active losses.

Some of these services are considered mandatory, while others are provided in a volunteer basis, some of them are non-remunerated while some others are contracted by TSO's using auction mechanisms. In this sense, reference [3] indicates that the provision of ancillary services should be made via competitive markets namely for the ones being complementary regarding energy markets. This is the case of secondary and tertiary reserves. Having in mind this complementary nature, several authors consider electricity as a multi commodity market and developed models to allocate simultaneously energy and some types of reserves [4, 5, 6, 7]. In particular, reference [6] describes an optimization model to settle energy and ancillary services as spinning reserve, non-spinning reserve and up and down regulation reserves. This paper derives locational marginal prices both for energy and for these services based on the Lagrange multipliers of the associated OPF model. Similarly, [7] develops a model considering an energy auction together with spinning reserve requirements and it discusses the adoption of different reserve types, namely when there are active transmission flow constraints. In recent years, wind power and DG in general is increasing in different countries. As a result, the number of papers addressing the evaluation of control performance, of the amount of reserves or the contribution of some DG to some ancillary services is increasing as illustrated in [8, 9, 10, 11]. The increasing use of volatile distributed resources suggests that the design of markets for some ancillary services will strongly depend on the delays imposed by communication devices [12]. The adopted design for these markets can have a strong impact on the performance of power systems in terms of frequency and voltage control as studied in [13]. As an example, these authors indicate that adopting different participation factors on the AGC software will originate different frequency responses some of them displaying better quality. On the other hand, [14] argues that a better sharing of reserves between different countries can counteract price spikes due for instance to peak demand levels, as the ones that occurred in Norway in October 2009 together with shortage of nuclear power in Sweden. This means this paper considers that more integration and more cooperation between TSO's should be the way to follow to avoid this kind of problems. To a certain extent, although price spikes didn't occur in the MIBEL, Sections IV and V are line with this position.

Regarding reactive power, designing auction mechanisms for this service is far less straightforward. On one side, reactive power is much more difficult to be priced and, on the other hand, it has a geographic nature that one shouldn't forget thus requiring considering the geographic location of reactive power providers. In any case, there are several papers addressing this topic as for instance [15 - 21]. Reference [15] describes the provisions in force in England & Wales after the privatization of the industry to price and allocate reactive power proposing a remuneration scheme based on an utilization term and a capability term and [16] discusses the implementation of reactive power markets and the structure of reactive power bids namely considering the capability curve of synchronous generators and opportunity costs. References [17, 18] model the reactive power allocation considering objective functions that include terms reflecting the cost of adjusting control devices in order to reduce the number of control changes. Reference [19] suggests that reactive power should be priced only according to the availability of reactive capacity since reactive power generation costs are difficult to estimate. Regarding the allocation of these costs to network users, the authors suggest adopting demand performance requirements defining a limit to absorb reactive power regarding active power without cost, or the implementation of local reactive power markets leading to the computation of nodal or zonal reactive power locational values. Zonal reactive power prices are also used in [20] as a result of the solution of a reactive optimal power flow study. Finally, reference [21] formulates an optimization problem to locate FACTS to be used to provide voltage control.

III. Brief Review of the Iberian Electricity Market

A. *The Power System of Portugal*

Since 1997, the Portuguese power system evolved a lot due to several legal changes. Privatization started in 1997 and the access to the generation activity was liberalized in 1998. In 2000 the transmission activity of the former vertical utility was separated originating the Portuguese Transmission System Operator, REN SA, in charge of the operation of the power system and having the concession of the transmission system. The legislation currently in force is the Law 29/2006 of 15th February. This law extended eligibility to all consumers and organized generation in normal regime and special regime in the sense that the generation facilities in this second group are paid according to subsidized fee-in tariffs. This involves renewables (namely wind parks and PV stations), hydro stations under 10 MVA and cogeneration facilities. In fact, these subsidizing schemes started back in 1988 and were very successful in inducing new investments. From a commercial point of view, normal regime generators and the demand can use the pool market or establish bilateral contracts to sell/buy electricity. By the end of 2009 the installed capacity corresponded to 16.738 MW, grouped as follows:

- normal regime – 11.268 MW
  - hydro stations – 4.578 MW;
  - thermal stations – 6.690 MW (coal stations – 1.776 MW, fuel stations – 1.476 MW, fuel/ gas stations – 236 MW, gasoil – 165 MW and combined cycles – 3.036 MW);
- special regime – 5.470 MW;
  - cogeneration stations – 1.631 MW;
  - hydro stations – 405 MW;
  - wind parks – 3.357 MW;
  - PV stations – 75 MW.

The Portuguese Regulatory Agency for the Electricity Sector, ERSE, was created in 1997 and its responsibilities were extended to the gas sector in 2004. In 1998, ERSE approved the first Tariff Code that created an additive tariff system comprising regulated tariffs for end users that remain in the regulated sector and access tariffs for free consumers. Access tariffs include the Tariff for the Global Use of the system (namely paying the costs of the control center, the subsidies to the special regime generation and the costs of ancillary services), the tariff for the Use of the Transmission System (including tariffs for EHV and HV networks) and the tariff for the Use of the Distribution System (including tariffs for HV, MV and LV networks). In 2009, the annual demand corresponded to 49.865 GWh and it was supplied by hydro stations, 15,8 %, coal stations, 23,9 %, combined cycles, 23,0 %, and special regime generation, 28,9 %, namely wind parks with a share of 15,0 %. The import share corresponded to 9,6% and the peak demand was 9.127 MW at January 12th.

As mentioned before, eligibility was recognized to all the consumers since early 2007. Regarding December 2009, the number of clients in the free market was 283811 out of 6.000.000 clients, and the annual demand corresponded to 18.838 GWh, that is about 40 % of the annual demand. During January 2010 there were about 10.000 changes of supplier including from the free market to the regulated system and vice-versa and inside the free market. In any case, the liquid increase of clients inside the free market was of 6853 clients.

B. *The Spanish Power System*

The Spanish system started to be restructured in 1995 and new legislation was passed by the end of 1997 so that the day-ahead market started to operate in the 1st of January 2008.

Currently, the Spanish generation system includes normal regime generation and special regime generation (small hydro stations, wind parks and other renewables as well as other non-renewable stations). The main figures regarding the installed capacity are as follows:

- normal regime – 61.806 MW;
  - hydro stations – 16.657 MW;
  - nuclear stations – 7.716 MW;
  - conventional thermal stations – 6.690 MW (coal station – 11.359 MW, fuel stations – 1.476 MW, fuel/ gas stations – 3.008 MW and combined cycles – 23.066 MW);
- special regime – 31.924 MW;
  - hydro stations – 1.974 MW;
  - wind parks – 18.719 MW;
  - other renewables – 4.480 MW;
  - other non renewables – 6.750 MW.

The Market Operator was in charge of the day-ahead market and the System Operator also has the concession of the transmission network. The trading platforms also include intra-day markets in which small quantities of electricity are typically contracted. There were 6 sessions of the intra-day market starting at 20.00 the day before and continuing along the day in which physical delivery would occur. Full eligibility was achieved in 2003 and in 2009 the annual demand reached 252.772 GWh with a peak power of 44.440 MW. This demand was supplied by hydro stations, 9%, nuclear stations, 19 %, coal stations, 12%, combined cycles, 29%, fuel/gas stations, 1%, and special regime generation, 30%, with particular emphasis to wind parks with a share of 13.8%.

C. The Iberian Electricity Market, MIBEL

In the 14th November 2001 it was signed a memorandum between the Portuguese and the Spanish governments aiming at establishing a common electricity market. After several partial agreements, in 2006 started the operation the market for bilateral physical and financial trading and in July 2007 started the common day-ahead market as an extension of the one that was already in operation in Spain since January 1998. The available interconnection capacity between the two countries increased to a maximum of 1900 MW. This value can be reduced due to technical constraints inside each country.

As mentioned above regarding the operation of the Spanish system, the operation planning involves a day ahead market that accepts buying and selling bids to the next day 24 hour trading periods. Then, the two TSO’s validate the schedules together with bilateral contracts checking interconnection limits in the first place. Market splitting is used to deal with congestion in interconnection lines, eventually leading to different prices in Portugal and Spain. Congestions internal to each country are solved using incremental/decremental bids submitted by generators. After obtaining a first feasible scheduled it is run a market to assign up and down secondary reserve leading to the final schedule by 15.00. At 20.00 each day starts the first session of the intra-day market completely covering the next day. As mentioned before there are currently 6 sessions of the intra-day market at 20.00 of the previous day, at 0.00, at 4.00, at 8.00, at 12.00 and at 16.00 of the operation day. Most of the energy, above 85%, is traded in the day-ahead market. Figures 1, 2 and 3 detail the evolution of the monthly traded energy and of the monthly average prices in the Portuguese and Spanish areas for 2008, 2009 and 2010.

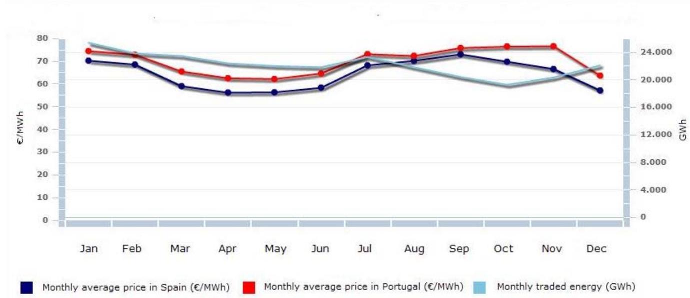

Fig. 1 – Total traded energy (GWh) (light blue) and average monthly market prices (€/MWh) in Portugal (red curve) and in Spain (dark blue) in 2008.

Fig. 2 – Total traded energy (GWh) (light blue) and average monthly market prices (€/MWh) in Portugal (red curve) and in Spain (dark blue) in 2009.

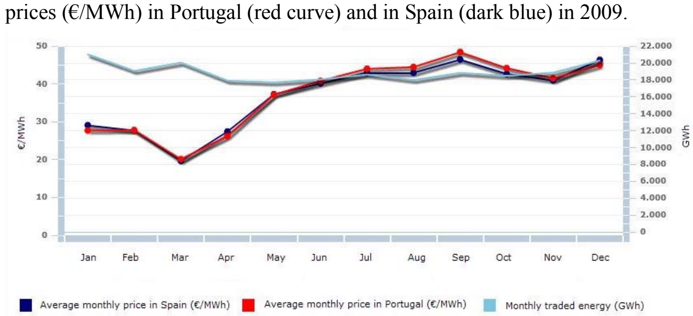

Fig. 3 – Total traded energy (GWh) (light blue) and average monthly market prices (€/MWh) in Portugal (red curve) and in Spain (dark blue) in 2010.

During 2008, the market price in Portugal was typically larger than in Spain indicating there was congestion in the interconnection lines towards Portugal. Then, the demand started to decrease due to the economic crises leading to a progressive price reduction. The final months of 2009 and the initial ones of 2010 were very rainy further reducing the prices. From April 2010 onwards the prices started to increase are now very close in the two countries indicating that there is no systematic congestion in the interconnection lines.

D. The Ancillary Services in the MIBEL

In the scope of the Common Iberian Electricity Market there are two control areas corresponding to Portugal and Spain. Portugal is then organized in a number of balancing areas that are used to compute and penalize deviations from scheduled values. Regarding Ancillary Services, the national operation codes as [22] indicate that TSO’s are in charge of contracting the required amounts of ancillary services and of solving the technical constraints that eventually result from the schedules of the day ahead and intra day markets. Currently, the ancillary services considered are the following ones:

solution of technical constraints, frequency control, involving different types of reserves, namely taking into account the way they are activated and time required to their use, voltage control / reactive power and black start.

1) Solution of technical constraints

A technical constraint corresponds to any limitation due to a particular situation of the transmission network that imposes special procedures in order to continue ensuring the reliable and safe operation of the system. Apart from network constraints associated with the day ahead and the intra day markets or to the real time operation, there are also constraints associated with insufficient secondary or tertiary reserves, insufficient capacity to control nodal voltages and insufficient reserve capacity to start the system after a major outage. The congestion on international lines is addressed using a market splitting approach. For congestions inside each country, each TSO accepts bids to change the output of the generators till 11.00. Using these bids the TSO includes in the schedule new bids that contribute to solve the constraints starting at the least costly one and eliminates bids starting at the most costly that was accepted for that trading period in the day-ahead market.

2) Primary reserve

Primary control [23] aims at stabilizing frequency at a stationary value after a disturbance or incident but without restoring reference values for the frequency and for power exchanges. Generators should be able to change their output automatically due to a frequency change using their speed-droop characteristic. Following [23], the amount of primary reserve to be in place on a national basis is given by (1) in which $P_{prim,i}$, E_i, E_{total} and $P_{prim,total}$ represent the primary reserve assigned to area i, the total energy generated in area i, the total energy generated in all involved areas and the power deviation of the reference incident, set at 3000MW. Using data of 2009, the primary reserve in Portugal corresponded to about 51 MW and in Spain to 318 MW.

$$P_{prim,i} = \frac{E_i}{E_{total}}.P_{prim,total} \qquad (1)$$

Following [22], the insensitivity band of speed regulators should be as small as possible and, in any case, smaller than 10 mHz, meaning that speed regulators should react to deviations at least larger than 10 mHz. The entire primary reserve should be activated for variations larger than 200 mHz. In Portugal, the activation of primary reserve is done till 15 sec for perturbations that originate deviations less than 100 mHz and change linearly from 15 to 30 sec for deviations ranging from 100 to 200 mHz. In both countries this is a mandatory non-remunerated service supplied by on line generators that should provide a regulation band of at least 5% of their output power.

3) Secondary reserve

Secondary reserve aims at bringing the frequency and power exchanges in main lines back to the reference values. The amount of secondary reserves, P_{sec}, is determined by each TSO, considering the UCTE (currently ENTSO-E) recommendations given by (2), in which P^{max} is the peak load forecasted for the control area under analysis and a and b are coefficients empirically set at 10 MW and 150 MW. Given the peak load in 2008, the secondary reserve corresponded to 185 MW in Portugal and 522 MW in Spain.

$$P_{sec} = \sqrt{a.P^{max} + b^2} - b \qquad (2)$$

After a disturbance, the Automatic Generation Control, AGC, sends the set point to the involved generators according to their contribution to bring frequency back to 50 Hz and to bring the power interchanges in key branches to scheduled values. According to [22], in Portugal the secondary control should be activated in no more than 30 sec and its operation should be completed in no more than 15 min. This code also indicates that secondary control can be supplemented by fast tertiary reserves in case the up secondary reserve is unable to cover the maximum lost generation. These reserves are contracted on a national basis activating specific markets. In Portugal, the TSO communicates till 13.00 of the day ahead the secondary reserve requests and the participant generators should sent selling bids including the up available reserve (MW), the down available reserve (MW) and the price of secondary reserve band (€/MW). The TSO should contract secondary capacity on a least cost basis and the reserve capacity price corresponds to the price of the last accepted bid. The energy used inside this reserve band in the event of a disturbance is termed as secondary energy and it is paid according to the price of the up or down tertiary reserve for the corresponding trading hour.

4) Tertiary reserve

The main objective of tertiary control is to replace the used amount of secondary reserve, as determined by the secondary control implemented via the AGC. Both Portugal and Spain currently assign tertiary reserve according to specific markets on a national basis. For each scheduling period of the next day, each TSO determines the minimum amount of tertiary reserve. In general, this minimum amount corresponds to the maximum power that can be lost due to any single equipment outage increased by 2% of the demand forecasted for that period. After clearing the secondary reserve market, each TSO activates the tertiary reserve market, typically from 18.00 to 21.00. The tertiary reserve bids should be presented by generators able to provide power variations within 15 min and the service should be maintained for, at least, two consecutive hours. The bids include the up and the down tertiary reserve in MW, interpreted as the maximum up and down variations of the generator's output within 15 min and the corresponding energy price in €/MWh. The used energy will be paid according to the marginal price of the up or down markets.

5) Voltage control

Voltage control is obtained through the activation of adequate reactive power generation devices spread along the networks. These can include generation units, the transmission network itself, distribution networks as well some consumers having suitable equipments. In Portugal, [22] specifies the admissible voltage bands for the different voltage levels of the transmission network, considering the normal state, for N-1 contingency states as well as in case of in case of successive failure of double circuit lines or of a line and a generator. This service is considered as mandatory and non-remunerated.

Reference [22] simple states that the TSO should monitor the operation of the network to ensure that these voltage operation bands are not violated and will transmit in real time control orders to change the operation points of equipments in the transmission network, to switch on or off capacitors, to change transformer taps or to switch on or off breakers along the grid.

In Spain, reference [1] details the regulatory provisions for the procurement and assignment of this service. It has a mandatory and non-remunerated term together with a remunerated part paid according to performance evaluation. Maintaining a mandatory term is explained given the importance of voltage control to ensure the system security and reliability. According to this mixed scheme, the TSO defines the minimum non-remunerated amount of reactive power and the amount above it can be offered to the TSO. If accepted by the TSO, it is paid at a fixed price.

6) Black start

Both in Portugal and Spain, black start capability is a non-remunerated service. In each country the TSO's define emergency plans in case of contingencies and also restoration plans in case a major black out occurs. In this case, as indicated in [22], the main objective of restoration plans is to restore the supply of electricity in an ordered, secure and as fast as possible way. These plans should be prepared in close collaboration between the Iberian TSO's defining the set of actions to take in every area of each of the systems in order to reenergize the whole system as quick as possible.

IV. Harmonization/Integration Strategies

After analyzing the ancillary services in Portugal and Spain and the way the TSO' procure and assign them, we will now detail three possible models that can be adopted to harmonize and progressively integrate the market of Ancillary Services, in general. These markets will not be extended to all services, given that some of these services are considered as mandatory and non-remunerated as mentioned above. As a result, these integration schemes will eventually be applied to secondary and tertiary reserves. The models will be described in terms of increasing the integration requirements thus eventually leading to the allocation of fewer resources and eventually originating less costly strategies leading to positive impacts on the tariffs paid by end consumers.

Model 1 – let us admit two control areas, A_1 and A_2. In this model, the system operators of the two areas continue to receive bids on a national basis for the marketed ancillary services but each of them is allowed to act as a seller in the specific markets ran by the other one. Under this model, the TSO of area A_1 and the TSO of area A_2 preserve their unique relation with the providers of ancillary services of the corresponding area setting the quantities and the prices for each service. However, the TSO of area A_1, for instance, is allowed to act as a representative of the providers of area A_1 in the markets ran in area A_2. This is simplest and less demanding model in the sense that all exchanges will be established by the two TSO´s. This also means that this model is the one that can be more easily implemented in the future.

Model 2 – this model admits that some providers of some ancillary services can operate in more than one control area. This means that a provider of tertiary reserve can communicate tertiary reserve bids in more than one area implying reserving the use of enough transmission capacity. This also means that an ancillary service provider can establish contractual and financial relations with more than one System Operator.

Model 3 – in this case, there is a more complete integration of specific ancillary services market requiring a stronger cooperation between the System Operators. In general, this model requires that an entity is in charge of receiving all the bids for the provision of a specific service and that a common list of bids is organized, independently of their geographic origin. This model is the most demanding one in terms of requiring a larger integration between the TSO's, but it is also the one that can originate a larger reduction of costs in terms of the provision of some services, for instance, tertiary reserve. Of course, for some other services as voltage control / reactive power an eventual common list should in any case be constrained from a geographical point of view given the local nature of the voltage control. This issue only contributes to stress that ancillary services have very different natures meaning that for some of them it is possible to adopt a larger integration path while for some others this is not practical.

V. Results of Simulations

A. Description of the simulations

After describing these models, we will focus in the provision of tertiary reserve in the Iberian Peninsula. Using public data available in the web pages of the TSO's of Portugal and Spain regarding tertiary reserve bids, allocated quantities and market prices, we analyze four cases, as follows:

- Case 1 - in the first place, we analyzed the tertiary reserve market in Portugal in January 2008 in order to compute the cost incurred by the Portuguese TSO in contracting up and down tertiary reserves. In this case, we admitted that the Portuguese TSO activates tertiary reserve bids with a geographical origin in Portugal;
- Case 2 – secondly, using the bids communicated by both Portuguese and Spanish agents, we simulated a common market for the provision of tertiary reserve, admitting that the capacity of the interconnection lines is unlimited. This is an unrealistic situation that, in any case, can be used to obtain a reference result to be used for comparison purposes;
- Case 3 – thirdly, we simulated again a common tertiary reserve market, that is, we considered a common bid list, but now we used the interconnection capacity that existed between Portugal and Spain early in 2008;
- Case 4 – finally, in order to evaluate the impact in the cost of providing tertiary reserve, we repeated Case 3 but now increasing the interconnection capacity by 300 MW regarding the limit we used in Case 3.

The simulations were run using data available on the webpage of the Portuguese TSO regarding the bids for tertiary reserve for up and for down regulation including the blocks of offered power (MW) and the energy bid price (€/MWh). The bids are communicated in the day ahead and the TSO defines the minimum tertiary reserve that is required for each hourly period. The up tertiary reserve is used when there is a generation deficit and the down reserve is used when there is an excess of generation. The up regulation bids are organized according the increasing order of the bid price and the down bids are organized by the decreasing order of their prices. This leads to the up and down regulation curves. When an up or a down reserve is required, the TSO selects up or down bids till obtaining the required up or down energy. When this up or down energy is obtained, it is identified the marginal price for up or down tertiary regulation and all the up or down used energy is then paid at the marginal up or down prices.

Using the tertiary bid curves available from the webpage of the Portuguese TSO (www.ren.pt) for January 2008 it was obtained the minimum, the maximum and the average prices for the up and down tertiary reserves together with the total amount of used energy. These values derived from public data correspond to Case 1 that will then be used for comparison purposes with the results obtained for Cases 2, 3 and 4. In the case of Spain the data regarding tertiary reserve bids was also obtained in the webpage of the Spanish TSO (www.ree.es).

In order to run the simulations for Cases 2, 3 and 4, it was developed an application that uses the tertiary reserve bids from Portugal and from Spain, that builds a common bid list and that, according to the required tertiary energy in each country, selects the required bids and identifies the corresponding up and down reserve prices. The integration of two national markets will potentially have an important advantage. Just consider that there is an up reserve requirement in a country and a down requirement in the other. This means it is possible to compensate, at least partially, opposite requirements, so that the global used tertiary energy is reduced regarding the values associated to a pure national basis operation. If the same type of reserve is required in the two areas, than compensation is excluded. In any case, if compensation is possible, there will be a reduction in the global cost, as illustrated in Cases 2, 3 and 4 regarding Case 1.

Table I – Minimum, maximum and average prices, energy and total cost of up tertiary reserve in January 2008.

	Min. price (€/MWh)	Max. price (€/MWh)	Average price (€/MWh)	Tertiary energy (MW)	Total cost (10^3€)
Case 1	45,40	108,39	73,30	88.927	6.833
Case 2	20,00	106,60	66,59	84.018	6.030
Case 3	20,00	106,60	72,02	84.018	6.304
Case 4	20,00	106,60	66,91	84.018	6.047

Table II – Minimum, maximum and average prices, energy and total cost of down tertiary reserve in January 2008.

	Min. price (€/MWh)	Max. price (€/MWh)	Average price (€/MWh)	Tertiary energy (MW)	Total cost (10^3€)
Case 1	28,58	101,20	64,18	151.175	9.749
Case 2	36,80	101,18	69,30	124.211	8.543
Case 3	27,01	101,08	65,23	124.211	7.772
Case 4	31,50	101,08	66,91	124.211	7.991

Finally, Cases 3 and 4 consider the limitations of the interconnection lines meaning that eventually not all tertiary energy will be allowed to flow from one area to the other one. In each trading period, the available interconnection capacity that can be used by tertiary reserves is the difference between the total interconnection capacity and the capacity already assigned in the day-ahead and in the intra-day markets. If the limit is reached in a trading period, although less expensive reserve bids are available in one country, the TSO of the other country has to use bids from its own national reserve list. As a result, the marginal price in that control area will increase as well as the final cost of the used tertiary energy.

B. Results of the simulations and comments

Using the above described reasoning, Tables I and II present the results obtained for the 4 simulated cases for the up and for the down tertiary regulation for the Portuguese system.

Regarding the up reserve, the values in Table I show that when going from Case 1 to Case 2, that is, when implementing a fully integrated market with no interconnection limitations, the average price gets reduced as well as the mobilized energy and global cost to be paid by the System Operator.

These values get degraded when going from Case 2 to Case 3 because Case 3 considers the limitations imposed by the interconnection lines that existed in 2008. The simulations done for Case 3 indicated that the importing capacity limit was reached in 192 out of the 744 hours of the month under analysis, that is during 25,81 % of the period. This suggested running Case 4, in which the interconnection capacity was increased by 300 MW regarding the value used in Case 3. As a result, the average price reduced to a value higher than in Case 2 (that corresponds to the most reduced amount that can be obtained) but smaller than the one obtained in Case 1 for the independent operation. As a result of the interconnection capacity increase, the number of hours during which the importing capacity would be reached is now reduced from 192 in Case 3 to just 14 hours in Case 4, that is to 1,88 % of the hours of the period. Regarding the used energy, it decreases when going from Case 1 to Case 2 and then it remains the same. The reduction from Case 1 to Case 2 is explained by possibility of compensating different reserve requirements occurring in the same period in the two areas. When going from Case 2 to Cases 3 and 4, this integration effect is already exhausted and so the used energy due to excess or deficit of generation in each area remains the same.

Considering now the results for the down reserve, the used energy is strongly reduced when going from Case 1 to Case 2 because there is a frequent compensation between down reserve requirements in Portugal with up requirements in Spain. In fact, in the Portuguese system, down reserve requirements are typically more frequent than up requirements, because excessive generation is relatively frequent. As a result, the cost reductions obtained with an enlarged market integration are larger for the down reserve than for the up reserve. Finally, it is important to notice that when going from Case 1 to Case 2 the average price increases, differently from what was mentioned for the up reserve. To understand this result, recall that the down reserve curve is obtained ordering reserve bids by the descending order of the bid price. As a result, if the tertiary energy required gets reduced when going from Case 1 to Case 2, the last used bid has a larger price leading to an increase of the corresponding marginal price.

VI. Conclusions

This paper described the main aspects determining the operation of the Iberian Electricity Market, MIBEL, involving Portugal and Spain. The establishment of this regional market involved several steps that started in 2001 and a more integrated operation was finally reached in July 2007 with the launching of the common day-ahead market. The Iberian system preserves two control areas, under the responsibility of the Portuguese and the Spanish TSO's but there are discussions to give further steps to a larger integration, namely regarding the markets for secondary and tertiary reserves.

This paper described three possible models to move towards a larger integration. The first one is the less demanding since the two TSO's remain in charge of their-own reserve lists while the third one involves building a single reserve bid list for the entire Iberian system. The simulations that were performed using public data for tertiary reserves highlighted the advantages that can be obtained from a larger integration, in terms of reducing the tertiary required energy and the corresponding cost, namely when the reserves required in each country were different, an up reserve in a country and a down reserve in the other one. The simulations indicate that Portugal would benefit from such integration because it typically requires down tertiary energy due to deviations towards excess of generation. At least, part of these requirements could be compensated by Spanish up reserves, thus reducing the global cost of this ancillary service. Finally, the simulations also indicate that an enlargement of the interconnection capacity would contribute to eliminate most of the limitations on transnational trading, allowing these markets to display larger benefits.

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VIII. Biographies

João Tomé Saraiva was born in Porto, Portugal in 1962. In 1987, 1993 and 2002 he got his MSc, PhD, and Agregado degrees in Electrical and Computer Engineering from the Faculdade de Engenharia da Universidade do Porto, FEUP, where he is currently Professor. In 1985 he joined INESC Porto – a private research institute – where he was head researcher or collaborated in several projects related with the development of DMS systems, quality in power systems, and tariffs due for the use of transmission and distribution networks. Several of these projects were developed under consultancy contracts with the Portuguese Electricity Regulatory Agency.

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