

Technical and Economic Aspects on Ancillary Services Markets in the Electric Power Industry*

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Abstract

In this work is developed a comparative analysis of technical and economic aspects of Ancillary Services on the markets of England and Wales, Nordic Countries, California, Argentina, Australia and Spain. We have considered the services of Voltage Control, Frequency Regulation and System Restoration for being these services the ones of major occurrence on the analyzed markets. All the analyzed markets rely on an administrator of Ancillary Services, function that dwelled into the figure of the System Operator. In relation to the services, stands out the obligatory nature of Voltage Control and Primary Frequency Regulation, being the services that shows a higher price in the markets considered and the services that are requested needed in minor time. The costs associated with the services in general correspond to investments, operation, maintenance, costs of opportunity and minor useful life of the equipments. Is not observed a clear preference for a type of management mechanism, being combined auctions, competitive offers and bilateral contracts to different periods.

1. Introduction

One of the aspects that have received increasingly importance inside the reorganization of the Electrical Systems corresponds to the reliability of the operation, the security and quality levels of the electricity supply. In order to face these challenges and to satisfy the new requirements of the industry several countries have implemented an Ancillary Services Market that operates in a parallel form to the power and energy markets [20]. Ancillary services have always been part of the electric industry, but only in the last years and after the introduction of competition is that their importance has been recognized and they have been considered as services that can be traded on the market [21].

Characteristics of the electric energy industry, of electricity itself and the problems related to the reliability of the electrical systems that are present in all the countries, make think about a market for Ancillary Services as a tool that allows a provision of a more reliable electrical supply to the consumers.

2. Objectives

The aim of this investigation is to realize a comparative study of Ancillary Services Markets, analyzing their technical and economic aspects, in order to provide a guide for their implementation in the electrical systems of the different countries. Section 3 provides a general description of ancillary services. Section 4 describes the functioning of the Ancillary Services Markets in electrical systems of England and Wales, Nordic Countries, California, Argentina, Australia, and Spain. Section 5 provides a comparative analysis of the analyzed markets. Finally, in section 6 the main conclusions of the investigation are presented.

3. General Description of Ancillary Services

Ancillary Services have been defined differently depending on the Electrical System in which they are implemented and on the regulatory organization of the market to which they belong. A general definition would say that they are those services provided by generation, transmission and control equipments that are necessary to support the transmission of electric power from the producer to the consumer [53].

As well as different definitions of Ancillary Services exist, different Ancillary Services are present in every electrical system.

In this section we present a general description of the most common Ancillary Services considered in the literature and the electrical systems, also a mention is

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made about the key cost concepts associated to the provision of each of them.

The simpler classification of Ancillary Services leads us to group them in: frequency control, coordination and operation, system backup and restoration.

A. Frequency Control

These are the services related to the short term balance of energy and frequency of the power system.

i) Primary Frequency Regulation

Fast variations in generation or electricity consumption are the main causes of frequency variations due to energy imbalances in the system. Primary Frequency Regulation service allows fixing these imbalances continuously and in real time [17]. It consists on the provision of a suitable generation capacity of autonomous response, by means of extra generation capacity, in order to keep the frequency inside its nominal value [23].

This service is typically provided using governors and automatic generation control systems (AGC).

The main fixed costs associated with this service correspond to the capital invested in the generation plants used to provide the service, the governors and AGC equipments. As for the variable costs, they are mainly concerned with an increase in the operation and maintenance costs, a minor efficiency and a decrease in the lifetime of the power plants [21]. Also, there can exist an opportunity cost if there is a tradeoff between providing the service of primary frequency regulation and the service of being dispatched as a base plant generator who sells energy.

ii) Operational Reserves

Besides frequency variations that are a consequence of the changeable nature of demand, Electrical Systems shows variations related with unexpected events or contingencies in the generation and transmission. Operational Reserves are intended to rescue the system from a major failure due to these variations using technology that allows to detect and to correct the imbalances between generation and consumption [22]. In general, operational reserves correspond to available generation in the short term to manage the imbalance between energy supply and energy demand [17]. According to the availability speed we distinguished three types of operational reserves: Secondary Frequency Regulation, Tertiary Frequency Regulation and Non Synchronized Reserves.

Secondary Frequency Regulation requires a response time that changes between 30 seconds and 15 minutes,

and Tertiary Frequency Regulation must be available within 10 to 30 minutes. For both services the power generation units must be synchronized to the grid, and in general is required that the suppliers can support these two services for at least 2 hours. The Non Synchronized Reserves are those power reserves available in generating units that neither have been dispatched nor even connected to the grid, but they can be connected and start generating in a period of about 30 minutes [21].

The technologies used to provide these services are, among others, automatic generation control, governors, rapid generation and rapid unit unloading [36], and on the demand side load shedding.

The fixed costs associated with these services correspond to the capital invested in the generating units plus the investment in control equipments. Variable component of the costs is associated with a bigger consumption of fuel and a minor efficiency [21]. Also, there can exist an opportunity cost if there is a tradeoff between providing the service of Secondary Frequency Regulation, Tertiary Frequency Regulation and Non Synchronized Reserves and the service of being dispatched as a base plant generator who sells energy.

B. Coordination and Operation

These services are related to quality aspects of the supply that are different from the frequency of the system, they are mainly related with voltage regulation in the different points of the electrical grid and with energy flows controls across the grid, subject to the grid limitations.

i) Scheduling and Dispatch

This service integrates the activities to complete the contracted transactions and it is also associated with the real time actions that are needed to support the system in the presence of variations in the load or demand [17]. It consists of operations planning using the generation and transmission resources available, to satisfy the demand. It corresponds to a service that only can be performed by the System Operator, and it cannot be provided competitively [21].

The costs associated with this service are expected to be low, since only metering, calculation and communication equipments are needed, plus the personnel in charge of the operation [21], no mayor investments are needed.

ii) Congestion Management

The actions that compose this service are the prescribed to reschedule the dispatch in order to fulfill the capacity restrictions of the transmission lines [8]. Though

congestion management is not always considered as an ancillary service, it can be considered in this way, since it is a necessary activity to make possible the power exchanges in the system.

The main costs associated with this service correspond to metering and calculation equipments plus the operators.

iii) Voltage Control and Reactive Power Supply

It consists of the use of generation and transmission resources to keep the voltage inside the range required in the System [17]. This service consists of the production of reactive power to solve the problems of low tension, and of the capability to absorb reactive power for high levels of tension [24]. In both ways there is a dynamic service delivered in a continuous way to face tension changes.

There is a collection of equipments that can be used for the provision of this service, as generators, synchronous condensers, capacitors and inductors, static VAR compensators and distributed generation equipments. They differ in characteristics and the reaction speed, capability to support voltage changes and investment and operational costs [24].

The choice of the equipment is related to the nature of the load to compensate and the reaction speed that is required [2], the selected equipment will also involve different costs.

The main costs associated with this service correspond to investment, operation, maintenance, depreciation and opportunity costs [4],[21].

C. System Backup and Restoration

These are services related to the backup capacity of the system and his capacity to return to a normal operation after been affected by a major blackout.

i) Blackstart Capability

It is the capacity of a generation unit to go from a non operational condition to an operational condition without the need of assistance of the electrical grid and then to energize the electrical grid and to support the start of other generating units when an important flaw in the System occurs [25].

This service has as purpose the restoration of the system as soon as there has happened a great disturbance or collapse of it [27]. The generators that provide this service must be able to consume and produce reactive power, in order to control the voltage during the process of restoration [26]. It is also important to have the necessary communication and coordination resources to keep the flexibility and stability of the system, minimize

the duration of the blackout and guarantee the safety during the process.

The main costs of this service are associated with the investment in equipments, and the operation and maintenance of these [26], nevertheless there are also costs associated to the operation of the transmission system during the recovery of the system and to system losses. In some cases, there is also a cost associated with feasibility studies.

ii) Replacement or Supplementary Reserve

This reserve has as function to support the Operational Reserves, being able to replace them in order that they recapture their normal levels. In general supplementary reserves are not operating, so they are asked to synchronize to the System in a longer period, generally an hour. To provide this service is a requirement that the supplementary reserve can be maintain until the lost capacity is back, in generally supplementary reserves are required for a minimum of two hours [7].

The main costs of this service are associated to the operation and maintenance of equipments.

4. Operation of Ancillary Services Markets on Selected Countries

The aim of this section is to analyze diverse electrical systems in which Ancillary Services Markets have been implemented successfully. Technical aspects have been studied as the requirements of each one by the System Operators; and economic aspects such as the management mechanisms, the costs associated with every service and the price that the consumers pay in every system are considered. For the analysis we have look the following Ancillary Services: Voltage Control, Frequency Regulation and System Restoration by means of Blackstart Capability.

A. England and Wales

The Electrical System of England and Wales is the most important of the United Kingdom. It supplies energy to more than 50 million people and generates near 350 TWh a year.

The deregulation process of the Electric Industry began in 1989 in order to reduce the government intervention in the economy and where total liberalization was reached in 1991. The Energy Pool of England and Wales was the institution entrusted to facilitate the process of energy auctions among the generators.

Despite the liberalization of the Electric Industry, the fall in electricity prices did not reflects the sharper costs reduction explained in part by the increased competition

observed in the generation sector, mainly because of the wide knowledge of the Pool that was embodied within the three major generation companies, what gave them a spacious market power [1].

In the year 2001 the Pool's former system was replaced by a system in which supply and the demand can freely negotiate their electricity contracts, this new institution was named New Electricity Trading Arrangements (NETA) [48]. The introduction of NETA allowed the creation of a market in which energy is traded as any another commodity, through bilateral contracts. The essential elements of NETA are Forwards and Futures Markets, energy exchanges, Balancing Mechanism and Imbalance Settlements [48].

Though the prices have diminished from the beginning of the operation of NETA [49], this decrease is mainly associated with an excess of capacity in the system explained in part by the high fines that the generators must pay when they do not have enough power to satisfy their assigned demand.

Ancillary Services are managed by the National Grid Company (NGC), who also operates the transmission grid [53]. The costs associated with the provision of ancillary services are transferred to the consumers through an uplift in transmission payment.

i) Voltage Control

It is required from all the generation units with a capacity above 30 MW. Voltage must be kept in the range of $V_{nom} \pm 10\%$ for 400, 275 and 132 kV and the power factor (PF) between 0,85 capacitive and 0,95 inductive. Is required an instantaneous response and is not specified the permanence period of the service [40]. The needed quantity of reactivate power is calculated on the basis of historical levels and is assigned in MVar for every hour.

The main costs that are identified correspond to capacity and operation; there are two ways to trade this service, a basic payment mechanism for capacity and operation and a biannual offer based auction mechanism. In consumers electricity tariff they pay through an uplift. The prices for capacity range from US\$0 to US\$0,58/MVar/h. The average operation price is US\$1,31/MVarh [39].

ii) Frequency Regulation

Is required for the system to have a frequency between 49,5 and 50,5 Hz. In the case of a contingency, is allowed for the frequency to be under 49,5 Hz., but for no more than one minute [41]. The supply of Primary Frequency Regulation is mandatory for all the generators with an install capacity over 50 MW, who provide it in continuously. Generators are required for a droop of 3 to 5 %, with an insensibility to frequency changes smaller

than ± 15 mHz. Large consumers can provide Primary Frequency Regulation through load shedding, where is required a response period of 10 seconds and permanence period of 20 seconds [43].

The costs associated with this service are difficult to identify, and is generally traded based on annual bilateral contracts. Consumers pay through an increase on their electricity payment for concepts of capacity, operation and compensation. The price of the service is in the order of US\$3,9/MWh [38].

The service of Secondary Frequency Regulation is considered a commercial service and it is not mandatory, generators provide it with AGC and load shedding. It is required a response period of 30 seconds and a permanence period of 30 minutes [43]. The required quantity is calculated annually by the System Operator.

As in the previous case, the costs associated with this service are difficult to identify, and is traded based on annual bilateral contracts and competitive auctions. The consumers pay through an increase on their electricity tariff for concepts of capacity, operation and compensation. The price of the service is in the order of US\$4,3/MWh [38].

iii) System Restoration by means of Blackstart Capability

Is only offered by generation units with over 200 MW of capacity, and the unit must be able to be synchronized with the grid in two hours and should be able keep the provision of the service between one and five days, if necessary, at 90 or 95% of his capacity avoiding that the frequency falls below 47 Hz [42].

The main costs associated with the provision of this service correspond to capacity, operation and maintenance, besides insurances and feasibility studies. The provision of the service is assured based on annual bilateral contracts. The suppliers receive financing for the equipments installation and later a payment for availability and operation.

B. Nordic Countries

The Electrical System of the Nordic Countries is incorporate the Electrical Systems of Denmark, Finland, Iceland, Norway and Sweden, countries that sinse 1991 moved into a deregulation that begun in Norway. As a whole it supply more than 24 million persons and generate more than 395 TWh of electricity per year [44].

Nord Pool ASA was until January 2002 the company that grouped the Transmission System Operators for the operation and planning of the market. Since that date, the activities related to the spot market and the physical delivery of the energy are responsibility of Nord Pool Spot AS, whereas the services associated with the

calculation and monitoring of the safety requirements of the system are in the hands of Nord Pool Clearing AS. These two companies are joint property of the System Operators and Nord Pool ASA [46].

The current market structure of the Nordic Countries includes over the counter markets (OTC) where bilateral contracts are traded (futures market), a spot market (Elspot) and an energy balance market (Elbas), both operated by Nord Pool.

Ancillary Services are traded in a real time market managed by the Transmission System Operators [47].

The costs associated to Ancillary Services are directly transferred to the users through the transmission payment, which is highly regulated.

i) Voltage Control

The local provision of Voltage Control and Reactive Power is mandatory for all the system generators. The requirement is defined depending on the PF according to the following criteria: $-0,2 < \text{tg } \theta < 0,4$. It is required a response period of 5 second and the service must be supported for all the time that is needed. There is no monitoring associated to the service [51].

The costs associated to the service are low, since the provision is in charge of the hydraulic generators, the transaction mechanism corresponds to annual contracts at a fixed price. The suppliers get an operational payment, only for quantities that exceed the mandatory range and the consumers pay an approximate price of US\$2,7/MVArh that is incorporated in the transmission tariff [52].

ii) Frequency Regulation

Is required that the system's frequency stays in the range of 49,5 and 50,5 Hz. The service of Primary Frequency Regulation must be provided in 30 seconds after being requested by the System Operator and must be supported for all the time that is needed [18]. The required quantity is locally calculated in every country. This is an obligatory service for all the generation units [45], where they are required to keep a droop between 2 and 5%.

The transaction mechanism correspond to annual contracts, the suppliers get a payment for capacity and other for operation, the consumers' pay through the transmission tariff. For example Statnett, System Operator in Norway, determines a total amount to be paid nearby US\$3,3 millions and each generator receives a payment according to his contribution [51].

The service of Secondary Frequency Regulation is only considered an Ancillary Service when it is provided in the case of an emergency. The required power has as limit 8% of the generator capacity. For this service is

required a response period of 15 minutes and a minimal provision period of 4 hours [18].

The costs associated with Secondary Frequency Regulation are minor, since his provision is in charge of hydraulic generators. The provision is assured through competitive offers. The consumers pay through the transmission tariff, only for concepts of operation, approximately US\$12/MWh [51].

iii) System Restoration by means of Blackstart Capability

This service is not considered as an Ancillary Service and all the system generators must offer it for free.

C. California, USA

The Electrical System of California supplies more than 35 million people with an annual electricity demand close to 265 TWh.

The process of deregulation began in 1992, but it became more explicit in 1996, after the Federal Energy Regulatory Commission dictated a mandate to allow for the free access into the transmission grids. The same year was born the California Independent System Operator (CAISO), to manage the transmission grids and to assure free access to all the participants of the market [19]. Since 1998 CAISO also takes care of the administration of the Ancillary Services Market. The provision of these services is based on competitive auctions, nevertheless, some services were traded through bilateral contracts [19].

The electric energy market of California had a good functioning until May, 2000 [31], when there began to appear the first indications of the electric and financial crisis that would last until the middle of the year 2001. As consequence of this crisis, CAISO redesigned the electric energy market of California introducing a series of modifications. In the new design, it introduced the concept of Available Capacity (ACAP), whose main objective is to allow the ISO to verify in advance that it counts with enough capacity to cover the load and reserves requirements of the system. It also introduced a large change on the structure of market. In the new design, the energy market, the Ancillary Services Market and the congestion management market are simultaneously optimized, along with the designation of the generators that will be in charge of energy delivery and the other services. The detail of this new market design can be find in [9].

i) Voltage Control

For all the system generators is mandatory to sustain a PF among 0,9 capacitive and 0,95 inductive [11].

Electricity transmission companies and electricity distribution companies should guarantee an appropriate voltage support in their business area, where the System Operator establishes operational limits for the transmission lines [11]. It is required that the service should be available in a period of one minute and that its durability is for all the period that the service is needed.

The main costs associated to this service correspond to operation and maintenance costs, and a reduction in the generators lifetime [24]; this service is traded through annual bilateral contracts. The generators are compensated only if they have to function out of the specified PF range, when the System Operator requests it.

ii) Frequency Regulation

Primary Frequency Regulation and Secondary Frequency Regulation are not mandatory services. For Primary Frequency Regulation is requested an instantaneous response and the durability of the service for the time frame that is needed [7]. The required quantity of the service is calculated through Area Control Error (ACE) as a percentage of the total predicted demand for the system, this value changes according to the time schedule between 5 and 12% of the load. There exists up and down service regulation.

The costs associated with this service correspond to capital, operation, fuel, and reduced efficiency costs, etc. The suppliers receive a payment for capacity of approximately US\$16/MW for up tuning frequency regulation and US\$20/MW for down tuning frequency regulation [28]. They also receive a payment for the use of the service valued at the spot market energy price.

For Secondary Frequency Regulation it must be available in 10 minutes and must be supported for at least 2 hours [7]. The System Operator calculates the quantity required of the service according to criteria on demand, contingency and others [6]. The quantity required generally come close to 3% of the maximum demand of the system [21].

The main cost associated with this service is the opportunity cost. The payment of the consumers for a capacity concept is approximately US\$2,3/MW [28].

iii) System Restoration by means of Blackstart Capability

The System Operator determines the quantity and location of suppliers for the service according to the system contingency information [10]. It is required a response period of 10 minutes and a permanence period of the service for 12 hours.

The main costs associated with this service are investment, operation and fuel costs [25]. This service is traded through bilateral annual contracts.

D. Argentine

The process of deregulation of the Electric Energy Industry of this country began in 1992, with a reorganization that was mainly seen to achieve greater efficiency in the sector.

The restructuring included the creation of the Wholesale Electricity Market Management Company (Compañía Administradora del Mercado Eléctrico Mayorista S.A., CAMMESA) in charge of the coordination of the dispatch operations, the establishment of wholesale prices and the management of the economic transactions of the Interconnected System [29]. The supervision and regulation in general of the Electric Energy Industry remains in hands of the National Regulatory Entity of Electricity (Ente Nacional Regulador de Electricidad, ENRE).

The Argentine Interconnected System supplies more than 36 million people with an annual demand of more than 73 TWh [12].

There is not an explicit Ancillary Services Market, but the provision of these services is considered in the current regulation. In conformity with the functions that they were previously mentioned, CAMMESA is the System Operator.

i) Voltage Control

Voltage Control and Reactive Power supply are a joint responsibility of all the agents of the Wholesale Electricity Market (Mercado Eléctrico Mayorista, MEM). In the case of the generators, it is required an instantaneous response and a permanent supply of up to 90% of the reactivate capacity, or transitorily of 100% of this capacity for 20 minutes, every 40 minutes [14].

The transmission companies must keep the voltage within the ranges established as normal conditions for the system, that is to say, $\pm 3\%$ for 500 kV and $\pm 5\%$ for 220 and 132 kV [13]. Likewise, generators, distributors and large consumers must monitor their PF.

The main costs associated to this service correspond to the over costs due to new energy dispatches and fines due to commitments violations by MEM members. The transactions are carried out through fixed monthly charges and the payments are determined based on the reactive power demand of distribution companies and large consumers [13].

ii) Frequency Regulation

Regulation establishes that under normal operation conditions the system's frequency must be kept between 49,8 and 50,2 Hz [16]. Primary Frequency Regulation is a mandatory service for all the system generators, in

accordance with the optimal requirement for primary frequency regulation (Requerimiento Optimo para Regulación Primaria, ROR) of the dispatch area where is located the generator. Generators receive no compensation for this service. It is required a response period of up to 30 seconds for thermal generators and of up to 60 seconds for hydraulic generators; and the capability to maintain the service for minutes [13].

If a generator is not able to provide the service that has already compromise, it must obtain that other generation unit to do it for him; in this case, the first one cancels the amount at the energy spot price of the market. Equally, generators are compensated when they realize a reserve contribution bigger than the one that they are requests ROR [13].

Secondary Frequency Regulation is a service under a voluntary provision. The regulation does not specify a minimal period of response, but mentions that the response period has to be around several minutes. Likewise, it does not mention for how long the generators must keep the provision of the service. It does require a minimal gradient of 30MW/min [13].

The main costs associated with the provision of this service are generation costs. The generators provide the service are selected from a priority list, hydraulic generators receive a payment equal to the energy price they offer, thermal suppliers receive a payment that corresponds to a maximum percentage of this price. Consumers pay a monthly fee calculated according to the hourly costs of the service, approximately this is US\$2,3/MW.

iii) System Restoration by means of Blackstart Capability

The procedures referred to System Restoration described in Argentine regulation have as intention the arrangement of the operators' action to favor the recovery of the 500 kV transmission system [15], nevertheless, there are not specific capability requirements, nor times of response, neither management mechanisms nor tariffs for this service.

In the Technical Procedures, each of the operators details the actions to follow after the system collapses totally or partially.

E. Australia

In this country, deregulation of the Electrical System began in 1998. As a part of this process was born the National Electricity Market (NEM), in order to increase competition in every stage of production and distribution of electric energy.

Nowadays, NEM supplies more than 7.7 million clients and trades more than US\$ 6.6 trillions in energy a

year. The National Electricity Market Management Company Limited (NEMMCO) is the System Operator and the Ancillary Services Market administrator [32].

Initially, these services were traded through long term bilateral contracts between NEMMCO and the services' suppliers, nevertheless, since 2001 Frequency Control Ancillary Services are traded in competitively spot markets [36].

There are considered payments for availability, enabling, use and compensation; these payments are carried out depending on the type of service. Likewise, according to the type of service, the payments are recovered from customers only or from customers and generators on a 50/50 basis [36].

i) Voltage Control

The energy code of this country demands to keep the PF between 0,9 inductive and 0,93 capacitive. Optionally, generators can produce and absorb reactivate power or operate the generation unit as a synchronous condenser [34]. Is required an instantaneous response period and is not specified the period by which the service should be supplied. The needed amount is calculated on the basis of reactive power demand and energy consumption.

The service provision is managed through annual bilateral contracts, the suppliers receive payments for availability, enabling and compensation, and the last one is proposed to pay for the opportunity costs [36]. The main costs associated with the service correspond to investment and operation. This service is paid only by the customers, who pay about US\$0,2/MWh [33].

ii) Frequency Regulation

Is required that the system's frequency varies only in the range of $50 \pm 0,1$ Hz. The System Operator can request additional amounts of Primary Frequency Regulation, up or down. It is required a response period of 6 or 60 seconds and the service should be supplied during 90 seconds [36]. The necessary amounts of the service are calculated by NEMMCO according to the proper operational procedure [35].

Generators with AGC are in charge of the service provision which is managed through annual bilateral contracts. The suppliers get payments for enabling and compensation. Customers and generators pay for this service on a 50/50 basis, payment is approximately US\$0,02/MWh [33].

Secondary Frequency Regulation is a service is provided by generators, load shedding or rapid generation. It is required in a period of 5 minutes and is not specified the period by which the service should be supplied [36]. The necessary amount of the service is

calculated according to the corresponding operational procedure [35].

The provision of the service is managed through annual bilateral contracts. Payments are carried out for enabling and compensation. Customers and generators pay for this service on a 50/50 basis. Tariff is approximately US\$0,03/MWh [33].

iii) System Restoration by means of Blackstart Capability

This service separates in two categories, fast service and general service [37]. For the first one the units are required to begin to re-energize the grid within an hour after the System fails, and to deliver the contracted level of generation, achieving a significant re-energization of the grid and the restart of several large units within two hours. In 8 hours it is required from them the recovery of at least 90% of the energy demand on the System. For the second one the units are required to begin to re-energize the grid within five hours after the System fails, and to deliver to the contracted level of generation, achieving a significant re-energization of the grid and the restart of at least one large unit within six hours. In 12 hours it is required from them the recovery of at least 90% of the Systems' energy demand.

This service is managed through annual bilateral contracts on each zone of System. The service is paid on the basis of availability and it supposed to be always available [36]. The service is paid by customers and generators on a 50/50 basis. Tariff is approximately US\$0,024/MWh [33].

F. Spain

In this country the Electrical Sector Law introduced the concept of Ancillary Services in 1997; and from 1998, with the birth of the Wholesale Electricity Market, began the provision of these services in order to coordinate in real time the energy supply to the market. Ancillary Services are considered to be separated products, with a remuneration based on the marginal price of the service [50].

The Spanish Electrical System supplies more than 40 million people, with an annual demand near to 200 TWh [50]. Spain Electrical Grid operates on the transmission grid and also acts as System Operator, whereas the Spanish Electricity Market Operation Company has the Market Operator function.

The Market Operator administers the Daily Market and the Inter-Daily Market of Energy, whereas the System Operator administers the Ancillary Services Market. Physical and financial bilateral contracts are used for management.

i) Voltage Control

This service is mandatory for generation units with capacities over 30 MW, they are required to keep the PF inside the range 0,989 inductive and capacitive, it is required an instantaneous response period and is not specified the permanence period. All the generators of the System must declare their maximum band to deliver and absorb reactive power for their different levels of active power generation. The System Operator establishes the minimal requirements for every generator, which can freely make offers over this value [50].

The main costs associated with the service are investment, operation and opportunity costs [4]. The transaction mechanism corresponds to annual bilateral contracts. Remuneration is realized on the basis of the availability and the correct functioning. Generators and synchronous condensers are remunerated in base to four concepts of service: for their availability to generate reactive power, for their availability to absorb reactive power, for the reactive energy generated and for the reactive energy absorbed. The delivery capacity is valued to the double of the absorption capacity [50].

Voltage control is also requested from transmission companies, distributors and customers with consumption over 15 MW [50].

ii) Frequency Regulation

Primary Frequency Regulation is a mandatory and free service. The service mandates an amount of energy equal to 1,5% of the nominal power. It is required a time of response of 15 seconds when frequency deviations are lower than 100 mHz., and linearly between 15 and 30 seconds for deviations between 100 and 200 mHz. The service provision must be maintained during all the period it is needed. The regulators' sensibility must be less than ± 10 mHz. To monitor the service, the System Operator is authorized to carry out inspections [50].

The Secondary Frequency Regulation service only can be offered by generators authorized by the System Operator. The needed amounts are calculated using ACE; and it is required a time of response of 10 minutes [3].

The main costs associated with the provision of this service correspond to investment, operation and opportunity costs. Generators place their bids with a day in advance for the reserve to move up and down, and the price for the regulating range [50]. The consumers pay for capacity and operation, the price range is about US\$15/MW and the energy price is approximately US\$23/MWh [30].

iii) System Restoration by means of Blackstart Capability

The implementation of the Blackstart Capability as Ancillary Service is still being studied.

The System Operator designates year after year the generators that will provide this service. The needed amount of the service is calculated according to contingency plans for the different zones of the country. There are no payments for this service.

5. Comparative Analysis

This section synthesizes the information presented in this document in order to facilitate the comprehension of the reader; the following tables show a comparison of the characteristics of previously analyzed Ancillary Services.

Table 1. Technical Aspects of Voltage Control Service

Technical Aspect	England	NORDEL	California, USA	Argentine	Australia	Spain
Response Period	Instantaneous	5 seconds	1 minute	Instantaneous	Instantaneous	Instantaneous
Permanence Period	Not specified	Not specified	Not limited	Permanente	Not specified	Not specified
Provider	Generators with capacities over 30 MW	All generators	Generation, transmission and distribution companies	All market participants	Generators and synchronous condensers	All generators
Monitoring	Voltage range must be kept between $V_{nom} \pm 10\%$ for 400,275 and 132 kV	No monitoring	Transmission lanes must operate according to the limits established by the System Operator	Voltage range must be kept between $V_{nom} \pm 3\%$ for 500 kV and $V_{nom} \pm 5\%$ for 220 and 132 kV	Permanent monitoring to generators and reactive plants	Generators must declare their maximum capacity of absorption and generation of reactive power
Necessary Amount	Based in historical levels, assigned in MVAR for every hour	The necessary amount to maintain voltages and system stability	Determined by the System Operator according to voltage and reactive power levels	Permanently, up to 90% of reactive capacity. And transitorily 100% for 20 minutes, every 40 minutes	According to reactive power demand and energy consumption	The necessary amount to maintain voltages between the range
Obligation	Obligatory to keep the PF between 0,85 capacitive and 0,95 inductive	Obligatory to keep the PF according to: $-0.2 < \text{tg } \theta < 0.4$	Obligatory to sep the PF between 0,9 capacitive and 0,95 inductive	Voltage Control in transmission. PF control in generators and large customers	Obligatory to keep the PF between 0,9 capacitive and 0,93 inductive	Obligatory

Analyzing the technical aspects of this service in the studied countries, the first thing that stands out is the great similarity of these requirements. The local character of this service influences highly the founded similarities.

This characteristic also makes that the requirements for Voltage Control apply, in some cases, not only to

generators, who provide most of the Ancillary Services in the Electrical Systems, but besides to other agents of the Electric Energy Market. The obligatory nature of this service is common in all the studied systems, emphasizing the operation of the Power Factor as critical variable.

Table 2. Economic Aspects of Voltage Control Service

Economic Aspect	England	NORDEL	California, USA	Argentine	Australia	Spain
Main Costs	Capacity and operation	Very low, service provided by hydraulic generators	Operation, maintenance and minor useful life	Diverse, over costs, fines, etc.	Investments and operation	Investments, operation and opportunity
Transaction Mechanism	Basic payment for capacity plus half-yearly auctions	Annual contracts with fixed price	Annual bilateral contracts	Fixed monthly charges	Annual bilateral contracts	Annual bilateral contracts
Payment to providers	Capacity and operation	For operation, only its for provision out of the obligatory limit	According to capacity and operation, only for its provision out of the requested PF	According to declarations of generators and transmission operators	Availability, enabling and compensation	According to absorption/generation band and time of response
Customers' payments	Through an uplift	Included on the transmission tariff	According to CAISO projected demand	According to declared reactive demand	Payments by final customers and Pool's customers according to their energy consumption	
Price	Capacity, between US\$0 and US\$0,58/MVAr/h. Operation, US\$1,31/MVArh	US\$2,7/MVArh			US\$0,2/MWh	

As for the economic aspects, the most important similarities are in the transaction mechanism, being common the use of bilateral contracts to assure the provision of the service; and in the payments, generally separated in two components, capacity and operation.

As for the costs, stands out the low consideration of opportunity costs in the analyzed markets. The reason that

justifies this fact is that opportunity costs of are often small in comparison with other costs during the normal operation of Electrical Systems and they only have high influence in episodes of very high demand, where the generators are producing closely to their limit and must reduce active power production to be able to deliver reactive power.

Table 3. Technical Aspects of Primary Frequency Regulation Service

Technical Aspect	England	NORDEL	California, USA	Argentine	Australia	Spain
Response Period	10 seconds	30 seconds	Instantaneous	30 seconds for thermal generators and 60 for hydraulic generators	Between 6 and 60 seconds	Between 15 and 30 seconds
Permanence Period	20 seconds	Not limited	Not limited	Minutes	90 seconds	Not limited
Provider	Generators and large customers with load shedding	Generators	Generators	All generators	Generators with AGC	All generators
Monitoring	Continuous, frequency must be always between 49.5 and 50.5 Hz	No monitoring, but frequency must be between 49.5 and 50.5 Hz	Through Area Control Error (ACE)	Continuous, frequency must be between 49.8 and 50.2 Hz	Frequency monitoring. It is allowed a range of 50 ± 0.1 Hz	System Operator inspections
Necessary Amount	Droop between 3 and 5%, sensibility to frequency changes smaller than ± 15 mHz	Droop between 2 and 5%	According to the System's demand, between 5 and 12% of demand, up and down	Calculated according to Optimal Requirement of Primary Regulation procedure	Determined by NEMMCO according to Operational Procedures	It is requested an amount equal to 1.5% of nominal power. Sensibility to frequency changes smaller than ± 10 mHz
Obligation	Obligatory for generators with capacities over 200 MW	Obligatory for all generators	Optional	Obligatory to provide or subcontract the service	Minimum obligatory, optional paid	Obligatory to provide or subcontract the service

Besides the similarities in the requirements relative to the time of response, proper of this service given its characteristics, the most outstanding is given by the necessary amounts, generally indexed to a percentage of the system's demand.

Stands out the fact that this service is obligatory in all the Electrical Systems studied except for California, system with minimal frequency variations.

Table 4. Economic Aspects of Primary Frequency Regulation Service

Economic Aspect	England	NORDEL	California, USA	Argentine	Australia	Spain
Main Costs	Low costs, difficult to determine	Low costs, service provided by hydraulic generators	Capital, fuel, minor useful life of equipments, maintenance and operators	Generation costs, fuel, etc.	Capital and opportunity	Is not applied
Transaction Mechanism	Annual bilateral contracts	Annual contracts	Competitive auctions	Self-provision or contracting	Bilateral contracts	Is not applied
Payment to providers	For capacity, operation (spot price) and compensation	Capacity and operation, according to their contribution	Capacity and operation (spot price)	Between generators, for extra-provision (spot price)	Enabling and compensation	Not rewarded
Customers' payments	Through an uplift	Through the transmission tariff	According to projected demand	Through energy provision payment	According to consume, with generators on a 50/50 basis	Not rewarded
Price	US\$3,9/MWh	According to the generator	For capacity, up: US\$16/MW, and down: US\$20/MW	Not available	According to consume. US\$0,02/MWh	Not rewarded

Within the similarities found in the economic aspects of this service stands out the use of the bilateral contracts as transaction mechanism and the incorporation of the payment on the consumers' transmission tariff.

Another prominent aspect corresponds to the price of the service, with a considerable payment in spite of being obligatory in almost all the studied systems. The importance of this service to assure a good supply quality justifies this fact.

Table 5. Technical Aspects of Secondary Frequency Regulation Service

Technical Aspect	England	NORDEL	California, USA	Argentine	Australia	Spain
Response Period	30 seconds	15 minutes	10 minutes	Minutes	5 minutes	10 minutes
Permanence Period	30 minutes	4 hours	2 hours	Not specified	Not specified	Not specified
Provider	Generators with AGC and load shedding	Hydraulic generators and load shedding	Generators	Only generators authorized by the System Operator	Governors, load shedding and rapid generation	Only generators authorized by the System Operator
Monitoring	Daily monitoring	No monitoring	In charge of the System Operator	Fines is irregularities are detected by System Operator	Performance testing and monitoring	Obligation to provide what the System Operator requests
Necessary Amount	Annually determined by the System Operator	Aviability of all the generation capacity not assigned in the spot market. Each generator can provide up to 8% of their capacity.	According to [6]: More than 5% of hydraulic generation plus 7% of the other generation sources. Contingency and other criteria from System Operator	A minimum gradient of 30 MW/min is requested	Determined by NEMMCO according to Operational Procedures	Calculated with ACE, generators bid for reserve, up and down, and price
Obligation	Optional	Optional	Optional	Optional	Optional	Optional

Basically, this service is equal to the service of Primary Regulation, but they defer in the times of response and provision that are demanded.

Unlike the previous service, the provision of Secondary Frequency Regulation is optional in all the Electrical Systems analyzed. Stands out the great variety of suppliers for this service.

Table 6. Economic Aspects of Secondary Frequency Regulation Service

Economic Aspect	England	NORDEL	California, USA	Argentine	Australia	Spain
Main Costs	Low costs, difficult to determine	Low costs, service provided by hydraulic generators	Opportunity costs	In thermal units, variable generation costs	Capital and opportunity	Investment, opportunity, operation and maintenance
Transaction Mechanism	Annual bilateral contracts and competitive auctions	Competitive offers	Competitive auctions	According to priority list	Annual bilateral contracts	Competitive offers
Payment to providers	Capacity, operation (spot price) and compensation.	Only operation	Capacity payment and operation payment for real-time dispatch	Operation payment (\$/MWh) as a fraction of spot price	Enabling and compensation	For capacity (\$/MW) and operation (\$/MWh)
Customers' payments	Through an uplift	Through the transmission tariff	According to projected demand	Monthly payment from all customers, included in the energy payment	According to consume, with generators on a 50/50 basis	Payment for band and for energy
Price	US\$4,3/MWh	US\$12/MWh	For capacity: US\$2,3/MW	US\$2,3/MW	According to consume. US\$0,03/MWh	For band: US\$15/MW. For energy: US\$23/MWh

As in the previous service, stands out the incorporation of the service payment in the customers' transmission tariff. As for the transaction mechanism, the

preferences are orientated to the use of auctions or competitive offers.

Table 7. Technical Aspects of System Restoration by means of Blackstart Capability Service

Technical Aspect	England	NORDEL (not considered AS)	California, USA	Argentine	Australia	Spain
Response Period	2 hours	Not specified	10 minutes	According to the provider	According to the type of service	Not specified
Permanence Period	Between 1 and 5 days	Not specified	12 hours	According to the provider	According to the type of service	Not specified
Provider	Generators with capacities over 200 MW	All generators	Only generators with blackstart capability	All generators	Several units with blackstart capability	Only generators with blackstart capability
Monitoring	Generators must operate between 90 and 95% their capacity. Frequency must be kept over 47 Hz.	All generators must have blackstart equipment	Generators must keep the provision of the service until the System Operator says	Not specified	Monitoring and control by the System Operator	System Operator designs providers
Necessary Amount	Determined by the System Operator. Providers are selected to create a grid	Is not applied	Determined by the System Operator, according to contingency data	Not available	Responsibility of the System Operator	System Operators creates reposition plans by zones
Obligation	Optional	Obligatory	Optional	Obligatory	Optional	Obligatory for designated units

Unlike other studied services, the Blackstart Capability is in development stage as Ancillary Service in countries as Argentina and Spain, and only partial information of the service can be found.

In Nordic Countries, all the generators of the Electrical System are forced to have blackstart

equipments, for what this one is not considered Ancillary Service.

The similarities found in the studied systems include the method used for the System restoration, creating “islands” inside the system in which the service is gradually restored, these “islands” are joint later, to achieve the total restoration of the system.

Table 8. Economic Aspects of System Restoration by means of Blackstart Capability Service

Economic Aspect	England	NORDEL (not considered AS)	California, USA	Argentine	Australia	Spain
Main Costs	Capacity, operation and maintenance. Feasibility studies	Is not applied	Investment, operation and fuel	Not specified	Capital and investment	No se aplica
Transaction Mechanism	Annual bilateral contracts	None	Annual bilateral contracts	Not specified	Annual bilateral contracts in different zones	Not rewarded
Payment to providers	Payments for equipment, availability and operation	Not rewarded	Not specified	Not specified	Availability payment (\$/MW)	Not rewarded
Customers' payments	Through an uplift	Not rewarded	According to projected demand	Not specified	Customers and generators pay on a 50/50 basis	Not rewarded
Price	Not specified	Not rewarded	Not specified	Not specified	US\$0,024/MWh	Not rewarded

Analyzing the available information, important similarities are observed in almost all the studied aspects. Bilateral contracts are the only transaction mechanism used, considered costs are repeated on the analyzed markets, besides being difficult to assign only to this service. The payment to the suppliers incorporates different variables, but it is common the payment for availability of the service.

The only differences are observed in the consumers' payments, emphasizing the case of Australia in which the assisted consumers and generators are responsible for paying the suppliers.

As for the prices, there is no possible analysis, since there is only one available information that corresponds to Australia.

6. Conclusions

From the global analysis of the different Electrical Systems stands out in all of them the presence of an organization dedicated to the operation and coordination of the Ancillary Services Market, function that dwelled into the figure of the System Operator. The most valuable services at these systems correspond to Primary Frequency Regulation and the Voltage Control, both obligatory on all the studied Markets, except for Primary Regulation in California. The provision of the other services, without being obligatory, is always present in the analyzed Electrical Systems.

The time of response demanded from the suppliers is directly related to the price that the consumers pay for the service; the faster the generators' response must be, the higher will the price charged to the customers be.

The mechanism used to manage the provision of the services use to be bilateral contracts or competitive offers, both with strong presence in the studied Electrical Systems.

The importance given to the costs associated with each service changes depending on the Electrical System that is considered, nevertheless similarities exist. Voltage Control costs are associated mainly to investment, operation, maintenance and opportunity. The most important costs associated to Frequency Regulation correspond to investments, operation, minor efficiency and opportunity costs. As for the service of System Restoration by means of Blackstart Capability, the main costs are associated with the investment in equipments, the operation and the maintenance of them.

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