CECRE: Supervision and Control of Spanish Renewable Energies in the Last 15 years

Gema García Platero, Mayte García Casado, Marta Pérez García, Paula Junco Madero, and David Alvira Baeza

***Abstract*—From its commissioning in 2006 to the present, the Spanish Control Centre for Renewable Energies (CECRE) has been a worldwide pioneer and reference centre in the integration of renewable energies in the electrical system. In the last 15 years, CECRE has allowed a high penetration of renewable energies in Spanish electrical system by means of the supervision and control of renewable facilities, while ensuring the power supply security. This paper defines the bases of renewable energy operation in CECRE and introduces forecasting systems for renewable energies. Furthermore, this paper describes the participation of renewable energies in balancing services and congestion management. Finally, new challenges for Spanish transmission system operator (TSO) are presented for the integration of renewable energies along with the energy transition and decarbonization.**

***Index Terms*—Balancing services, controllability, forecasting system, observability, Control Centre for Renewable Energies (CECRE), renewable energy, photovoltaic (PV), wind.**

I. Introduction

During the last years, renewable energy sources (RESs) have become significant contributors to the generation mix of Spanish peninsular electrical system. As shown in Fig. 1, RES accounted for around 36% and 58% of the total installed capacity in 2006 and 2021, respectively.

As shown in Fig. 2, wind has been one of the major sources of electrical energy in the Spanish peninsular power system for the last decade. In 2013, wind generation was the one with the highest energy produced, and since then, it has consistently provided around 20% of the electrical energy generated. In 2021, wind generation reached 24% of the share, being again the technology with higher contribution. Besides, the production of RESs including hydro, wind, photovoltaic (PV), concentrated solar power (CSP), and biomass accounted for around 48% of the total energy generated in 2021.

One of the requisites to be able to have this achievement

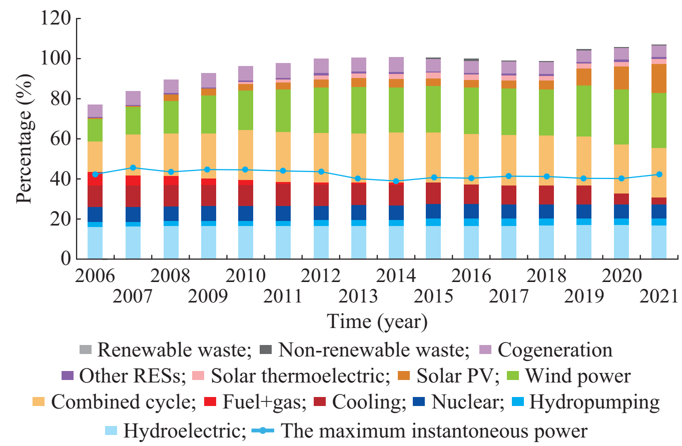

Fig. 1. Evolution of installed capacity in Spanish electrical system.

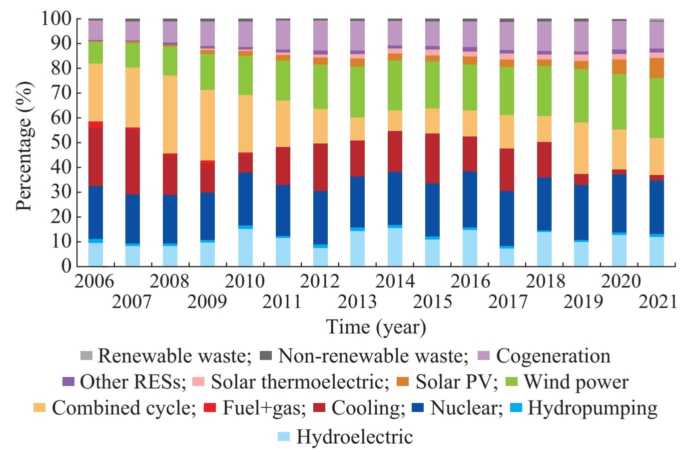

Fig. 2. Evolution of demand coverage with RES in Spanish electrical system.

in the Spanish peninsular power system is the development made in monitoring and control. For this purpose, the specific Control Centre for Renewable Energies (CECRE) has developed a crucial task for the integration of RES in Spanish electrical system for the last 15 years, without jeopardizing the security of the system. In CECRE, it is possible to monitor the production of almost 99% of wind generation facilities, 87% of PV plants, and 100% of CSP generation facilities. In addition, the CECRE operator can issue real-time limits for the maximum production of each plant or each

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group of plants that share a point of common coupling (PCC) with a power capacity greater than 5 MW connected to the transmission or distribution network. From the moment the limitations are sent by CECRE, generation plants must follow such limits in real time at the latest 15 min.

However, monitoring and control are just one area of development to achieve an even larger share of RES in the generation mix. Significant regulatory changes were introduced in 2014 to adapt the regulatory framework to the new reality, removing the differences between RESs and conventional generation as much as possible. The two most significant changes are the possibility of participation of RES in the balancing markets such as the tertiary reserve market, and the introduction of market-based downward redispatching for solving congestions on either the transmission or the distribution network. The following sections will focus the description of CECRE, the implications of mentioned regulatory advancements, and new development for future integration of RES in Spanish electrical system.

II. Brief Description of CECRE

The supervision and control of RES was achieved by the Spanish transmission operator (TSO) through the commissioning of the first specific CECRE in the world, in June 2006, as wind generation started to become a relevant technology in the Spanish electrical system. As shown in Appendix A, CECRE is composed of an operation desk, where an operator continuously receives real-time telemetry and can issue real-time limits for the maximum production of RES, waste generator, and combined heat and power (CHP) facilities connected to the transmission or distribution network.

As required by the current regulation established in the Royal Decree 413/2014 [1], all single production facilities or clusters that have a total installed capacity greater than 1 MW and share the same connection point send real-time telemetry of the active power produced every 12 s. The production facilities or clusters with a total installed capacity greater than 5 MW send additional tele-measurements of the reactive power and voltage at the connection point. Additionally, each wind or PV plant or cluster with a total installed capacity greater than 5 MW receives the active power setpoints from the CECRE, which must be followed within 15 min, as shown in Fig. 3, where CECRE is managed by the system operator, i.e., REE; and RESCC is the intermediarie between the CECRE and the facilities.

This real-time measurement is collected from the plants by the RESCC and it is channelled via the International Conformity Certifcation Programm (ICCP) links that connect these control centres to the CECRE.

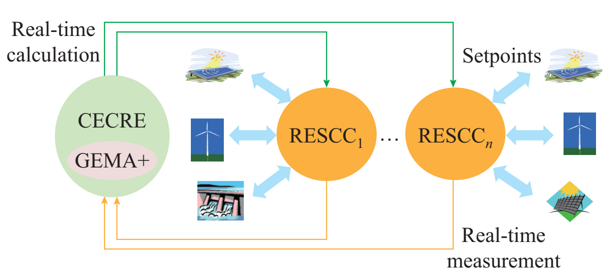

Fig. 3. Functional scheme of CECRE and RESCC.

To minimize the number of intermediate points in contact with the TSO, the RESCC acts as the only real-time speaker with the TSO, i.e., RESCCs are intermediaries between the CECRE and the facilities. Each RES facility can freely choose the RESCC of its convenience, regardless of its technology or its connection point to the network.

The generation control is managed by CECRE limitations, which are established in an individual way for each facility by the setpoints through its RESCC.

Therefore, on one hand, RESCCs collect real-time information from RES facilities and send them to CECRE (supervision), and on the other hand, RESCCs collect the setpoints established by CECRE and send them to facilities (control).

Such scheme assures that the system is continuously under the TSO control to overcome unexpected events related to congestion management or balancing within 15 min, such as by returning the system to an $N-1$ secure state after the trip of an element. Thus, it allows a high penetration of dispersed renewable facilities, while maintaining the same high standards of power supply security.

This real-time control and supervision scheme leads to the improved security and effectiveness in system operation and allows the substitution of permanent or long-lasting production hypothesis and preventive criteria due to generation uncertainties with real-time production control. Therefore, it allows higher energy productions with the same installed capacity and a more efficient real-time operation of the plants.

The main tool used by the CECRE operator to carry out these tasks is named GEMA+, which is the Spanish acronym for the maximum admissible wind generation accommodated by the power system. Nowadays, GEMA+ accesses the real-time information received in CECRE for all RES technologies, not only wind facilities, and uses it to automatically determine whether the present generation scenario is admissible for the system based on the following criteria.

1) The fault ride-through capabilities of generation connected to the network through power electronics will not cause an inadmissible simultaneous disconnection of generation.

2) Congestions must be solved by reducing renewable energy generation, either in base case or $N-1$ secure state.

3) The system balance can be achieved while maintaining an appropriate level of downward reserves.

GEMA+ has been designed considering that the operator must be able to create, manage, and activate plants rapidly, as it is necessary to return the system from some situations to a balanced or $N-1$ secure state as soon as possible. It must be noticed that there are more than 1000 wind farms and more than 1200 PV facilities installed in the Spanish peninsular electrical system, so they must be managed in a way as automatic as possible. The reliability of GEMA+ is a crucial issue as the inablity to deliver limitations to the RESCCs could result in a significant decrease of the power supply security [2].

III. Spanish TSO Forecasting Systems for Renewable Energy

Spanish TSO has been working on the development and improvement of its wind and PV forecasting models for more than 20 years. The first version of SIPREOLICO's wind power forecasting system came up in 1990. Years later, in 2011, SIPRESOLAR's forecasting system for PV and CSP was released and set up in operation. Since the first release of these forecasting models, the Spanish TSO has been working on reducing the forecasting error and thereby achieving the integration of as much renewable energy as possible [3].

As shown in Fig. 4, both systems respond to a combination scheme of different generation forecasts, one of which is generated by the own model of Spanish TSO and the rest from external suppliers. In the case of wind power, this model is based on neural networks, while in the case of solar energy, the methodology based on neural networks was replaced by a new analogous model in 2020. In both cases, the data of weather prediction and historical production are used to train and adjust the models. Spanish TSO makes a great effort to improve onsite forecasts every year.

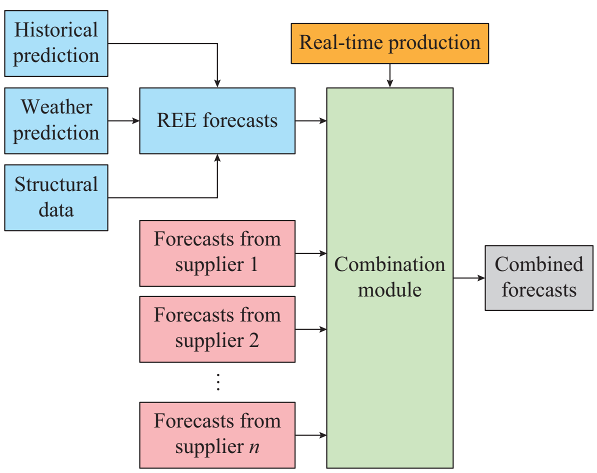

Fig. 4. General scheme of forecasting methodology.

A. Input data

Apart from the models, there are other factors such as the input data that help the continuous improvement. The input data can be divided into the following four categories.

1) Real-time production: currently, Spanish TSO receives real-time measurements from 100% of CSP plants, 95% of wind farms, and 82% of PV plants, so only a small part should be estimated. It allows the Spanish TSO to distinguish between the generation and demand by receiving the real-time measurements of all the generation facilities, which avoids the demand forecasting errors as well. The models receive the instantaneous production values every 15 min. The improvement of these data in recent years has also led to an improvement in the forecasting models.

2) Structural information: one of the essential data used in Spanish TSO forecasting models is structural information. Over the years, this information has been refined and compared to obtain the best forecasting results (location, installed capacity, grid connection point, etc.).

3) Numerical weather prediction (NWP): different weather forecasting models have been evaluated in the last few years, and so far the European Centre for Mid-term Forecast (ECMWF) model has obtained the best results. Spanish TSO-forecasting models take advantage of the continuous improvements of the ECMWF model to achieve more accurate forecasts. The current version offers a spatial resolution of 0.1° and a temporal resolution of 3 hours with 240-hour range. Spanish TSO receives new weather prediction every 12 hours.

4) Power forecasts from external suppliers: another fundamental aspect of SIPREOLICO and SIPRESOLAR schema is to include the forecasts from external suppliers in order to obtain the optimal combined forecasts. It is essential to continuously supervise and search for new suppliers, who can contribute to improve the quality of Spanish TSO forecasting system.

B. Performance Quality of Spanish TSO Forecasting Systems

The forecasting errors of Spanish TSO forecasting systems are shown in Figs. 5-7, which illustrate the continuous improvement from year to year. Spanish TSO continues working to further enhance its forecasts.

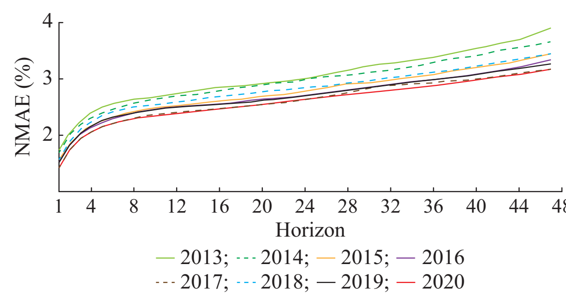

Fig. 5. NMAE of Spanish TSO forecasting system for wind power.

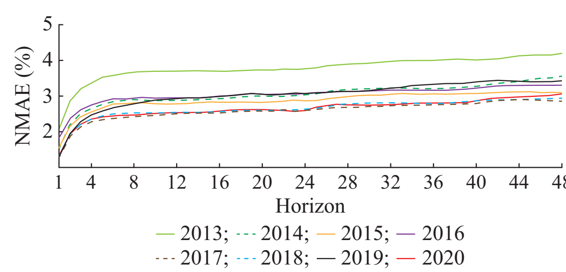

Fig. 6. NMAE of Spanish TSO forecasting system for PV plants.

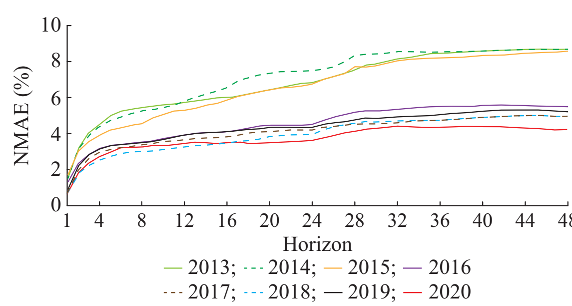

Fig. 7. NMAE of Spanish TSO forecasting system for CSP.

In Figs. 5-7, the normalized mean absolute error (NMAE) is used, which is defined as the difference between forecasting and real production divided by the installed power and it is expressed as a percentage. The decrease in the forecasting error is the result of a continuous searching for the improvement in both the forecasting algorithms and the quality of the input data.

IV. Participation of Renewable Energies in Spanish Balancing Services

The publication of the Royal Decree 413/2014 [1] regulates the rights and obligations for RES, CHP, and waste generators and introduces the possibility for variable renewable energies to participate in the optional and remunerated markets for balancing services, achieving a similar role as conventional generation in assuring the demand-generation equilibrium.

The markets for balancing services, in which RES, CHP, and waste generators can participate, are automatic frequency restoration reserve (aFRR), manual frequency restoration reserve (mFRR), and replacement reserve (RR). In these balancing markets, RES, CHP, and waste generators compete with conventional generation and the cheapest bids are assigned first.

The different balancing services currently considered in the Spanish electrical system are described below. The terminology used for each balancing service is the one reflected in the System Operation Guideline (SO GL) [4], referring to a direct translation of the terminology used in the Spanish operation procedures.

1) Primary reserve

The primary reserve is the balancing service defined in the corresponding Spanish grid procedures P.O. 7.1: Primary reserve [5]. The participation in this service is mandatory and not remunerated, and its purpose is to maintain a balance between the generation and consumption within the synchronous area and to stabilize the electrical frequency system by means of the joint action of the suppliers of this service. In terms of the SO GL [4], it matches with the process of frequency containment reserves (FCR).

2) Secondary reserve and automatic generation control (AGC)

The secondary reserve is the balancing service defined in the corresponding Spanish grid procedures P.O. 7.2: Secondary reserve [6]. Its purpose is to automatically maintain the generation-demand balance, correct deviations with respect to the anticipated power exchange schedule of the 'Spain' Control Block, and the resolve system frequency deviations. Its temporary action horizon ranges from 30 s to 15 min. This service is provided by different groups of generators (called control zones) connected to an AGC system. These control zones, which are somewhat a balance perimeter, can be integrated by facilities that are able to modify their power output following the signals from a secondary reserve master regulator in an active way, or integrated by passive units that do not actively follow such signals. Active units react to the signals from the master regulator as well as to the own imbalance of the control zone. This service is optional and remunerated by means of market mechanisms via two concepts, i.e., availability (control band) and usage (energy). In terms of the SO GL [4], it matches with aFRR.

3) Tertiary reserve

The tertiary reserve is the balancing service defined in the corresponding Spanish grid procedures P.O. 7.3: Tertiary reserve [7]. Its purpose is to resolve the deviations between the generation and consumption and the restoration of the control band for secondary reserve. The control band for tertiary reserve is defined as the maximum power variation that a generation unit can perform within 15 min, and which can be maintained for at least 2 hours. In terms of the SO GL [4], it matches with the process of mFRR. Although this service is optional, the units that choose to participate are obliged to bid on their available reserve at any time.

4) RR or generation-demand imbalance market

The RR is the balancing service defined in the corresponding Spanish grid procedures P.O. 3.3: Deviation management service [8]. This service is optional and its purpose is to solve the generation-demand imbalances that could remain after closing each session of the intraday market until the starting hour of next session's programming period. It is managed through a European TSO-TSO balancing platform (TERRE project, Libra Platform), in which several TSOs participate and are remunerated by means of market mechanisms. In terms of the SO GL [4], it matches with the process of RR.

To participate in the markets for balancing services, i.e., aFRR, mFRR, and RR, the prequalification of the units by the TSO is needed.

A. Prequalification Processes for Balancing Services

The current prequalification protocols are included in the Spanish grid procedure P.O. 3.8 for the participation of the facilities in the processes and services managed by the TSO [9], which defines the requirements and tests that power plants have to fulfill to show their ability to provide balancing services.

These prequalification tests are a prerequisite to participate in the markets for these services, for all generators (both conventional and renewable generation) or transmission and distribution networks. In the same way, these protocols have been adapted to consider the characteristics of RES generation and allow for the prequalification of a single or a group of power plants.

The protocols define the tests that power plants have to pass to demonstrate that they comply with the technical requirements established in the corresponding Spanish grid procedures P.O. 7.2 [6], P.O. 7.3 [7], and P.O. 3.3. [8]. The tests focus on the capacity of the power plants to change the active power output with the required speed and the exchange of information with the TSO.

B. Prequalification Test for Secondary Reserve

Prequalification tests for aFRR verify the correct exchange of real-time signals with the master regulator of the TSO at the first stage. Afterwards, the constant upward and downward requirements are sent to the power plant so it shall change its power output as soon as possible until its nominal power or the technical minimum power is reached. The regulation limits and band availability are calculated with the real-time measurements collected during the test. The band availability is calculated considering that 95% of this band shall be modified in less than 300 s. An additional check is performed to verify that the delay between the moment the signal is sent and the moment the active power output changes is less than 1 min.

C. Prequalification Test for mFRR and RR

The prequalification test for mFRR and RR is a single test that serves both services, and it consists of upward and downward ramping tests and the check of the maximum and minimum available power variations in 15 or 30 min.

There are two options to pass the ramping tests, as shown in Fig. 8.

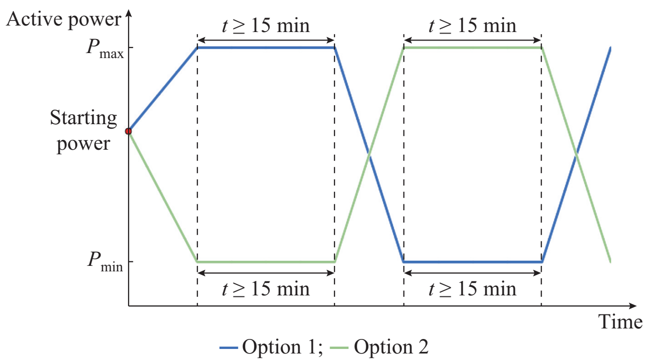

Fig. 8. Ramping tests for mFRR.

In the first option (option 1), the power plant starts with any power output between the technical minimum and maximum power. For RES generation, the technical maximum power is the maximum forecasting active power P_{max} according to the availability of its primary resource and the technical minimum power P_{min} is always considered as 0 MW. Then, the power plant has to ramp up to the technical maximum power and maintain at this value for at least 15 min. Next, it shall ramp down to the technical minimum power and maintain at this value again for at least 15 min. Finally, it shall ramp up again to the technical maximum power. In this way, a full upward ramp and a full downward ramp will be completed. All ramps shall be made as fast as possible for the power plant. The second option (option 2) to pass the ramping tests is the opposite, modifying the programming order of the power increase and decrease.

The prequalified power will be calculated with the slope of the ramps according to real-time measurements, and the maximum variation in 15 and 30 min will then be the prequalified power in mFRR and RR, respectively.

Figure 9 shows the real ramping tests by a group of wind generators. At the beginning of the test, the wind generators are working at their maximum available power. After that, they ramp down to zero and maintain at this value again for 15 min. Then, they ramp up to the maximum available power again. Figure 9 shows the high slope of the ramp that wind generator can follow.

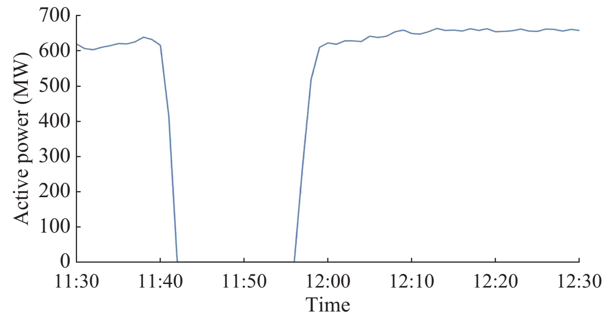

Fig. 9. Real ramping tests by a group of wind generators.

D. Participation of Current RES Generation in Balancing Services

The effective participation of RES generation in mFRR and RR markets has increased significantly during the last years. Currently, 16.4 GW of renewable generation is prequalified to participate in RR and aFRR balancing markets, approximately 95% of which is wind generation. Figures 10 and 11 show the contributions of different technologies to RR and aFRR in 2021, respectively.

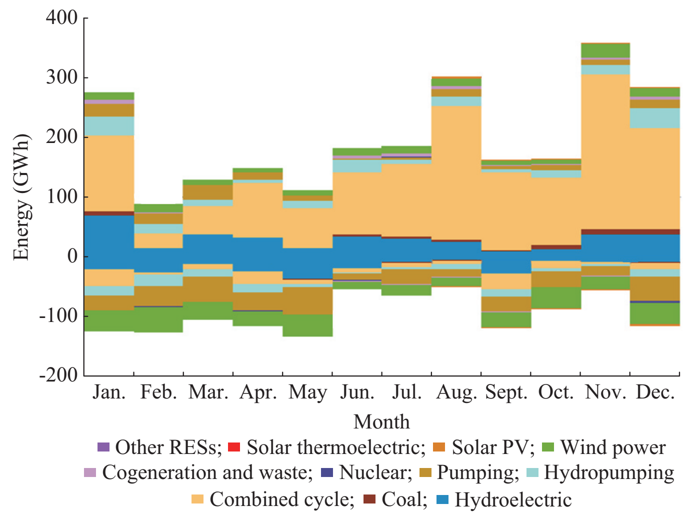

Fig. 10. Contribution of different technologies to RR in 2021.

In the case of secondary reserve, the effective participation of RES plants is still very low. There are 9.1 GW of wind power and 1.9 GW of PV power forming part of different balancing parameters, but only around 970 MW of wind generation and 1050 MW of PV power actively participate in aFRR.

V. Interaction Between Balancing Services and Congestion Management

The participation of all generators and pumping units in balancing services is organized through the programming units (PUs). The PU may consist of a large conventional generator or pumping unit (>100 MW) or one or a group of several smaller generators with the same primary source (hydro, wind, solar, etc.), each of which creates a physical unit (PhU) as shown in Fig. 12.

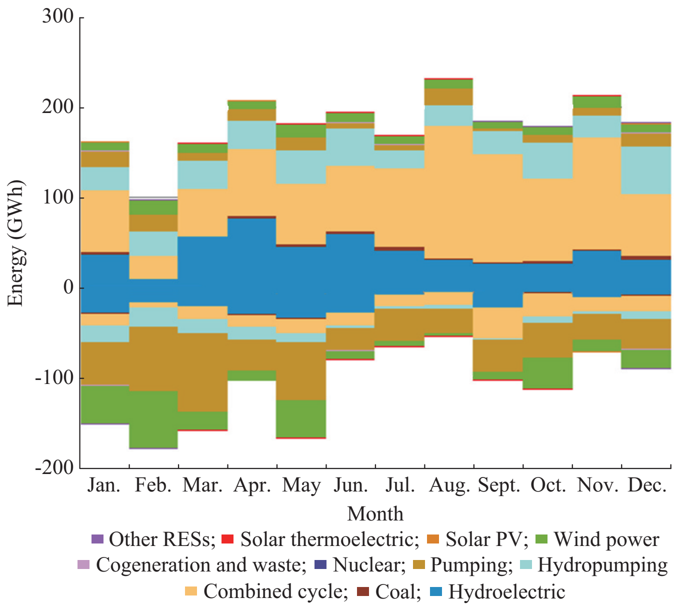

Fig. 11. Contribution of different technologies to aFRR in 2021.

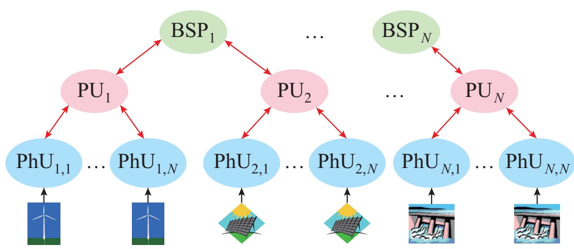

Fig. 12. Organization of programming and physical units.

A PU may include PhUs connected to different nodes and areas of the network, as well as units connected to the transmission or distribution network. A generator belongs to only one PU for all balancing services.

Each balance service provider (BSP) uses one or several PUs to participate in balancing services. BSPs submit balancing bids for their PUs in the markets, in which they have been prequalified and are allowed to participate, and the TSO acts as a single buyer in these markets, activating the submitted bids when necessary.

Bids in the balancing markets are managed through eSIOS, which is an information system developed by Spanish TSO to perform the management tasks of information and processes specifically related to the electricity market. eSIOS allows Spanish TSO to communicate with market subjects who come to Spanish electricity market with bids to buy or sell energy, to notify the acceptance or rejection of such bids in a transparent and confidential manner, and to publish the results of different markets and schedules.

After each notification for activation and before the physical activation of the reserves, BSPs must nominate how the new PU schedules are broken down between the PhUs that compose that schedule. This means that, before the activation, the TSO has locational information of each PhU schedule at any time. This locational information can be then used to perform real-time security analysis to check if the activation of the bids may cause congestions. PUs may be formed by PhUs that connect to both the transmission and the distribution networks.

If congestions are detected on the transmission network by TSO, all PhUs that can be used to solve the congestion are grouped into a bundle, and a total limitation to ensure the $N-1$ security is calculated for this bundle. This bundle may include units with or without participating in balancing services or units located in the transmission or distribution network. Then, GEMA+ calculates the required limitation to each PhU of this bundle according to the rules of sharing the limitation burden that are established by the operational procedures. If the limitation is lower than the PhU schedule, the PhU is redispatched by the difference between the original PhU schedule and the imposed limitation. For example, if the original PhU schedule is 20 MW and a limitation of 15 MW is settled, a redispatch of 5 MW will be established and the final PhU schedule will be 15 MW. The limitations are issued both to the control centre of PhU via the supervisory control and data acquisition (SCADA) system and to the BSP via eSIOS.

The rules of sharing the limitation of this bundle within the PhUs guarantee that the least cost option is chosen to solve the congestion. To calculate the cost of the limitation, the downward bids of congestion management are used, which are compulsory for all generation units.

As shown in Fig. 13, in case the congestion is detected on distribution network by a distribution system operator (DSO), the DSO identifies the PhUs that can solve this congestion and notifies the TSO which units form the bundle and the maximum possible production of the bundle. The TSO solves the congestion via the CECRE by limiting, and if necessary, redispatching the PhUs included in the bundle in the same way as if the congestion was located in the transmission network.

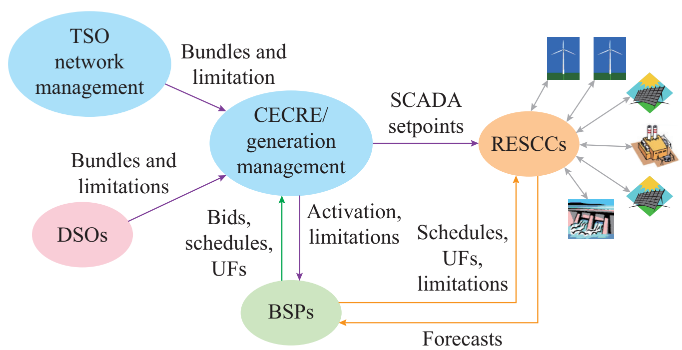

Fig. 13. Information exchange for participation in balancing services and congestion management.

This structure of programming units and physical units allows the possibility for aggregations to participate in the TSO balancing markets while conforming a real-time mechanism, through which both the TSO and the DSO are able to solve the congestions that can be solved by distributed generation as well.

VI. Participation of Spanish RES in Voltage Control Service

Apart from the participation in the balancing services, Spanish RES also participates in the voltage control service, as defined in the Spanish Royal Decree 413/2014 [1] and Spanish grid procedure P.O. 7.4: Voltage control [10]. On a mandatory basis, all RES generators shall have a power factor inside a yearly defined range, otherwise they will be penalized. The limit values are 0.98 both for capacitive and inductive ones. Additionally, those facilities over 5 MW shall follow the instructions of possible power factor range from the TSOs according to system requirements. Alternatively, on a voluntary basis, RES generators over 5 MW can decide to receive the voltage setpoints from the TSO for the voltage control of the substation in the transmission system, to which they are connected. None of the RES generators are participating in this voluntary modality, even though those who participate have dispatch priority over other generators under the same economic conditions for the congestion solving process.

VII. Challenges for Future

In the last 15 years, CECRE has successfully faced the challenge of integrating the renewable energy with a significant increase in the Spanish electrical system. Thanks to CECRE, the contribution of RES can be up to 75% of the total generation in Spanish electrical system. The integration of renewable generation, mostly wind and PV plants, means a strong boost to the energy transition and decarbonization process. The increase in the contribution of RES to the demand coverage in the Spanish electrical system leads to a decrease in the contribution of energy from fossil fuels. In this sense, it is noteworthy that the production of energy using the coal as fuel decreases. From 2015 to the present, CO_2 emissions associated with the national electricity generation have been reduced by more than a half, going from 77.6 million tCO_2e in 2015 to 36.1 million tCO_2e by 2020.

But this is not the end of the way. Spanish TSO continues working to achieve even a larger integration of renewable energies into the Spanish electrical system. For this aim, the Spanish TSO has launched the QUIJOTE project, whose objective is the development of a new application that can quickly solve any violation of the security criteria that may appear, by means of automatic operation instructions emitted in real time, including power reduction of generation facilities. In this way, the need for power limitation setpoints as preventive remedial action to solve network contingencies will be reduced.

In addition, the Spanish TSO is developing the VOLTAIREE project, whose objective is the creation of a new voltage control service in the Spanish electrical system, optimizing the current voltage control based on power factor instructions. With the implementation of this project, all facilities with a total installed capacity greater than 5 MW including renewable generation and demand connected to the transmission network receive real-time setpoints from the Spanish transmission or distribution network, to which the installation is connected. These setpoints will establish the minimum range to be complied with. There will be four different types of setpoints, depending on the type and commissioning time of the facility, i.e., ① voltage setpoint; ② reactive power production/absorption setpoint; ③ power factor setpoint; ④ constant power factor to maintain the current ranges.

Besides, if the available voltage control resources are not sufficient in the power system at a certain moment, new additional reactive capacity markets are planned, which will allow the participating subjects to offer their available reactive capacity in addition to the mandatory part.

To achieve the objectives set by the European Union (EU) for 2030, which is about reducing greenhouse gas (GHG) emissions by 23% compared with 1990, improving energy efficiency by 32.5%, and increasing the RES contribution up to 32% on the total final energy consumption, Spanish National Integrated Energy and Climate Plan 2021-2030 (PNIEC) [11] establishes a 74% contribution of RES facilities with respect to total electrical energy in Spain in 2030.

VIII. Conclusion

RES has reached high penetration levels into the Spanish electrical system, rising to 58% of the total power installed capacity in 2021 and reaching an RES contribution of 75% with respect to instantaneous energy production.

CECRE has been a key part for achieving such a significant contribution of RES in Spanish electrical system. Since its commissioning in 2006, CECRE has been a reference renewable energy control centre, with the aim of maximizing the integration of RES generation, without jeopardizing the security of the Spanish electrical system.

From CECRE, the real-time telemetry observability of all single production facilities or clusters with a total installed capacity greater than 1 MW and sharing the same connection point is managed. Additionally, plants or clusters with a total installed capacity larger than 5 MW receive active power setpoints from the CECRE, which they must comply with within 15 min.

Due to the significant increase of RES generation facilities in Spanish demand supply, it is necessary to have wind and solar forecasting tools that enable reliable system operation. Spanish TSO has developed its own solar and wind forecasting models and has achieved continuous improvement from year to year in the forecasting systems.

In order to achieve high levels of RES in the generation mix, the system operation activities and market mechanisms shall evolve to allow these generation sources to be securely and efficiently integrated into the power system. Two of these evolutions are the possibility for RESs to participate in balancing markets and congestion management processes as providers and the successful coordination of both through real-time tools regardless of whether the congestions are detected in the transmission or distribution network.

Spanish TSO continues working to achieve even a larger integration of renewable energies into the Spanish electrical system. For this aim, new projects are being developed such as QUIJOTE by means of automatic operational instructions emitted in real time, and the VOLTAIREE, whose objective is the implementation of a new improved voltage control service in Spanish electrical system.

APPENDIX A

Fig. A1. General view of CECRE.

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