Challenges for the integration of ocean energy in Ibero-American power systems

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I. INTRODUCTION

Offshore wind, floating solar PV, tidal, waves and even saline or thermal gradient are the technologies considered under the scope of ocean renewable energies. They are commonly referenced in the roadmaps [1] of many countries as part of the energy matrix. Apart from the intrinsic technological challenges of these generation technologies, their success in the electricity markets is conditioned by the possibilities to be integrate the marine generation power plants in the electric systems. Among others, the compliance of the electric grid codes must be fulfilled to ensure the stability of the electric grids.

The integration of ocean renewable energies is still not a problem since the penetration level of these energies is not so high. However, the objectives established in the energy roadmaps invite to analyse the expected effects of new power plants of this nature from the point of view of performance at the electric systems. In fact, some preliminary research works have already identified an increase in the number of frequency and voltage events in electric systems due to high penetration of ocean energies [2], so it is time to analyse the potential problems and this way facilitating the deployment of the ocean energies.

Many countries in Centre and South America have already included in their roadmaps the renewable ocean energies [3]. In fact, one of the main issues in these countries is the lack of robust electric grids or the condition of weak grids in coastal areas.

This paper aims at analysing the electric grid situation of the countries under study, considering how would behave after the integration of ocean renewable energies. countries. Although some other countries will be finally integrated in the last version of the paper, in a first round, information about the electric grid and the integration of renewables have been compiled from: Ecuador, Peru, Costa Rica, Argentina and Spain.

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II. GRID INTEGRATION ISSUES OF OCEAN ENERGY

This chapter describes the main problems in electrical grid when integrating ocean renewable energies and the main regulations and grid codes that ocean renewable energies facilities must comply.

The generation devices associated to ocean energies tend to be connected to distribution grids instead of transmission grids. For this reason, stability problems occur in the electrical grid [4] such as: frequency oscillations, undervoltage, overvoltage, voltage transients, harmonic distortion, power black-outs and power lines saturation due to temporal power increase. All these effects as well as the limited dispatchability associated to renewable energies produce stress on the electrical grid and other effects [5] like: reduction of efficiency, equipment malfunction or even disconnection, loss of information, overheating of conductors and electromagnetic interferences. These problems mainly depend on the size of the generation power plant and the characteristics of the point of common coupling (PCC). Fig. 1 summarizes the potential problems in the electrical grids when integrating ocean energies [6].

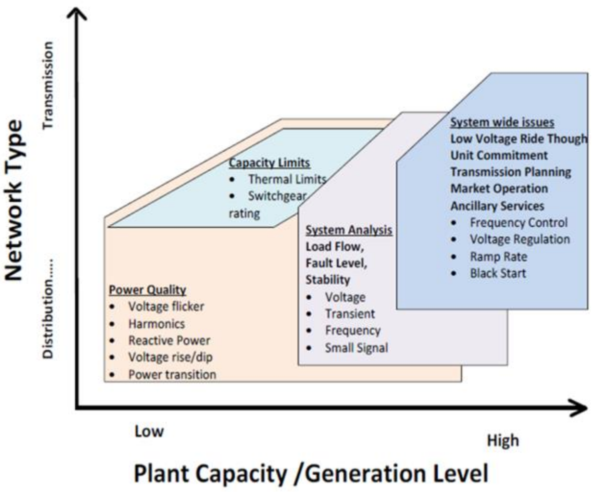

Fig. 1. Grid impact issues of marine energy systems [5].

In the case of the limited dispatchability the transmission systems operators (TSO) have determined that the resource intermittency and interactions with network control systems may increase the levels of voltage flicker for ocean energy devices [7] [5], it compromises voltage and frequency stability. In the case of the stress on the electrical grid, the impact of these variations depends on the grid strength at the PCC [7] [5]. Additionally, operational challenges may be introduced by the effect of harmonics and thermal overload. Furthermore, power electronics and submarine cables cause problems as well. Cables produce changes in the grid impedance and amplifying the harmonic emissions. In the case of high penetration effects, the small and medium scale ocean energy projects may cause impacts such faults, transient voltage and frequency stability oscillations and the high scale projects may cause impacts such low voltage ride through capability, transmission planning, planning, market operations, unit commitment and ancillary services [5].

Based on these potential problems in electrical grids, specific modifications and guidelines for ocean renewable energy have been included in the regulations and grid codes. Currently there are no common specific regulations or grid codes for all ocean renewable energies. This aspect is because ocean renewable energies such as wave energy, tidal energy or the saline gradient are at intermediate levels of technological maturity (TRL6-7). Only standards such as EQUINOR [8] [5] and in laboratory test environments have been applied to these installations.

TenneT [9] and National Grid [10] grid codes have a special focus on offshore wind.In the case of National Grid, the code considers in a general way “offshore power generating 216 units powered by intermittent sources [5]. The International Electrotechnical Commission (IEC) technical committee is currently working on power quality requirements for wave, tidal and other water current energy devices [11].

III. Analysis of the grid integration of ocean energy in Ibero-American regions

Some countries and particular regions of Ibero-America have been analysed to provide an overview of the difficulties of their power systems in terms of technical, political or social limitations to enhance the integration of oceanic renewable energies the electrical grids. The countries under analysis are: Ecuador, Peru, Costa Rica, Argentina, and Spain. Additional information from the Canary Islands in Spain has been compiled as an example of integration in isolated electric systems.

Some results are based on the energy policies identified in these countries [3]. .

A. *Argentina.*

The Argentine electrical matrix has an installed electrical capacity of 42989 MW in 2021, of which 59% corresponds to thermal power plants with fossil fuels, 25% to hydroelectric power plants, 4% to nuclear energy, and 12% to other renewable energies. The Argentine Secretariat of Energy determines that there are 187 renewable energy projects in operation in Argentina: 64% correspond to onshore wind, 20% to solar, 11% to hydroelectric and 5% to biomass.

The most relevant law is the "National Promotion Regime for the use of renewable energy sources for the production of electricity" [12]. This law has a section dedicated to the national scheme to promote the use of renewable energy sources to produce electricity. It is expected a 69% increase in renewable energy installed in Argentina by 2030 due to the existence of this legislation. Although ocean energy is not currently part of the electrical matrix in Argentina, there are the first studies on the potential of ocean energy in Argentina, most of them related to wave and tidal energy [13] [14], accomplished by the Universidad Tecnológica Nacional (UTN) [15].

The national electric system requires an expansion plan for the high-voltage transmission network in approximately 2200 km of high voltage lines (500 KV), giving flexibility and capacity. to the system to integrate of renewable energies in Argentina under a model of long-term contracts. Fig. 2 presents the electric interconnections of Argentina with Brazil, Chile, Paraguay, and Bolivia. This aspect makes Argentina one of the Ibero-American countries that presents better conditions from the point of stability of the network for the integration of oceanic energies. The integration of ocean energies is not expected to create events outside the normal operating state of the grid once the expansion plan of the planned transmission network is carried out.

Fig. 2. Main electrical grid of Argentine, Brazil, Chile, Colombia, and Uruguay [3].

B. *Costa Rica.*

Currently, the installed power capacity in Costa Rica is 3482 MW, made up of 67% hydroelectric plants, 12% thermal plants, 8% geothermal plants, 11% wind plants, and 0.16% solar plants.

The Costa Rica Electricity Institute (ICE) has prepared the Generation Expansion Plan 2022-2040 (PEG 2022) [16] according to the detection of an important increase on the power demand. The objective is to increase the installed power of renewable energies in its electrical system. The expansion plan is designed considering Costa Rica as an isolated electric system.

As the most important renewable energy projects, a significant volume of wind and solar sources is expected (605 MW 2029-2035). Batteries have been considered as part of the generation system, considering them as necessary to maintain the system stability. It is expected to incorporate around 300 MW of energy storage systems based on batteries by 2027.

Ocean energies are not considered so far in the Costa Rica Generation Expansion Plan. However, there is a study that evaluates the potential of oceanic energies in Costa Rica [17]. It has concluded that wave energy resource on the coasts of Costa Rica has an approximate gross potential of 16GW of which 2.3GW is usable. Additionally, the geographical situation of Costa Rica, in tropical latitudes and its oceanic platform (depth 1000m), provides a potential for Ocean Thermal Energy Conversion (OTEC) in 7 regions on the Guanacaste coast of Costa Rica (25 km from the coast) presenting a capacity between 44.8MW and 51.4MW.

In relation to grid integration, the Costa Rica national electricity system (SEN) and its operating procedures are managed by the National Electricity Control Center (CENCE) [18] have reveal that the Costa Rica electrical grid may present a greater number of events related to the stability of its grid frequency due to the integration of oceanic energies in its system.

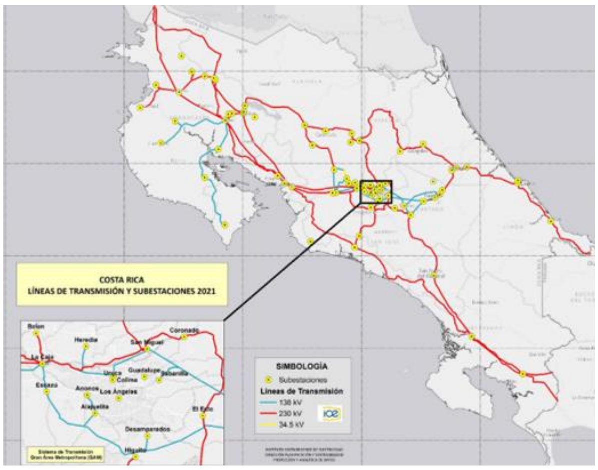

Fig. 3. Costa Rica transmission grid [18].

C. *Ecuador.*

The use of renewable energy sources in Ecuador is limited to the generation of electricity, of which 78.5% is produced in hydroelectric plants, 18.8% in thermal plants and 1.5% from other renewable sources such as biomass, biogas and wind farms. In addition, despite the investment made in past decades for the implementation of hydroelectric generation plants and reconditioning of refineries, Ecuador still depends on imported energy.

In 2013 a study about wave energy, currents, and kinetic energy of rivers in Ecuador for electricity generation was presented by the National Institute of pre-investment, based on the information compiled by the Oceanographic and Antarctic Institute of the Navy (INOCAR) [19]. In this study, the coastal profile was analysed, including the Galapagos Islands, as well as the rivers of the coast. These studies concluded that tidal and wave energies have a low potential for use in Ecuador, since the existing conditions are below what is required for the operation of these systems (14 kW/m for wave energy and 0.8 to 1 m/s for currents). An exception are the channels between Posorja and Puná and the channel between Puná and Puntilla de Jambelí, where there is an opportunity to generate current energy because they have current speeds between 3 and 4 m/s.

Ecuador's energy planning and the changes in its energy matrix are summarized in its Electricity Master Plan 2016-2025 [20]. The Ecuatorian TSO, CENACE [21], has identified the problems of voltage drops and overloads in the Ecuadorian electrical grid. These problems have nothing to do with the renewable energy presence but there is a weakness in the Ecuadorian electrical network that would cause the presence of voltage and frequency events.

The Electricity Master Plan (2016-2025) has proposed an improvement of the transmission system by means of two actions: expansion of its base structure and interconnection with neighbouring countries to make the grid robust. It is important to highlight the electric interconnection with Peru and Colombia, exporting 192 GWh in 2022.

D. *Peru.*

Electricity production in Peru grew at an annual rate of 7.04% in the last 21 years, going from 12170 GWh to 50817 GWh between 1997 and 2018. The country's energy matrix has changed in the last two decades. From 1997 to 2003, the share of hydroelectric production was on average 89.7%. Renewable energy plants have gone from zero participation in 2008 to 7.2% in 2018.

The document "Elaboration of the new sustainable energy matrix and strategic environmental evaluation, as planning instruments" [22], includes the Development Plan for renewable energies 2012-2040. Among its results, the total installed capacity of renewable energies in Peru is expected to be 4321 MW (17.3% of the total).

Ocean renewable energies are not included in this new energy matrix for Peru. However, a study on Peru's potential in ocean energy has been carried out in [23].

In the case of wave energy, Peru presents a potential wave resource in latitudes between 30º and 60º degrees and the average power ranges between 15 kW/h and 25 kW/h. In the case of tidal energy, the area of greatest tidal range is present from south to north.

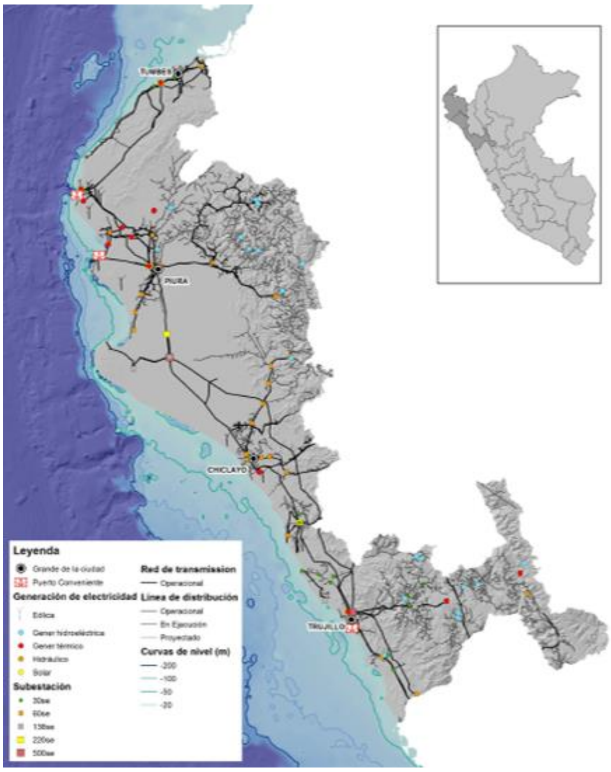

Fig. 4. Peru transmission north grid [23].

The diagnosis of the grid from the TSO in Peru, COES, has concluded that in the long term there will be congestions in different transmission lines (500kV-220kV range) in the northern and southern areas of the country due to a high penetration of renewable energies. The main substations may present short-circuit current levels below the minimum short-circuit capacities of their facilities. Loss of synchronism is also expected to occur. No transient angular stability problems are expected. These aspects will limit the integration of ocean renewable energy into the Peruvian electricity grid.

E. Spain.

The document: "Integrated National Energy and Climate Plan (PNIEC) [24] compiles the current status and future energy forecast for the Spanish electricity system. The energy generation matrix in Spain is made up of 86% fossil fuels and 14% renewable energies. In the PNIEC, the integration of oceanic energies in the renewable generation park is contemplated, specifically a 50GW of wind power installed in 2030 consider both onshore and offshore wind (between 1-3GW in the case of offshore wind). In the PNIEC for other renewable technologies, among which are the energies of the sea, it is 80 MW by the year 2030 (case 40-60MW ocean renewable energies). These data show a large increase in renewable energy in Spain's energy park in 2030.

Red Eléctrica España (REE) is the Spanish transmission system operator (TSO) compiles the events that have affected the stability of the electrical grid. These events can be found in the document [25] prepared by the European system operator (ENTSO-E). Considering the events associated with ocean renewable energies, it is concluded that the integration of ocean energies planned for 2030 in the Spanish electrical system will increase the number of events outside the operating limits established by REE in the Spanish electrical grid. Analysing the REE grid codes, the following aspects have been found that in the future may affect the Spanish electricity grid by integrating ocean renewable energies:

- Voltage and Reactive Power Control. The voltage ranges and reactive power regulation requirements are: 0.9-1.15 pu (400-110 kV nominal voltage).
- Control of frequency and active power. Spain has the narrowest frequency operating range (between 47.5 and 51.5 Hz) and operation within 47.5 – 48 Hz is allowed only up to 3 seconds.
- Low Voltage Ride Through capabilities. Spain requires a 15% voltage ride capability by injecting reactive current during voltage falls.

In Spain, strategies have begun to be developed for the development of offshore wind and ocean renewable energies in Spain [26]. Within these strategies, a section is included to define the deployment of ocean energy facilities. These strategies will aim to meet TSO requirements and adapt ocean energy facilities to meet operating procedures.

Isolated electrical systems have specific characteristics such as: systems not interconnected with other networks, low system inertia, high consumption demand, low power/frequency ratio and high resistance/reactance ratio. For these reasons, the operating ranges established by the TSO of the Canary Islands (REE) are stricter than for interconnected systems [27]. For example, the ranges of the frequency values for these isolated systems to operate in safe conditions are smaller (49.85Hz < f < 50.15 Hz) than the interconnected electrical systems (48 Hz < f < 51.5 Hz). These characteristics make these systems more vulnerable to the integration of renewable energies.

IV. CHALLENGES FOR THE FUTURE

After the analysis of the different challenges and situations within the different regions under study, some guidelines and suggestions will be delivered in order to achieve a better grid integration of oceanic energies. Among others, there are define the following:

• The use of Energy Storage Systems (ESS) together with renewable generation will contribute to reducing the events associated with the stability of the electrical grids. The ESS will be a complement to the electricity grid management systems. They will serve to smooth the generation peaks of the power curves of oceanic renewable energies. In addition, they will help to make better use of renewable resources, by storing surplus renewable generation. They may be used by the TSOs as currently done with non-renewable generation.

• Device design optimization of wave energy technologies and their components. In this way, problems associated with power quality will be minimized.

• Control strategies. By integrating power electronic systems. This need has been identified both on the ocean technologies side and on the power grid side. The control strategies will improve the quality of the energy to be poured into the network, minimizing the appearance of harmonics or flickers.

• Prediction of the renewable resource. Knowing the power of renewable generation parks in advance is one of the basic pieces to increase the penetration of renewable energies in electricity networks. The creation of computational tools that help to predict renewable resources will contribute to improve the scheduling and dispatch actions in the TSOs. Decreasing the number of events outside the limits of safe operation of electrical systems. This will cause a greater participation of renewable energies in the coverage of demand.

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