MARKET DESIGN ALTERNATIVES FOR REGIONAL INTEGRATION: A CASE STUDY OF THE ANDEAN ELECTRICITY MARKET (SINEA)

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Overview

In the current paradigm of power systems around the world, the energy transition is in a prominent position. In this context, special emphasis has been placed on the integration of renewable energies, which, despite being cost-competitive and in line with the decarbonization objectives, pose greater challenges for the planning and operation of electrical systems [1]. In addition, reliability and resilience have gained increasing prominence in recent years, whether related to stricter security of supply criteria to deal with variable generation, or with climatic events, such as El Niño and La Niña. At this juncture, one of the solutions listed to address the issues of decarbonization and resilience of the supply in an integrated approach is regional integration [2].

In South America, the most prominent electricity integration initiative is presented by the Andean Community, composed of Bolivia, Colombia, Ecuador and Peru. After a long period of preparation and studies, these countries, in addition to Chile, are seeking to implement the so-called *Sistema de Interconexión Eléctrica Andina* (SINEA) in the region, which would allow them to take advantage of the energy surpluses and hydrological complementarity between the countries. This initiative took an important step forward in 2023, with the approval of the regulations for the *Mercado Andino Eléctrico Regional de Corto Plazo* (MAERCP), a short-term energy market which will initially include international electricity transactions between Colombia, Ecuador and Peru. According to preliminary estimates, this first stage of the interconnection would generate an internal rate of return (IRR) for the countries involved of almost 28% [3]. The first stage of the Market is expected to begin in 2025, encompassing transactions between Colombia and Ecuador, with the inclusion of Peru once its interconnection line with Ecuador is completed in 2027 [4].

However, just as important as the existence of a physical interconnection line connecting the different countries is the market model and commercial rules that will regulate this exchange, and the economic gains that can be achieved out of it. According to the literature and the international experience, different market frameworks can be implemented, such as those involving an Exchange Market with coordinated dispatch (example of MER/SIEPAC, in the Central America), those involving an Integrated Energy Market (example of the European Common Market) and those based on a Single Regional Market, with integrated optimization of energy and operating reserve (example of American Markets, such as PJM). In this context, this article seeks to carry out an economic analysis of the implementation of MAERCP/SINEA, comparing how the different market models for the operation of regional integrations would impact on the economic gains expected from such integration. To this end, it is proposed to use a stochastic optimization model under uncertainties on an hourly scale, determining energy prices, exchanges between countries, national generation mix, operating costs, among other relevant results. The model takes into account operating constraints considered by the National Operators, such as operating reserve and transmission network, and allows for the modeling of an energy and reserve exchange scheme between the different countries in the regional market alternative.

Methods

As mentioned above, a Regional Market can be based on different operating rules and levels of integration between markets. In this context, this article proposes to analyze the impact of each of the main Regional Integration models, namely (i) "coordinated" energy dispatch, a model that maintains the autonomy for National Operators, with electricity exchanges made on an opportunity basis (which is conceptually tied to what should be adopted in practice); and (ii) "integrated" dispatch, where a regional entity would carry out energy dispatch for all the connected countries. These results will be compared to a third set of simulations, comprising each country separately, in order to assess the eventual gains with respect to the status-quo. To this end, dispatch simulations are carried out for the year 2028, considering the three member countries (Colombia, Ecuador and Peru). The system is simulated using a mathematical model of dispatch under uncertainties, considering multiple scenarios of inflows and renewable generation, with hourly granularity. Such modeling is essential for systems where there is a significant importance of hydroelectric and renewable resources, such as for the countries of the region, making it possible to analyze the impact of drier or wetter flows on the operation of the system, and the variable availability of wind and solar resources. Finally, the dispatch model considers the systems' plants in detail, modeling them individually and taking into account operating constraints.

In addition to an energy exchange market, an important product for a reliable operation of electricity systems is the operating reserve. This product, present in Electric Power Systems around the world, is based in a power capacity reserve in order to cover short and very short-term uncertainties. Historically, the amount of this product for daily operation (or the requirement imposed by the Operator) has been defined as a percentage of demand to compensate for forecasting errors and natural fluctuations that occur throughout the day and/or the failure of relevant generation units in the system. However, as the insertion of renewables into electricity systems increases, it also becomes necessary to consider the need for operating reserves caused by these sources. In this sense, a Dynamic Probabilistic Reserve requirement is considered, with the aim of calculating the need for additional operating reserve in order to mitigate the intermittency of non-conventional renewable sources [5].

As operating reserve becomes increasingly important for the resilience of the system, meeting it also brings new challenges. In this context, it is considered that countries can exchange reserves, either opportunistically in a coordinated dispatch, or through a Single Regional Market model, where the Regional Operator would be responsible for optimizing energy dispatch and allocating operating reserves among the countries. In order to allow for the possible use of surpluses between operating areas, a model for sharing operating reserve surpluses is proposed - in other words, the possibility that an area that has a surplus supply can share this product with another area that has a scarce or more expensive supply available. The shared reserve is defined by the following equation:

$$\sum_{i \in P_a} r_i + \sum_{k \in \Gamma_a^+} (\phi_k^+ - \phi_k^-) - \sum_{k \in \Gamma_a^-} (\phi_k^+ - \phi_k^-) \geq R_a, \quad \forall a \in A$$

Where r_i is a decision variable corresponding to the reserve of generator i, ϕ_k^+ e ϕ_k^- are variables that indicate the unidirectional idle capacity in opposite directions, P_a s the set of reserve-providing generators (compensators) in area a e Γ_a^+ e Γ_a^- as the sets of lines that have, respectively, bus to and bus from in area a.

Results

Based on the proposed methodology, this work sought to explore the impact of different Market Models for the future Andean Regional Market through detailed, stochastic power dispatch hourly simulations. The set of variables analyzed included total system operating costs, emissions, reserve allocation, generation mix by country, exchanges and marginal costs. Throughout the article, the values obtained between the different alternatives studied were compared among themselves and the with the ones obtained in other works (preliminary values of 338 million VPN and an internal rate of return of 27.9%). Special focus was given to the total costs perceived at a systemic level and at a country level, both on average and also at more critical percentiles, for example in the event of drier series - making it possible to analyze how demand would be met and how the market would perform in the event of a severe drought, as occurred in the region during 2023 with the El Niño phenomenon. Finally, with regard to the environmental issue, the market's potential for reducing emissions at a systemic level is analyzed, as a result of making better use of available resources.

Conclusions

This study sought to quantify the impacts of adopting an integrated energy market in South America (SIEPAC) composed of Colombia, Ecuador and Peru. It is shown that regional integration provides benefits for the countries. In addition, different market models can be implemented, and alternatives that are based in a deeper integration between countries provide greater overall benefits, although they tend to face more complexities in their implementation given the relative loss of autonomy of national operators. In terms of energy supply, it is possible to observe an optimization between the countries' hydrological resources, especially when analyzing the complementarity between Peru and Ecuador. Finally, this optimization also generates environmental gains for the countries in the market, since it makes it possible to reduce emission factors in the region by reducing the dispatch of thermal power plants, which is enabled by hydro and renewable complementarity.

References

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