# FIRM CAPACITY IN HIGHLY INTEGRATED RENEWABLE ENERGY SYSTEMS

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## Overview

The massive incorporation of Variable Renewable Energy (VRE) in the electro-energy matrices seems to be a common horizon towards which most countries are aiming. This trend has several driving forces among which are purely economic convenience, independence from imported fuels (in the case of importing countries) and commitments to reduce greenhouse gas emissions. This context of changes forces the review of certain concepts of the operation of the electricity markets in their regulations for the remuneration/recognition of the contribution of the components of the system in the supply of different products. Without a doubt, the main product is energy and depending on the organization of the market, its remuneration is based on offers or on a Spot price associated with the marginal cost of generation (generally with a regulated ceiling price). But there are other products such as auxiliary services (frequency control, voltage, power balance monitoring, etc.) and Firm Capacity.

The Uruguayan electricity market is of the centralized dispatch type due to variable generation costs. The spot price is defined as the marginal cost (MC) with a Spot Price Ceiling (SPC) of 250 US$/MWh.

In this work, Firm Capacity means the system's ability to meet the power requirements at all times. The topic has been widely discussed with arguments such as that a solar plant cannot have Firm Capacity since at night said generator would be incapable of supplying a load. An argument that is easily refuted when thinking about the electrification of a small town based on batteries and solar energy. Neither the battery nor the solar panels alone are capable of meeting the power balance at night, but the set can safely supply the load. This simple example also allows to quickly identify that Firm Capacity is a property of the system and not of each element separately.

In this work, a methodology is developed for determining the Firm Capacity of a system and assigning the contribution of each element, as part of the system, to said value.

## Methods

The physical attributes of electricity and networks require that supply and demand for electrical energy must be balanced in real time, otherwise unforeseen interruptions of electricity supply occur.

When there is excess demand in a market with demand insensitivity to real-time prices, the price is undefined, and the signal to convey information about the shortage of electrical energy is absent. In these circumstances, the supply response is insufficient to meet the demand, and consequently, the system operator must reduce demand through controlled interruptions of electrical supply to prevent system collapse. These interruptions are an administrative response by the operator to the electricity shortage. Regulators address this problem by defining scarcity prices for electrical energy that reflect the value of the energy not supplied in those periods. This value serves in the long term as an economic signal to determine the investment required in generation capacity.

In systems dominated by renewable generation technologies the reliability risk depends on the availability of renewable resources and, consequently, on climatic phenomena. These technologies are not considered entirely manageable because, even if they are available, the generation of electricity depends on phenomena beyond the control of the system operator. In the case of renewable resources with high short-term variability, periods of higher reliability risk are not necessarily those of peak demand but rather those with the greatest difference between demand and generation based on these renewable resources (net demand).

The Firm Capacity of the system is the Demand that the set of generators is capable of supplying. No system has a 100% supply guarantee. To identify critical situations and thus be able to determine the firm capacity of the system and the contribution to it of each generating plant, the use of the MC is a good indicator. The greater the power requirement in an hour, the greater the MC.

Using the SimSEE simulation platform, detailed simulations of the optimal operation of the Uruguayan system were carried out. The simulations are of the Monte Carlo type and 1000 realizations of the stochastic processes were simulated. With the intention of determining the monthly Firm Capacity, the energy dispatch of each month was considered for each of the 730 hours of the month in the 1000 realizations. Thus, 730,000 possible energy dispatches were obtained for each month. With these dispatches, the Set of Critical Hours (SCH) is defined as the set with the highest power requirement in the system. It is in this SCH that the demand that the set of generators is capable of satisfying and the contribution of each one to that value is determined.

For the identification of the SCH based on the MC, there are at least two alternatives. a) Cut by Marginal Cost Level (CMCL) as the set of hours in which CM > SPC and b) Cut by Marginal Cost Probability (CMCP) as the set of the 1% hours with greather MC.

The main objective of calculating and recognizing the Firm Capacity is to create a market that allows generators to receive the incomes that they do not receive in the energy market (due to the SPC) and thus recompose the signal that leads to optimal investments. Thinking about this, it seems natural to choose the SCH as those hours in which MC exceeds the SPC and measure in that SCH the income that each generator does not receive per action of the SPC.

The Colombian implementation for Firm Capacity remuneration is an example of an implementation considering CMCL. It is based on Arriaga's bibliography (C. Vázquez, M. Rivier, and I. Pérez-Arriaga, "A market approach to long-term security of supply," IEEE Trans. on Power Systems, Vol. 17, No. 2, pp. 349-357, May 2002). Where the generators participate in auctions where they offer a price (P) and a fixed amount to be collected per month, to cover the difference between the Marginal Cost and a Strike Price in critical situations when the MC exceeds the Strike Price. The price of the last accepted bid determines the price in the reliability market, which is the per-unit premium fee paid to all the accepted generators.

Although in Uruguay the ADME initially proposed a methodology based on CMCL, in the process of putting it for consideration by market agents and discussion workshops, a methodology based on CMCP was adopted. The work explains the reasons for the change that are directly associated with the simplicity of the calculation and making it more robust. The methodology based on CMCL needs a balance between demand and supply so that the SCH is populated enough to obtain robust results. The probability of exceeding 1% was chosen for the CMCP in order to achieve equivalence between the two criteria for a system with an optimal balance between Demand and installed capacity.

In the ADME proposal, unlike the Colombian implementation, instead of waiting for critical events to try to get the generators to comply with the commitments, in the Monthly Supply Guarantee Service (MSGS), an estimate for the generator availability to comply with the assumed commitments is performed in order to reduce the risk of generators not actually being available if the system enters risk situations.

**Synergy between resources to supply demand.** Using the synergy of the system means employing the economic dispatch function where all generators are included. Denying the possibility of the system being supplied by all generators based on optimal dispatch, and insisting that each generator (or group of generators) must be capable of supplying in isolation, is denying the possibility of a competitive market.

The Firm Capacity calculated according to the proposed methodology utilizes the same synergy of resources applied to supply the demand resulting from the economic dispatch. The supply risk conditions that the system will face are mainly associated with the lack of contributions from the hydroelectric plants. During times of drought, these plants have excess power and lack energy, and it is the wind and solar plants that manage (by having firm energy) to provide what is necessary so that the whole system is capable of supplying demand.

Someone could argue that it makes no sense to allow a solar plant to make a supply contract with demands outside of solar hours. To refute this argument, imagine a unique demand of 1 MW from 7:00 p.m. to 8:00 p.m., and that the only options for supplying that demand are solar panels and battery banks. The installation of solar panels alone is not capable of supplying the demand. The battery bank alone is not capable of supplying the demand. However, installing both is possible and with the reliability you want. This example makes it clear that the ability of each element alone to meet the supply has no sense.

## Results

The table 1 shows the calculation of the Firm Capacity in % of the installerd capcity for each type or generation resource. The results obtained with the two proposed calculation methods, CMCL and CMCP are compared. For the CMCL the SPC is 250 USD/MWh and for the CMCP the probability of excedence is 1%.

The results are grouped by technology: 'eol' corresponds to wind generation, 'sol' to solar generation, and 'RN' and 'SG' correspond to hydroelectric generation. However, it's important to note that 'RN' has a longer storage time in the lake, while 'SG' has greater generation power.

*Table 1: Comparison of results between the two methods of calculating Firm Capacity in % of the installed capacity. cut by reference and cut by 1 % probability*

| | | eol | | sol | | RN | | SG | |
|---|---|---|---|---|---|---|---|---|---|
| | Month | CMCL | CMCP(1%) | CMCL | CMCP(1%) | CMCL | CMCP(1%) | CMCL | CMCP(1%) |
| 2024 | 1 | 16% | 12% | 31% | 30% | 61% | 58% | 15% | 15% |
| | 2 | 15% | 12% | 29% | 29% | 59% | 55% | 15% | 14% |
| | 3 | 15% | 12% | 26% | 25% | 50% | 50% | 14% | 13% |
| | 4 | 16% | 13% | 19% | 16% | 41% | 44% | 13% | 11% |
| | 5 | 18% | 15% | 17% | 14% | 46% | 55% | 16% | 13% |
| | 6 | 20% | 17% | 16% | 14% | 53% | 59% | 26% | 15% |
| | 7 | 23% | 21% | 16% | 17% | 51% | 46% | 36% | 22% |
| | 8 | 21% | 19% | 18% | 18% | 50% | 49% | 32% | 28% |
| | 9 | 19% | 19% | 19% | 19% | 45% | 45% | 36% | 36% |
| | 10 | 19% | 21% | 24% | 22% | 35% | 39% | 22% | 30% |
| | 11 | 18% | 18% | 27% | 27% | 38% | 37% | 15% | 14% |
| | 12 | 17% | 16% | 29% | 28% | 54% | 51% | 16% | 14% |

## Conclusions

Firm capacity is a property of the system and not of each element in particular. The developed methodology is consistent with the market design with marginalist signals that point to the economic optimum. The values obtained for firm capacity correspond to the marginal contribution of each technology to the system in its current composition and therefore will change with the evolution of said composition. It is noteworthy that the implemented methodology was incorporated into the regulatory framework of Uruguay by Decree No. 242/023.

## Disclaimer

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