CONSEQUENCES AND ECONOMIC CONDITIONS FOR THE TECHNICAL SIZING OF THE LONG-TERM ENERGY FLEXIBILITY IN A FULLY VARIABLE RENEWABLE POWER SYSTEM

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Overview

The technical and economic feasibility of a low-carbon mix with a very high variable renewable energy (VRE) sources penetration represents a major challenge for the energy transition. Indeed, the management of a power system's security of supply is undergoing a paradigm shift for the use of primary energy as it moves from a stock to a flow logic. This increases the sources of uncertainty due to the variability of renewable production, the latter being observed on different time scales, from daily to annual and multiannual. This uncertainty leads to a increased need for flexibility in terms of both power and energy. Due to the succession of periods of VRE production deficits, the sizing of energy flexibility sources can reach very high values depending on the geographical context. Among these sources of flexibility, energy transfer appears as a a natural solution in a system where periods of deficit and surplus follow one another. This is achieved through a long duration storage (LDS), whose transfer roles vary over different timeframes, from daily to annual and multiannual[1]. Other sources of flexibility, such as oversizing renewable generation or importing energy – the storage vector – from outside the power system, may also be considered.

Ensuring security of supply over any time horizon necessitates the technical sizing of substantial energy flexibility resources. This sizing is essential but incurs a significant economic cost. The aim of this work is therefore to study the economic consequences of these cost for the power system and to identify and discuss the economic conditions for the deployment of these sources of flexibility.

Methods

This work is divided into three parts. First, we introduce a technical sizing of an full VRE power system. To this end, we assume an isolated power system in a temperate European climate. Two type of storage are introduced: a short-term storage with a fixed sizing and a long duration storage – based on a hydrogen vector. The latter guarantees the energy adequacy and hence the security of supply. Sizing is calculated in this regard. No other conventional assets are considered but the modelling of a conventional gas asset can be assimilated to long-term storage for which part of the energy is imported. We choose to calculate a first reference power system configuration in which excess renewable generation is minimized in order to obtain a design that is independent of economic considerations, which hypothesis are also subject to considerable uncertainty in the long term. The LDS and VRE capacities are calculated using a storage capacity expansion tool associated with a renewable generation capacity exploration loop. Multi-annual scenarios are used, representing a variety of sequences of past years.

Then, other sources of flexibility are introduced, such as the oversizing of the VRE capacity, exogenous imports of the energy vector of the long duration storage – supposed variable or constrained on an annual pattern –, as well as an additional and baseload final industrial consumption of the storage vector. This allows us to study the impact of their introduction on the storage capacity sizing as well as to formulate different security of supply strategies.

Finally, the economic feasibility for the different power system configurations is assessed through three main elements: (1) the impact of the cost of the energy flexibility on the complete cost of the power system, (2) the average cost of the energy delivered by long duration storage, calculated throught its levelized cost of storage (LCOS), and (3) the impact of its cost of capital on the complete cost. A method for disaggregating storage transfer roles according to the various time horizons is also proposed and the results of this disaggregation are discussed.

Results

Firstly, the formulation of different power system configurations highlight a important sensitivity of the LDS capacity sizing to the renewable generation. This reinforces the interest in oversizing renewable generation as a

[1] We consider LDS to be a very long duration storage, also known as inter-seasonal/annual storage in the literature.

source of flexibility for the system. It also highlights the significant sizing uncertainty associated with the variability of the average load factor and its annual and multiannual dispersion between the data sets used and the actual future generation output. Furthermore, we find that the different security of supply strategies are not all equally resilient to the uncertainty of the multiannual variability of renewable generation.

We then show that the costs associated with energy flexibility in the full cost of electricity represent an equivalent share as well as a majority share of the complete cost (~50-60%) whatever the diversification of the sources of flexibility. Indeed, although the other sources of flexibility mentioned above – overgeneration of VRE capacity, exogenous import and/or baseload final consumption of the storage vector – reduce the need to transfer energy, the reduction in the LDS cost is offset by the additional investment in these other sources of flexibility. The complete costs are differentiated only when the flexibility sources costs assumptions are extreme and opposite.

We also find that the LCOS of long duration storage reaches significant values due to its role as a guarantor of security of supply, which requires significant sizing, at around 500 €/MWhe. These values are around up to twice those proposed in the literature for similar assumptions (RTE, 2021). We show that this value is not particularly sensitive to the diversification of flexibility sources. In fact, the economic effect of reducing the LDS capacity sizing is offset by the reduction in its use insofar as the others sources of flexibility reduce its need. Only by diversifying the roles of the LDS through the final industrial consumption of the storage vector (hydrogen) can the LCOS be effectively reduced thanks to the increased sollicitation. Finally, by decomposing the transfer services at different time horizons, we show that there is a significant mismatch between the sizing necessary to cover the worst-case deficit and the majority of the usage: between 70 and 80% of the transfers take place at the infra-monthly horizon.

A last result concerns the cost of capital, which determines the conditions for investing in an asset. First, we find that the LDS plays a role similar to that of peak capacity. Consequently, and according to the literature (Peluchon, 2021), its exposure to risk is significant, and the cost of capital to which it is exposed is equally important, with important consequences on its economics. Indeed, an increase in WACC from 8% to 16% would raise the complete cost of system by around 20%. Without calculating its exact cost of capital, we explore its possible evolution according to the diversification of sources of energy flexibility. By assimilating the variability of usage to that of remuneration, we also show that the risk associated with long duration storage tends to increase with the increase of renewable production. Finally, this risk is diffused in the cost of capital of renewable generation. Indeed, in certain power system configurations that were considered, nearly 40% of renewable generation is dedicated to flexibility which make its usage and the level of curtailment as uncertain as the solicitation of the LDS.

Conclusions

Three main conclusions stand out: firstly, the decision criterion for the different security of supply strategies lies more in assessing the risk in the face of multiannual uncertainty in renewable generation than in an economic calculation, since the complete cost of the different mix configurations considered is equivalent. However, not all strategies are equally resilient to the pluriannual VRE uncertainty. In particular, we identify a risk of transition when the power system switches from a resilience guaranteed by imports to a resilience guaranteed by excess VRE generation. In this transitional in-between period, these sources of flexibility are in competition with each other and give rise to a risk of stranded renewable assets, whereas a network operator will prefer to continue importing the energy vector that guarantees security of supply, which is more certain. As a result, these considerations call into question our ability to break away from gazeous import dependency in power systems with a high VRE penetration.

Secondly, our results underline the need for regulation and public planning of assets guaranteeing security of supply. On the one hand, the financial risk and the high cost of capital hamper the realisation of long duration storage, particularly in the absence of a final consumption of the storage vector. However and on the other hand, excess and curtailed renewable generation, which also plays a energy flexibility role in the system, also requires an appropriate regulation, without which its financial risk increases just as much.

Finally, our results shed light on the risks associated with the multiplication of energy flexibility sources, for example storage technologies, due to the mismatch between the use of the flexibility sources and their sizing. On the one hand, this exacerbates the financial risks associated with the variability and uncertainty of demand, which are all the greater for security of supply assets, and on the other, the risk of competition between flexibility assets, which would reduce their margins. Once again, this calls for regulation and planning of security of supply assets.

References

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