WHICH VALUE OF NUCLEAR FLEXIBLITY TO FOSTER THE INTEGRATION OF INTERMITTENT RENEWABLE ENERGY SOURCES? PROSPECTIVE STUDY ON TECHNICAL POTENTIALS AND ECONOMIC IMPACTS IN THE FRENCH POWER SYSTEM

Camille Cany, I-tésé, CEA, Université Paris Saclay, F-91191 Gif-sur-Yvette; Laboratoire Genie Industriel, CentraleSupélec, Université Paris-Saclay, Grande Voie des Vignes, 92290 Chatenay-Malabry, France, +33(0)1 69 08 39 57, camille.cany@cea.fr

Alizée Chazottes, I-tésé, CEA, Université Paris Saclay, F-91191 Gif-sur-Yvette, France, +33(0)1 69 08 39 57, alizee.chazottes@cea.fr

Christine Mansilla, I-tésé, CEA, Université Paris Saclay, F-91191 Gif-sur-Yvette, France, +33(0)1 69 08 36 86, christine.mansilla@cea.fr

Gilles Mathonnière, I-tésé, CEA, Université Paris Saclay, F-91191 Gif-sur-Yvette, France, +33(0)1 69 08 68 59 gilles.mathonniere@cea.fr

Pascal da Costa, Laboratoire Genie Industriel, CentraleSupélec, Université Paris-Saclay, Grande Voie des Vignes, 92290 Chatenay-Malabry, France, +33(0)1 41 13 14 16, pascal.da-costa@centralesupelec.fr

Overview

The current international context is characterised by emerging intentions to switch to low-carbon energy mixes with country-specific energy transition pathways. In France, the Energy Transition Act, voted in August 2015 (French Government, 2015), paves the way for such an energy transition. The French case is very specific. The power system is characterised by a high nuclear penetration which supplied 77% of the total production in 2014 (RTE, 2015a). The nuclear share is to be reduced to 50% of the power production from 2025 onwards, and the renewable share should reach 27% by 2020, 40% by 2030 (French Government, 2015) and will grow up to 2050.

Among renewable sources, some are intermittent. These are characterised by power variability, uncertainty and non-dispatchability with, what is more, a current priority dispatch. Integrating a high share of intermittent sources, such as wind and solar, means additional needs for flexibility in the power system (Silva, 2010). As stated in (Ma et al., 2013), “the term flexibility describes the ability of a power system to cope with variability and uncertainty in both generation and demand, while maintaining a satisfactory level of reliability at reasonable cost, over different time horizons”. In what follows, we will focus on one dimension of flexibility: power variability, or in other words, power modulation, assuming that the uncertainty is managed.

As nuclear is a highly capital-intensive technology with low operating costs, it is commonly operated as baseload power, what makes the plant operator and social planner viewpoints converge. The massive introduction of wind and solar with a priority dispatch, such as it is in France, calls for a system-wide transformation in the long term. The transitional period requires relevant choices among existing flexibility options to optimise the power system from an economic and technical perspective, and to be in line with decarbonisation targets (OECD/ IEA, 2014). For reliability issues, the French nuclear fleet could be asked for more power ramping and higher amplitude variations in the near future. Nuclear power has characteristics compatible with power modulation (Lokhov, 2011), and already contributes, in France, to load following because of its high share in the mix.

In this context, we investigate the nuclear fleet as a potential flexible asset to conduct this transitional period, both from technical and economic viewpoints. We evaluate the new needs for nuclear power modulation in France depending on wind and solar shares and confront them to the nuclear technical abilities.

Methods

The analysis starts with an outlook of the French nuclear fleet power modulation, built in two parts: a state of the art on the technical abilities of the French nuclear reactor technologies to participate in load following; and a statistical analysis of the behaviour of both the French nuclear fleet and reactors as individual items. The power modulation is examined on an hourly timeframe thanks to the profiles established from RTE data from 2012 to 2015 (the French Transmission System Operator, RTE, 2015b).

The second part is a prospective assessment. It involves, at first, designing scenarios of nuclear, wind, and solar penetration levels. Secondly, we carry out the construction of nuclear production profiles resulting from wind and solar introduction in the power mix, by calibrating the renewable profiles to higher penetration levels. The modified profiles are constructed on the basis of historical hourly profiles from RTE data (2012 to 2015; RTE, 2015b). Thirdly, we evaluate the nuclear flexibility needs for different prospective scenarios and, we compare these needs to the technical ability to achieve them, on a defined set of constraints. To delineate the nuclear fleet abilities to modulate, we have to address the challenge of moving from the scale of the reactor to the scale of the fleet, and vice

versa. While the reactor design defines the technical boundaries as regards modulation, at the scale of the fleet, one needs to catch other limitations related to the dynamics of the fleet in operation. In that purpose, a new set of indicators related to the fleet power variations, based on power and energy, is developed.
The last part of the article aims at evaluating the added value of a flexible nuclear fleet for the power system, if there exists. Following a sensitivity analysis on some flexibility indicators for the nuclear fleet, we quantifiy the associated lack and surplus of nuclear power production. On this basis, a cost-benefit analysis is carried out by comparing the levelised cost of electricity depending on how the nuclear constraints are dealt with to balance the power system, with an hourly time frame.

Results

The results of the situational analysis show that the French nuclear fleet power variations answer to the daily, weekly and seasonal load cycles, with power ramping and amplitude variations far from the theoretical boundaries. Besides, no straightforward key factors could be extrapolated from data analysis to explain the participation of a given reactor to power modulation. Factors are diverse, inter-dependent and inherent to each reactor (technical constraints, economic or safety issues), which makes it difficult to model future reactors' operational behaviour. That is why we chose to model the nuclear fleet profile as a whole, evaluating it through relevant indicators.
As regards the prospective analysis, it shows that the nuclear profile will be patterned by new, less cyclical and regular drivers depending on wind and solar shares. Indicators measuring power ramping and amplitude variations do not appear critical in general, whereas those measuring the frequency and magnitude of extreme situations can be limiting. These extreme situations are characterised in terms of power ramping, amplitude variations, number of hours for which power decreases below a threshold value, and number and duration of reactors shutdowns and start-ups per year. One result is that, for a 50% wind and solar penetration level and 63 GWe of installed nuclear power (i.e. the current French nuclear capacity), the nuclear fleet would be asked to operate more than 700 hours a year under 20% of its nominal power.
In the transitional period, the increase of wind and solar would trigger a decrease of the nuclear annual load factors down to 40% for proactive assumptions, thus generating a direct increase of the nuclear annual production cost, as part of additional system costs. However, from the power system viewpoint, nuclear flexibility could reduce both the levelised production cost of electricity and CO_2 emissions for the power system. The cost-benefit analysis shows that the added value of nuclear flexibility for the power system does exist and grows with the increase of wind and solar. The nuclear operator would be all the more prompted to contribute to this value as new markets would be targeted, such as the hydrogen market, to sell its newly available energy. This would, at the same time, boost the development of interconnections between energy sectors to help the renewable integration.

Conclusions

In the near future, the French nuclear fleet will have to address new challenges when it comes to power modulation. Such an analysis provides some insights to anticipate, better adapt the fleet, and adequately prepare its replacement. Indeed, the choice of the nuclear fleet replacement policy is at the core of the French power debate as half of the fleet will be older than 40 years by 2025.
Promoting nuclear flexibility improvements would be a benefit from the macroeconomic level to address the power system new needs for flexibility. In the transitional period, it would decrease the need for investments in new flexible power plants, as well as be more in line with the carbon emission targets.
Resulting from the loss of annual load factors, the nuclear production cost increase could be compensated by modulating the use of nuclear power rather than modulating its production. This would mean that nuclear power flexibility could accomplish two things with one action: available power would be converted into valuable services to the electric system and, at the same time, into valuable industrial products. In this respect, hydrogen seems especially worthwhile, given its multiple outlets and future specific position within the energy system.

References

French Government, 2015. LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte, 2015-992.
Lokhov, A., 2011. Technical and economic aspects of load following with nuclear power plants. OECD/NEA.
Ma, J., Silva, V., Belhomme, R., Kirschen, D.S., Ochoa, L.F., 2013. Evaluating and planning flexibility in sustainable power systems, Presented at the 2013 IEEE Power and Energy Society General Meeting, pp. 1–11.
OECD/ IEA, 2014. The power of transformation. Wind, Sun and the Economics of Flexible Power Systems.
RTE, 2015a. Le bilan prévisionnel de l'équilibre offre-demande d'électricité en France.
RTE, 2015b. RTE database - Portail clients - Production réalisée par groupe. Available online at https://clients.rte-france.com/lang/fr/visiteurs/vie/prod/production_groupe.jsp (accessed 11.30.15).
Silva, V., 2010. Value of flexibility in systems with large wind penetration. University of London.