THE ECONOMICS OF FLEXIBLE NUCLEAR GENERATION IN LOW-CARBON POWER SYSTEMS: A STOCHASTIC DUAL DYNAMIC PROGRAMMING APPROACH

Ange Blanchard | Climate Economics Chair | Université Paris-Saclay, CentraleSupélec, Industrial Engineering Research Department, France | +33 7 88 37 75 38 | ange.blanchard@chaireeconomieduclimat.org

Olivier Massol | IFP Energies Nouvelles | Université Paris-Saclay, CentraleSupélec, Industrial Engineering Research Department, France | +33 6 64 38 16 46 | olivier.massol@ifpen.fr

Overview

This paper proposes a new way of modelling nuclear flexibility in a stochastic environment. The amount of cycling operations a reactor can undergo is considered as a fixed stock whose optimal dispatch is set with the use of a Stochastic Dual Dynamic Programming (SDDP) algorithm. This formulation allows considering the uncertain production from renewables and testing the resulting policy on hundreds of simulations. The modelling framework provided by this formulation is implemented on the French case, by 2035. Results show an increase in nuclear flexibility is largely achievable and can significantly reduce energy curtailment from renewables. Solar panels are the technology that most benefit from any increase in nuclear flexibility, with payoffs almost doubled in the most extreme considered case, compared to benchmark. Nuclear power plants profits are found to plateau for flexibility levels between benchmark and up to twice this value, which unleashes the potential of operating them in a load-following mode more often.

Methods

In this study, we present a stochastic linear programming model for the hourly dispatch of the power system. The model considers electricity generation from different power plant technologies over a full year with 8760-time steps. To account for the intermittent nature of renewable energy sources, daily power generation from renewables is fixed to a set of possible values. Additionally, nuclear generation is allowed to vary within a specific range, which is determined during the SDDP training phase. The resulting policy ensures optimal use of nuclear flexibility while maintaining compliance with a maximum total power variation over the year.

Results

The method is applied on the French power system in 2035, with generating capacities fitting national energy plans. The results show that the increased flexibility of NPPs reduces the total cost of the system, but with winners and losers. Owners of Pumped Hydro Storage (PHS) may see reduced profits due to fewer opportunities for time arbitrage between high and low prices, while solar panel owners may benefit from an almost doubled payoff due to reduced curtailed energy and producing when prices are high. Wind turbine owners may experience reduced curtailed power but with no significant trend on profits. For NPP operators, the results show a lowering of profits for high levels of flexibility, but a plateau of possible payoffs for a certain range of cycles operated per year, indicating that French NPPs may not suffer from operating in a more flexible mode up to twice the current level of flexibility. This counter-intuitive breakthrough is due to a better dispatch of NPPs during moments of high prices that offset the loss in load factor induced by such a flexible operating mode.

Conclusions

Based on market simulations, the policy question of the need for load-following operations from nuclear power plants can be answered by stating that it is manageable compared to international standards. Implementing a more flexible operating mode for NPPs can reduce energy curtailment from renewables, particularly solar panels, which benefit the most from this approach. Moreover, this study reveals a breakthrough finding that NPP profits may not be affected by increased flexibility up to a certain point. The simulations suggest that NPPs can undergo up to twice as many cycling operations as they currently do without any profit loss. However, limitations to this work highlight the need for further research in this area. For example, extensive cycling operations on NPPs may increase maintenance costs and cause unplanned shutdowns, but these effects have not been clearly quantified yet.

References

[1] J. Jenkins et al., *The benefits of nuclear flexibility in power system operations with renewable energy*, Applied Energy 222 (2018) 872-884.

[2] C. Cany et al., *Nuclear power supply: Going against the misconceptions. Evidence of nuclear flexibility from the French experience*, Energy 151 (2018) 289-296.

[3] A. Papavasiliou et al., *Application of Stochastic Dual Dynamic Programming to the Real-Time Dispatch of Storage Under Renewable Supply Uncertainty*, IEEE Transactions on Sustainable Energy 9, (2018) 547-558.