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PROBABILISTIC WELFARE ANALYSIS FOR SYSTEM ADEQUACY – ANALYTICAL INSIGHTS

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Overview

Current developments in electricity systems such as the growing penetration of renewable energy sources challenge the existing infrastructure. While incentives for generation investment remain market driven, transmission planning is a public task in most European countries. So far, this planning is usually based on the deterministic N-1 criterion. However, in the light of fluctuating renewables and efficient resource use, the application of probabilistic approaches bears the potential to increase efficiency.
In this paper, system adequacy is analytically investigated in order to depict the trade-off between the value of lost load (VOLL) and investment costs taking into account the probability of failure of system components. The analysis is meant to shed light on factors influencing system adequacy and on the way probabilistic approaches differ from the traditional N-1 criterion. The focus is on generation assets in a first step, however, the elaborated insights provide a better understanding of underlying relationships and may be transferred to more complex settings. Starting from the application to a single country, the analysis is broadened towards the connection of two countries. Analytical results are supported by numerical calculations.

Methods

The analytical model takes the maximization of (probability weighted) social welfare as starting point. It furthermore considers load variations over time through a load duration curve and includes investment and marginal costs for generation units as well as the probability of failure for the individual units. Thereby a single uniform power plant technology is used as starting point. The failure of its units is modelled through a binomial distribution, providing probabilities for each conceivable number of simultaneously failing units. In order to allow an analytical differentiation, the discrete binomial coefficients are converted with the help of the continuous gamma function. Consequently, the optimal number of generation units or respectively optimal generation capacity can be derived as the result of the maximization problem. Sensitivity analyses for the parameterization of value of lost load, investment costs and probability of failure are conducted.
In an extension, the value of interconnecting two countries is determined. Therefore, the separate optima of generating units for both countries are compared to a situation of unlimited transmission capacity between these countries in which the generation need can jointly be derived. This indicates the pure value of transmission capacity with respect to improved reliability – in practice this value will be complemented by the value of resource diversification and increased cost efficiency in generation. Complementing Cepeda et al. (2009), who numerically investigate the impact of transmission capacity on generation adequacy, this paper is meant to provide analytical insights.

Results

The analytical solution provides the relation of installed generation capacity to maximum load. This ratio decreases both with increasing system size and decreasing probability of failure. Furthermore, for the consideration of unrestricted transmission between two countries, the optimal extent of overall generating capacity is lower than for separated countries, yet the marginal benefits of interconnection are decreasing with the size of the participating countries.

Conclusions

The analytical results for generation adequacy and unlimited transmission between two countries should be used to derive implications for more complex situations, especially with respect to the adequacy of electricity transmission.

References

Cepeda, M. et al. (2009) Generation adequacy and transmission interconnection in regional electricity markets, Journal of Energy Policy 37(12), pp. 5612-5622.