Using the Shapley value to share costs of congestion management in a realistic power grid model

Simon Voswinkel, University of Duisburg-Essen, House of Energy Markets and Finance, +49 201 183 3127, simon.voswinkel@uni-due.de

Overview

A side effect of the increasing share of renewables in power systems has been an increasing number of grid congestions across all voltage levels. With this increase in the number of congestions comes the need to allocate the costs resulting from congestion management either to individual congestions or to the grid operators responsible for the congested elements. Voswinkel et. al. (2022) and others have demonstrated that the Shapley value, a concept known from cooperative game theory, can be used to fairly allocate costs resulting from congestion management to individual grid elements. Because the Shapley value is computationally expensive to calculate, Voswinkel et. al. (2022) have developed new methods that are suited to the use case of redispatch which can be used to substantially decrease the computational complexity, and demonstrated the efficacy of these methods on a small, stylized grid topology.

This paper aims to extend the work of Voswinkel et. al. (2022) by validating the simplification methods using a more realistic grid and developing further strategies to transfer the application of the Shapley value from a small test case to a realistic grid topology.

Methods

As Voswinkel et. al. (2022) have shown, to apply the Shapley value to the redispatch cost allocation problem, one can define this cost allocation problem in game theoretic terms. For a specific grid load case, the congested elements are defined as individual players, with the set of all congested elements forming the *grand coalition*. Performing congestion management for all the elements (players) in the grand coalition results in the total sum of congestion costs that have to be allocated for the given grid load case. The Shapley value can be used to allocate these costs to all the players that form the grand coalition by calculating the average marginal contribution of each player to all possible sub-coalitions that can be formed by members of the grand coalition. This necessitates the calculation of all of the possible coalitions, a total number of 2^N calculations, where N is the number of total players (congested elements). Voswinkel et. al. (2022) have developed two novel approaches to reduce the number of coalitions that have to be calculated and applied it to a small grid topology, constituted by interconnected CIGRE benchmark grids for three voltage levels.

This paper will apply the newly developed methods to a grid topology of more realistic proportions, encompassing the German extra high voltage transmission grid and some of the high voltage distribution grids connected to it. The congestions that arise in multiple representative grid load cases will be resolved by performing an optimal power flow (OPF) and the resulting costs will be allocated to the individual congestions by using the Shapley value together with the simplification methods as outlined above.

Results

While the calculations are still pending, the results are expected to show, whether the promise the simplification methods developed by Voswinkel et. al. (2022) have shown when applied to a small simplified grid topology transfer to a realistic grid topology. Additionally, the efficacy of possibly necessary adjustments to the simplification methods will become apparent.

Conclusions

The challenges created by increasing shares of renewable energy sources include an increasing amount of congestion management. Especially in power grids with multiple system operators, these costs have to be allocated to the congested elements. One fair method to allocate these costs is the Shapley value, which is very computationally expensive. This paper will demonstrate if and to what extend simplification methods developed by Voswinkel et. al. (2022) retain their performance when applying them to a realistic setting such as the German power system.

References

Voswinkel S., Höckner J., Khalid A. and Weber, C. (2022): Sharing congestion management costs among system operators using the Shapley value. In: Applied Energy (in press).