

ECONOMIC EFFECTS OF REACTIVE POWER SUPPLY FROM DISTRIBUTED GENERATION ON THE ELECTRICITY SYSTEM

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Overview

Electricity system operators are required to ensure system stability by means of provision of ancillary services. While frequency control respectively control power as well as redispatch have been subject to economic research, voltage control – despite its growing importance – has hardly been analyzed from an economic perspective.

Voltage stability of transmission grids is ensured by the controlled feed-in of reactive power. Capacitive and inductive reactive power are typically provided either by generation units or by reactive power compensators, such as Flexible AC transmission systems (FACTS). With a shift of electricity generation from large central power stations to decentralized renewable power plants, the capacities and thus the potential to provide reactive power from plants connected directly to the transmission grid decreases.

At the same time, many wind power and PV installations connected to the distribution grid are technically capable of providing reactive power, diminishing the need for compensation facilities or voltage-induced redispatch. To analyze the role of reactive power from renewable sources in the high voltage transmission and the distribution system, a techno-economic AC-load flow model of the German electricity grid is developed, which can cope with real and reactive power flows. Based on this model, economic benefits of reactive-power feed-in from renewable energies are determined based on a comparison of opportunity cost of reactive power provision as well as system cost.

Method

Electricity grid models based on PTDF or DC-approximation approach, that are common in energy economics, neither consider voltage stability nor reactive power flows. This makes them inadequate for the assessment of reactive power provision. A techno-economic AC load flow model of the European transmission grid is developed to cope with these shortfalls. Power plants are represented with their generator capability curves characterizing their ability to provide reactive power. Compensation facilities, such as Static VAR compensators that have the purpose to provide reactive power to the grid are reflected by means of their operating range. Furthermore, the possible reactive power provision of HVDC converter stations with VSC technology is considered.

To test the model validity, model results are compared to a DC-approximation model and – based on a test network – as well to a commercial load flow calculation software. As model results indicate a good model accuracy, the model is used to analyze the economic benefits of renewable energies for providing reactive power via the distribution grid. Opportunity cost of reactive power provision as well as system cost determined by the model is compared across different load situations. The work includes an analysis of the status quo as well as a future outlook based on different scenarios for the installation of renewable and conventional energy sources as well as network extensions.

AC load flow equations are non-linear, which makes solving the problem difficult. Therefore simplifications have to be made in order to consider inter-temporal restrictions such as investment decisions in compensators.

Results

The AC load flow model increases the accuracy compared to a DC approximation approach, although the deviations between AC and DC model are rather small ($< 6\%$) in 90% of the cases. The backtesting of the AC model with a commercial load flow software shows a very good fit with most deviations being less than 1%. Preliminary results for the status quo of the German transmission network show, that in situations with a low residual load, opportunity cost for the provision of reactive power reaches up to 10 EUR/Mvarh (capacitive). In high load situations opportunity cost is in the order of 2 EUR/Mvarh, while in most other situation it is nearly zero. In the case of a low residual load, this increased value can be explained by a small number of conventional power plants dispatched and able to provide reactive power. In these situations that will occur more often in the future, the feed-in of reactive power from the distribution grid could reduce this opportunity cost to nearly zero. In a future 2024 scenario with HVDC links from North to South installed, a considerable amount of reactive power can be provided by the converter stations. If additional feed-in from the distribution grid is considered, opportunity cost can be reduced to nearly zero in most situations.

Conclusions

The analysis shows that a techno-economic AC load flow model does not only allow the valuation of reactive power supply by means of opportunity cost, but also improves the accuracy of load flow calculation compared to common DC approximation models. Furthermore, the work adds an economic perspective to the discussion about voltage stability in future energy systems.

On the one hand the provision of reactive power from distributed generation facilities is able to reduce opportunity as well as system cost for voltage stability. On the other hand it is demanded that renewable energy sources assume more system responsibility. Therefore, the regulatory environment should foster the provision of ancillary services from renewables. This work shows that reactive power has an observable value. Thus, the question arises, what the optimal economic setting for reactive power supply to an electricity system with increasing shares of distributed generation is.

In this context, the work unveils which factors influence the opportunity costs of reactive power provision and what its value in different situations would be. It also helps to understand which reactive power sources – conventional power plants, compensation devices or distributed generation – contribute best to voltage stability from an economic point of view.

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