# *THE INFLUENCE OF VOLTAGE STABILITY ON CONGESTION MANAGEMENT COST IN A CHANGING ELECTRICITY SYSTEM*

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**Overview**

The installation of renewable energy sources has been changing the energy landscape for the past decade. The intermittence of volatile sources like wind and solar power as well as the construction, which is often far away from load centers, poses challenges both for the planning and for the operation of electricity grids. In Germany, not only offshore wind energy is installed in the North, but also for onshore wind energy preferable areas are located in Northern Germany. Consequently, transmission grids have to be extended in order to transport electricity from North to South, which causes problems of social acceptance. Meanwhile, congestions increase, leading to costly redispatch and curtailment measures in order to maintain the system stable.

System operators do not only have to ensure that load limits of their assets are not exceeded, but also have to maintain the operating voltage in their grids within the stablished boundaries. Historically, large power station in the transmission grid were the main source of reactive power that can be used to control the operating voltage in the grid. As most renewable energy sources are decentralized, more and more generation from conventional sources connected to the transmission grid is replaced by generation on distribution grid level. This leads to a lack of reactive power availability in the transmission grid, especially when conventional power plants are not running. On the other hand, grid extensions require increasing reactive power flexibilities to cover a variety of emerging grid situations. If reactive power from conventional sources is not sufficient to maintain the operating voltage within the limits, voltage-induced redispatch measures have to be conducted in order to increase the reactive power provision, leading to higher grid charges for electricity customers.

Additionally to power stations, reactive power can also be provided by compensation devices. System operators can invest into those devices, which also leads to an increase in grid charges. Alternatively, reactive power can be provided by renewable energy sources connected to the distribution grid. This approach requires a sufficient equipment with information and communication technology as well as a cooperation between TSO and DSO to ensure a coordinated reactive power provision.

The aim of this work is to analyze the influence of reactive power and voltage stability on the development of redispatch measures and their cost. Reactive power provision from conventional sources shall be compared to a provision from the distribution grid and from compensation devices. Different scenarios for the extension of electricity grids as well as changes in the layout of the market zones are compared.

**Method**

A redispatch model is applied that does not only consider current-induced redispatch (overload of system equipment, such as transmission lines) but also voltage-induced redispatch. The model considers the German transmission and 110kV distribution grid as well as the transmission grids of the neighboring countries with a high spatial resolution. It contains load grid nodes, transmission lines, transformer stations, load centers, power plants and renewable energy sources. In order to consider load flows as well as the operating voltages at different nodes of the grid that result from a market-based power plant dispatch, an enhancement of the DC-approximation approach is used. Reactive power and operating voltages are considered using an approximated, linear and iterative approach. The quadratic reactive

power behavior resulting from the load flows on the power lines, is calculated ex-post and fed back into the next iteration.
The accuracy of the load-flow calculations is proven by testing them against a non-linear AC load flow model. These calculations show that load flows can be estimated very well with a linearized model, while voltages still show a good congruence with voltages obtained from AC load flow models.
The redispatch model allows to estimate current-induced and voltage-induced redispatch costs separately. A two-step approach is applied for this purpose. In the first step, only line utilization is restricted and it is assumed that unlimited reactive power is available. In the second step, reactive power behavior and feed-in are considered, restricting the grid voltages to an acceptable voltage band. This method allows to distinguish current- from voltage-induced redispatch. Hence, the cost of voltage- and current-induced redispatch can be compared for different scenarios.

**Results**

Model results indicate that delays in the grid extension have a large influence mainly on current-induced redispatch cost. If grid extensions are delayed by five years and HVDC links in Germany are not constructed by 2025, preliminary results show an increase of congestion management costs from 300 mio. EUR to 2 bn. EUR per year. A split of the German-Austrian market zone would reduce this redispatch cost by approximately 100 to 200 mio. EUR and would lead to welfare changes on the underlying day ahead electricity markets. Consequently, a split of the market zone cannot be seen as an alternative to grid extensions in Germany. An analysis of splitting the German market zone is pending.
Considering a delayed grid extension, also voltage-induced redispatch costs increase compared to a scenario including the planned grid extensions. This cost can be reduced by including sources connected to the 110 kV grid into the reactive power management. Preliminary results show a cost reduction potential between 10 and 50 mio. EUR.

**Conclusions**

The analysis shows that common techno-economic grid model approaches for current-induced redispatch can be adjusted to incorporate voltage stability considerations. In decentralizing electricity systems the controlled provision of reactive power from the distribution grid can be one component of assigning more system responsibility to renewable energy sources. Redispatch costs can be reduced by exploiting these resources, but other drivers, such as grid extensions and the layout of the market zones, have a much greater influence on those costs.