Executive summary

Modeling electric network capacity under different institutional settings

Master's thesis by Christina Roolfs*

Background and objective

The master's thesis is motivated by Switzerland's situation as a transfer country for electricity. Switzerland is and will remain a transfer country for electricity and, consequently, will be neither a net importer nor a net exporter. Power trade between European regions will increase. From economic theory, it can be concluded that for net exporting and net importing countries, the price in the low-price (net exporting) regions increases while the price in the high-price (net importing) regions decreases. This raises the question: what happens to transfer countries, which neither primarily import nor export?

Given that power does not flow along a single transport path in a network, this question becomes interesting when a flow-based pricing model is applied and network congestion occurs. It allows the integration of electric network properties into a generation cost minimization process. The objective is to minimize total cost by allocating as much generation as possible in low-price regions and to transfer it to high-price regions. A transfer country is in between these two price poles.

Applying a flow-based power pricing model to the highly complex network and interest structure in continental Europe is rather new and has been gathering attention over the last ten years due to restructuring of the electricity sector. Flow-based pricing mechanisms are superior to congestion management based on net transfer capacity (NTC) values because they allow for a more efficient use of the existing network capacity. Various flow-based congestion management mechanisms are already applied in parts of Europe. The Central Western European (CWE) region is planning to integrate a flow-based market coupling method, which Switzerland may eventually join. This master's thesis focuses on analyzing the consequences for Switzerland under a multilateral flow-based power pricing mechanism. To date, no such analysis has been completed for a transfer country with storage facilities.

The process for evaluating the consequences of a flow-based power pricing scheme for network planning in transfer countries was divided into four steps:

1. comparing existing congestion management schemes and concluding about the suitability and shortcomings of those schemes to justify the chosen approach;
2. modeling flow-based power prices and deriving conclusions for power transfer regions such as Switzerland;
3. applying the findings of flow-based power prices and developing two preliminary value-based network expansion models based on a central and national planned perspective; and
4. comparing and applying the qualitative findings to the current Swiss situation and its expansion policy.

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Results

Congestion management schemes integrate scarce electric network capacity into the power market. A variety of cross-border congestion management concepts exist in the European electricity market. This is especially attributable to the haphazard development of the power sector: varying control areas and power markets exist that were, in former times, not primarily constructed for the purpose of cross-border trade. In general, market-based concepts are most favored and an integration of power flow properties in a network increases cost-effectiveness.
The calculation of the cross-border network capacities is extremely complex. The entire system is highly dependent on many interrelated structures. Hence, the power system's complexity, with its physical properties integrated into different market designs, makes it difficult to accurately attribute price effects to a certain impact.
The theory of nodal pricing[1] stems from an engineering approach and produces the only cost-effective solution. It also allows approximation of aggregated zonal pricing schemes such as flow-based market coupling which requires a lower level of market harmonization. Even though nodal pricing does not reflect the real world situation, it is the most precise instrument to analyze interactions in electricity trade with limited network capacities. Hence, nodal pricing is an adequate method for modeling the flow-based power prices in a network and to give guidance for transmission line scarcity. Therefore, this method is chosen to derive a benchmark for the value of transmission capacity for expansion planning.

Within this master's thesis, we distinguish between low-price, high-price and transfer nodes which are representing the situation of a net exporting, net importing and transfer regions. Derived from the optimization process of the nodal pricing theory and depending on the network structure, transfer nodes can either increase or decrease congestion in a network. A network congestion relief is reflected by a price below the system's marginal generation cost. This becomes interesting if storage facilities are located at the respective node: if one can withdraw at that node from the grid, one could even be paid for the withdrawal. On the other hand, if additional demand at a transfer node increases the network congestion, the price is even higher than at the high-price nodes. The network congestion relief effect occurs if the outflow line is congested[2]. Thus, nodal pricing does minimize total cost, but not every region would benefit under such a scheme. Hence, different perspectives based on flow-based power pricing are relevant. The congestion relief or increase effect should be included into the network planning as it provides benefits or cost for transfer countries if a flow-based mechanism is or will be applied.

For decision-making in network planning based on a flow-based pricing scheme, we apply a value-based expansion model to two institutional planning settings. First, network expansion planning was, and still is, to some extend done on a national or sub-national level. Second, due to continued European market integration and a higher penetration of renewable energy supply, central coordination is increasingly used in order to integrate the impacts of transmission expansion projects.
Under a value-based expansion scheme, for the central planner the optimal transfer capacity is reached when the marginal cost of expanding the transfer capacity equals the marginal congestion rent. For the national planner, the optimal line capacity is based on the properties of the nodal prices at the transfer nodes. The national planner is maximizing net benefit with respect to the congestion rent of the national transfer capacity, the national capacity expansion cost and the constraint to keep the outflow lines congested. The optimal capacity is reached

1 Nodal pricing is also known as locational marginal pricing (LMP).
2 Inflow and outflow lines are those lines that transfer power from the low-price nodes to the high-price nodes with a transfer node in between: The outflow line is the line from the transfer node to a high-price node.

for a national planner where the marginal congestion rent of the national lines equals the marginal expansion cost minus a term derived from the outflow line constraints. This analysis raises questions concerning the nature of this term and the complications posed by the dynamic (as opposed to static) nature of the surrounding network.

Switzerland's important role as a transfer country in the continental European electricity market will remain stable at least for the next four decades. Thus far, the cross-border transfer capacity is based on bilateral calculations between transmission system operators. When the transfer demand is higher than the available transfer capacity it is reflected in a positive price for transmission rights. Switzerland is already an important supplier of transfer capacity between the neighboring countries. It holds 20 percent of the cross-border transfer capacity of the Union for the Coordination of the Transmission of Electricity but accounts for only 3 percent of electricity consumption. However, the transmission capacity from Germany and France to Switzerland and from Switzerland to Italy are frequently congested and represent a bottleneck in the European trade structure.
The findings of this master's thesis project suggest that Switzerland should keep the outflow lines congested. These are the transmission lines from Swiss nodes to Italy’s demand nodes. This yields a comparably lower power price for the respective Swiss transfer nodes, if they can withdraw from the grid and store electricity. Hence, high demand and congested transmission capacity benefit the operating transmission system operator through the congestion rent, and the possibility of congestion relief benefits owners of storage facilities, as it enables them to buy cheap power and sell it at peak-hours or to offer balancing power. Therefore, a flow-based generation allocation mechanism could have positive effects on Swiss welfare as it not only gains congestion rent, but also can yield a lower price at Swiss transfer nodes if the outflow lines are congested.
In reality, the necessity of expanding the capacity from Switzerland to Italy is weighted differently. The International Energy Agency (IEA 2012) and Consentec (2012) stress the major bottleneck at the Italian border and recommend an expansion. However, from the Swiss Federal Office of Energy (SFOE) perspective, the expansion of the capacity to France, Germany and Austria has priority whereas the expansion of the transmission bottleneck between Switzerland and Italy does not. Thus, the theoretically derived conclusion of this research project to keep the outflow lines congested is in line with Swiss national planning. The SFOE’s priorities can also be explained by the motivation to ensure the security of supply by increasing import possibilities from low-price regions under the current cross-border congestion management schemes instead of a preparation to join a flow-based pricing scheme. Thus, both explanations are justifiable as the security of supply and a possible integration of Switzerland into the CWE region, which is moving towards a flow-based management scheme, are stated as objectives by the SFOE and are in line with the expansion recommendation from a national planning perspective derived in this master's thesis

Conclusion

The results of this study suggest that under a flow-based pricing scheme in a multilateral power trade situation, a national planner of a transfer country should keep its outflow lines congested. This enables the transfer country to relieve network congestion in cross-border power trade settings and achieve comparably lower power prices at the transfer nodes. The strategy regarding network expansion planning for cross-border trade based on the flow-based power pricing is in line with the priority of the SFOE to increase network capacity to the low-price regions whereas the IEA sees the priority of capacity expansion between Switzerland and Italy.

Outlook

From a wide perspective, this master's thesis discusses both the high sensitivity of a generation cost minimization problem under a flow-based congestion management and power pricing scheme on the one hand, and the complexity of network expansion planning on the other. If the nested TSO structures in continental Europe and the interests of national planners, who can control parts of the network to some extent, are taken into consideration, an analysis becomes extremely complex.
Therefore, as a next step in the development of a flow-based power price and network expansion model for Switzerland, an appropriate stylized network topology with respect to the nodal aggregation should be developed to guarantee robust results. An important question is whether to include either a detailed representation of the European network, or to analyze what kind of stylized aggregated network topology of Switzerland and its neighboring countries is suitable in order to depict major interactions. The latter approach is most likely sufficient, if not superior, since a flow-based market coupling approach is also based on an aggregated zonal model and the probability of its application in Switzerland within the next few decades is higher than a nodal pricing scheme.
Additionally, problems related to the investment into transmission should be studied in more detail, since the formal model for expansion planning remains on a preliminary level. There are two important aspects which could not be attributed properly with regard to expansion planning: First, the national planner in the developed model is not yet able to consider the decisions of other network planners, despite the fact that they are part of the system. Second, the applied expansion model is based on a value-based approach and therefore does not solve the problem of cost-recovery by congestion rents.

Thus, this master's thesis provided a basis for decision-making processes if a more efficient management scheme of scarce cross-border transmission capacity is applied. It presents important insights for future research to inform decision-making processes in network expansion planning: depending on their network structure, transfer countries may benefit or suffer from flow-based pricing schemes. Future research could build upon this work to either analyze quantitative impacts for Switzerland under a multilateral flow-based power pricing scheme or further develop a complex network expansion model.

References

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