Reliability, Congestion and Investment in Electricity Transmission

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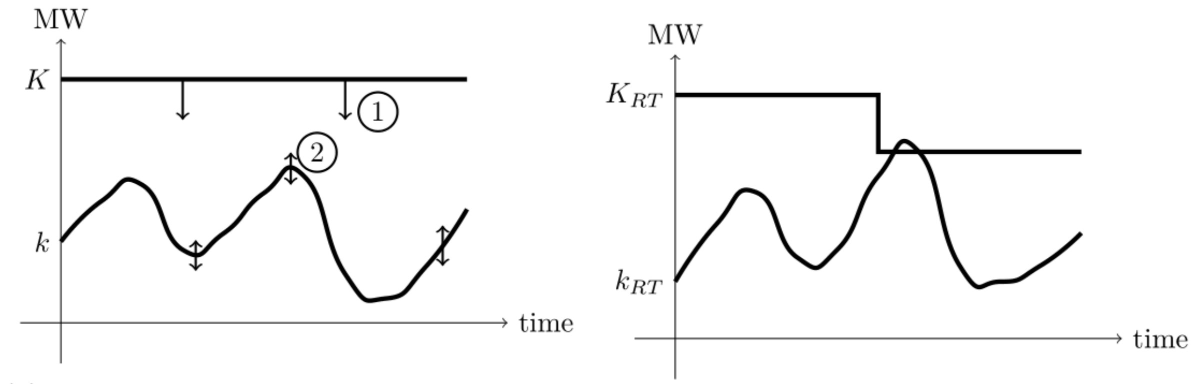
Overview

The motivation of this paper is twofold. First – a theoretical motivation – Joskow (2006, p.12) states that "Neither reliability transmission investments nor the interrelationship between reliability criteria and economic parameters are given much attention in the literature on competitive electricity markets." Second – a practical motivation – many countries are aiming for more regional integration of electricity transmission network to better coop with renewable energy integration and to lower wholesale electricity prices. For example, the European Union wants to bring the electricity interconnection level of all member countries to 10% by 2020 and is looking into raising the target to 15% by 2030 (European Commission, 2015) to achieve a common EU electricity market and facilitate renewable energy integration. Considering the costs of transmission investments and the difficulties to build new lines in both rural and urban areas, the question is whether a more efficient of current transmission capacity is possible.

This paper makes two contributions. First we incorporate reliability into the standard economic model of transmission investment to provide insight into the trade-offs between reliability, congestion and investment in electricity transmission. Second, we study the effect of the currently-used N-1 reliability criterion on reliability, congestion and investment. We show that the reliability margin implied by the N-1 reliability criterion is suboptimal since it does not depend on technical and economic parameters such as marginal investment cost, the value of lost load, the marginal congestion cost and the line failure probabilities.

Methods

The model studies the optimal investment and optimal use of transmission capacity between two regions. The installed capacity, called 'total transfer capacity' K, is the maximum possible electricity flow between the two regions. Only a part of this total transfer capacity, called 'net transfer capacity' k, is used for electricity transmission. That is, transmission system operators (TSOs) keep a transmission margin $K - k$ [MW] in case in real time the physical flow differs from the scheduled flow and the maximum transfer capacity is lower than expected due to transmission line failures. This is shown in the left-hand panel of Figure 1. The right-hand panel of Figure 1 shows a possible real-time realization of maximum transfer capacity and physical flow. In this case a combination of a higher physical flow and a line failure causes the physical flow to be larger than the real-time maximum transfer capacity at some point. As the transmission capacity of the remaining lines is insufficient to accommodate the physical flow between the regions, the network operator needs to shed load such that the physical flow is back within the bounds of the real-time transfer capacity..



(a) Maximum transfer capacity K and scheduled flow k before real time

(b) Real-time transfer capacity and physical flow

Figure 1: Maximum transfer capacity and electricity flow in day-ahead and real time.

The first-best benchmark of this model is:

$$\max_{\{k,K\}} \{S(k) - EIC(k,K) - c(K)\} \quad s.t. \quad k \leq K$$

where $S(k)$ is the net positive effect of interconnection on surplus, $EIC(k,K)$ is the expected interruption cost and $c(K)$ is the investment cost.

Results

The first-best benchmark shows that investing in more transmission capacity can lead to more interconnection surplus and to a lower expected interruption cost. How they are distributed depends on TSO regulation and the stringency of the reliability criterion. This also shows that a categorization into reliability transmission investment and economic transmission investment is arbitrary. In the short term, one can increase reliability by increasing congestion, and vice versa. However, TSOs and regulators still distinguish between reliability and economic transmission investment as two separate objectives (FERC,2006), (ENTSO-E,2014,p.60) and PJM (Joskow, 2005, p.111).

In contrast to the standard economic result that optimally the sum of congestion rents equals total transmission investment cost (under constant marginal cost of investment), the model also concludes that optimally the sum of congestion rents should be higher than the total transmission investment cost.

Secondly the model allows to assess alternative reliability criteria like the N-1 rule. It shows that the optimal reliability margin depends on both economic parameters and technical parameters. We show in a four-node network that the currently used N-1 reliability criterion is suboptimal since it only depends on the topology and the use of the network. A probabilistic reliability criteria, which incorporates economic and technical aspects, would improve efficiency.

Conclusions

This paper makes two contributions. First we incorporate reliability into the standard economic model of transmission investment to provide more insight into the trade-offs between reliability, congestion and investment in electricity transmission. Second, we study the effect of the currently-used N-1 reliability criterion on reliability, congestion and investment. We show that the reliability margin implied by the N-1 reliability criterion is suboptimal since it does not depend on technical and economic parameters such as marginal investment cost, the value of lost load, the marginal congestion cost and the line failure probabilities.

Moving towards probabilistic reliability criteria will decrease both the current short-term and long-term inefficiency. However, determining a more detailed expected interruption cost function is vital for practical implementation of probabilistic reliability management. This requires e a richer model of the network, failure contingencies, and the supply and demand equations per zone.

References

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