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Coordinating cross-border electricity interconnection investments and trade in market coupled regions

Manuel V. Loureiro[a,b,*], João Claro[a], Paul Fischbeck[b]

[a] INESC TEC and Faculdade de Engenharia, Universidade do Porto, Campus da FEUP, Rua Dr. Roberto Frias, 378, 4200-465 Porto, Portugal
[b] Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, United States

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ABSTRACT

Investments in cross-border electricity interconnections are key for the integration of the European energy market. To analyze policy frameworks for these decisions, we model two settings for the expansion of transmission capacity between two regions, where the volume of investment is agreed upon through either Nash-Coase or Nash bargaining. For each setting we provide fair share cost allocation solutions, respectively with and without compensations. Each region has its own TSO, maximizing social welfare within its geography, and the markets are modeled with linear supply and demand curves, with trade enabled by the interconnection. The results of the application of the models to the Iberian market suggest their ability to estimate realistic values for the capacity of cross-border interconnection between two regions.

1. Introduction

1.1. Background

The European Union (EU) sees the integration of its national electricity transmission networks into a single European energy market as a key enabler of competition and in general of the long-term improvement of social welfare in the Eurozone. Taking a resolute step in this direction was already the objective in 2002, when the Barcelona European Council set a target for the installed interconnection capacity in 2005 of 10% of the existing production capacity, even across borders where congestion was not a concern at the time [1].

It has been argued in several fora that this policy target has failed to be met. Until recently, most European countries still featured low interconnection capacities, regardless of the capacity of their internal electricity transmission networks: the cross-border transmission bottlenecks that existed in 1996 were still present in 2007; up to 2004, only 4% of the electricity transmission investment was being directed to interconnections; and an interconnection priority project presented by the European Commission largely underestimated the required investments [2]. In the EU, the most important bottlenecks have been four regions whose interconnection capacity with mainland Europe is clearly insufficient: the Baltic States, the Iberian Peninsula, Italy, and Great Britain and Ireland. These "electric peninsulas" have a high renewable generation development potential, which will be constrained in the long-term if interconnection capacity is not increased up to 10 times, in the case of the Iberian Peninsula's connection to mainland Europe, or at least doubled, in the other regions [3].

The interdependencies between national energy markets and Transmission System Operators (TSOs) in the EU have increased significantly in recent years, for the most part due to the significant development of renewable energy sources and the ongoing efforts to liberalize the EU electricity market. Cross-border power flow growth can only be appropriately supported if an adequate electricity interconnection structure is in place [4].

The management of cross-border flows can be implemented through the auctioning of transmission rights, although Joskow and Tirole [6] have shown that this mechanism results in a higher market power for generation in the importer. The EU started by using non-market-based methods to manage cross-border congestion, such as access limitation, priority listing, and pro-rata rationing. Currently, prices are set implicitly through market coupling. Market-based methods have the advantage of providing reliable economic signs of the need for interconnection expansions [5].

Market coupling allows interconnection flows to be managed in a joint regional Power Exchange (PX) that dispatches power based on demand and available interconnection capacity. In the EU, seven PXs have joined efforts to launch the Price Coupling of Regions (PCR)

* Corresponding author at: INESC TEC and Faculdade de Engenharia, Universidade do Porto, Campus da FEUP, Rua Dr. Roberto Frias, 378, 4200-465 Porto, Portugal.

E-mail address: loureiro@cmu.edu (M.V. Loureiro).

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initiative, with the objective of devising a single price coupling solution to define electricity prices and manage cross-border capacity in Europe. The most important step in this direction was the launch of the North-Western Europe Day Ahead (NWE DA) initiative, a day ahead market coupling implementation that went live in February 2014, accounting for more than 75% of the total electricity consumption in Europe. This initiative was supported by the European Network of Transmission System Operators for Electricity (ENTSO-E) and coordinates the TSOs and PXs of Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Great Britain, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland and Sweden. A few months later, in May 2014, an additional step was given, with the extension of the initiative to Portugal and Spain, enabled by the interconnection between France and Spain.

The reinforcement of interconnection infrastructures requires neighboring TSOs to reach an agreement and commit to a single interconnection investment solution capable of delivering benefits to all parties involved. This single solution can be reached either through a centrally regulated and coordinated process, voluntary local agreements, or a combination of both [7].

As the EU power system evolves into a truly trans-European infrastructure, and especially considering the recently implemented price coupling initiatives, cross-border interconnection management is becoming increasingly important, and thus warranting increased attention from both researchers and practitioners.

1.2. Interconnection expansion in market coupled regions

In this paper we introduce the Interconnection Transmission Expansion Problem for Market Coupled Regions (I-TEP-MCR), which can be regarded as a particular case of the more general Transmission Network Expansion Problem. It considers the decision to invest in a single electricity transmission corridor to establish or reinforce cross-border electricity transfer between two regions that are part of a single coupled market. Each region has its own TSO, which we assume to seek only social welfare maximization within its own geography, and to be unable to place any additional artificial constraints on transmission capacity.

Cooperative game theory provides an adequate framework to analyse I-TEP-MCR, as the modelling of bilateral negotiations allows balancing conflicting design objectives, i.e., the optimal interconnection capacity, between the two regions [35], and allows regions to improve their individual conditions [34], as measured herein through variations in net social welfare.

Optimal interconnection investment policies for settings with and without compensations, i.e., where the volume of investment is agreed upon through either Nash-Coase or Nash bargaining, respectively, are illustrated with a study of cross-border investment between Portugal and Spain, using detailed data on the buy and sell bids in the Iberian market throughout the year of 2013. The region and time frame were chosen due to the full availability of raw data for the bids.

1.3. Structure

The remainder of the paper is structured as follows: in the following section, we review prior relevant contributions to the literature; in Section 3, we present I-TEP-MCR, and describe a case application focusing on the Iberian market; optimal interconnection investment policies are illustrated for the case application in Section 4; Section 5 closes the paper, with conclusions, policy implications, and suggestions for future work.

2. Literature review

In restructured energy markets, the supply and transmission businesses have been unbundled to foster increased competition among electricity producers, that stand on equal footing to access the transmission network. Historically, however, the number of operating electricity companies has mostly remained low [14,15], and insufficient unbundling has been suggested as one of the key reasons for the difficulties in increasing interconnection capacity in the EU [16]. A low level of interconnection capacity limits electricity trade and contributes to price differentials across regions, burdening social welfare with congestion costs.

An additional important benefit of international power flows is the ability to improve the matching between uncertain generation and uncertain demand, allowing a reduction of the total level of resources required to guarantee an appropriate operation of energy markets [17]. The desired increment in competition remains challenged and so does the possibility of accessing cheaper sources, as well as larger shares of renewable sources [18].

It has also been argued that TSOs do not act independently of the political sphere [2], with national goals interfering with the investments towards an interconnected EU. With interconnections and trade, *ceteris paribus*, the prices in at least one of the connected countries must rise, even if social welfare rises in all countries, i.e., the consumer surplus may decrease even if the consumer and producer surplus increases in total [19]. In the exporting regions, generation increases, prices increase, and both consumer surplus and demand decrease. The opposite happens in the importing regions, where consumer surplus increases due to a decrease in electricity prices, but producer surplus decreases. This pattern of variations is a source of disagreement that may lead to politics interfering with the investment decision process. Parisio and Bosco [20] identify these variations as volume effects, and in addition point out an important bid-level effect related to the impact of a higher trade on generator dispatch strategies. In the exporting regions, generators with higher marginal dispatch costs will bid higher quantities and those with lower marginal costs will bid lower quantities, the opposite happening in the importing regions. Whereas by the former mechanism price differentials will always decrease, the bid-level effect can in fact lead to variations in any direction.

Apart from the complexity of permission procedures, reaching an agreement between the TSOs is arguably the other major difficulty that is faced in this context [21]. In general, TSOs will have different preferences regarding the desired level of interconnection capacity, but a single volume of investment and allocation of transmission investment costs will have to be agreed upon, satisfying all regions. This decision can be made centrally by a supraregional planner, independently by each regional planner, or cooperatively between the regional planners.

Buijs et al. [22] propose two models for this problem, based on the first and second approaches outlined above. One is a Mathematical Program with Equilibrium Constraints, in which all the planners accept the decisions that maximize the total social welfare, as if a supraregional planner existed, and the transmission planner acts as a Stackelberg leader, preceding the market dispatching decisions. In the other model, the planners act individually, with responsibility only for the parts of the interconnection lines that are located in their own territories, seeking to maximize the social welfare of their own regions but taking into account the decisions of the other planners. The problem is formulated as an Equilibrium Problem with Equilibrium Constraints, with a non-cooperative Nash equilibrium solution. In equilibrium, the capacity of each interconnection is the minimum among the levels desired by each region that it connects, as this would become the bottleneck. Circumstances in which all the planners might benefit from a different split of the investments costs, e.g., with one region covering part of the costs of another, are not considered, possibly leading to solutions with lower levels of investment.

Without a regulatory framework capable of leading the planners to consider the total social welfare, if such solution does not provide economic benefits to all planners it is extremely unlikely that it will be accepted by those unfavored. Motivated by this concern, Buijs and Belmans [23] suggest another approach that considers only the