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Optimal transmission planning under the Mexican new electricity market☆

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ABSTRACT

This paper addresses electricity transmission planning under the new industry and institutional structure of the Mexican electricity market, which has engaged in a deep reform process after decades of a state-owned-vertically-integrated-non-competitive-closed industry. Under this new structure, characterized by a nodal pricing system and an independent system operator (ISO), we analyze welfare-optimal network expansion with two modeling strategies. In a first model, we propose the use of an incentive price-cap mechanism to promote the expansion of Mexican networks. In a second model, we study centrally-planned grid expansion in Mexico by an ISO within a power-flow model. We carry out comparisons of these models which provide us with hints to evaluate the actual transmission planning process proposed by Mexican authorities (PRODESEN). We obtain that the PRODESEN plan appears to be a convergent welfare-optimal planning process.

1. Introduction

Until 2015, Mexico's electricity system's supply side had been characterized by an industrial structure with a vertically integrated state owned monopoly, the *Comisión Federal de Electricidad* (CFE), which exclusively carried out almost all activities in electricity generation, transmission, distribution and marketing, as well as the operation of the entire electricity system.[1] The idea of the Mexican electricity reform, passed by Congress by mid-2014, is now to evolve from this closed system with asymmetrical information between CFE and the energy regulator (*Comisión Reguladora de Energía*-CRE) to a more open and transparent one, where the generation sector is liberalized so that new private generators enter the market to compete with incumbent CFE's generating plants.

The new electricity market in Mexico started operations in January 2016. For the first time in many decades, actual commercial exchange between private generators and consumers will then be possible. This in itself represents a significant change in the organization of Mexican electricity markets. Moreover, another deep transformation implied by the reform relates to electricity system operation. This function is now to be taken out from CFE's hands and left to an *independent* system operator (ISO), the *Centro Nacional de Energía* (CENACE), which will be in charge of both the short and long-run system operation as well as of electricity-grid expansion planning. The rest of the industry areas –including transmission, distribution, marketing activities and supply in the retail market– remain within CFE, but with the aim of subcontracting private agents through competitive tenders.[2]

The expected growth in demand and increasing use of renewable energy sources in the country furthermore requires both expansion and reshaping of the current transmission network. The foreseen growth in electricity demand for 2003–2028 (85%) can be compared against the corresponding expected growth of transmission capacity (18%).[3] In its

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[1] Only some cogeneration and self-supply activities were allowed to private generators under restrictive conditions on their surplus power (that had to mainly be sold to CFE). Since 1992, independent-power-production (IPP) projects were also allowed, but only to sell under long-term contracts all of its power to CFE, who subsequently sold it to final consumers.

[2] Another crucial decision of the reform is radical transformation of the electricity pricing system, evolving from a complex regressive subsidized system (see López-Calva and Rosellón, 2002) to a more transparent pricing scheme based on nodal prices, financial transmission rights (FTRs), and direct lump-sum subsidies.

[3] CENACE (2016).

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recent 15-year plan,[4] CFE has in fact gauged 19.3 billion USD in transmission projects including 19,555 circuit-km of new lines. Compared to its main North American trade partners (USA and Canada), where electricity transmission capacity usually expands faster than demand growth,[5] it is evident that Mexico should become much more aggressive in promoting investment in transmission lines, both in terms of planning and regulatory measures.

The approach of Mexican authorities to transmission expansion is based on projected electricity demand and generation supply for an extended period (see CENACE, 2016). This projected supply and demand is ex-ante forecasted by the Mexican energy ministry (SENER). CENACE will be actually taking care of grid expansion planning based on a power-flow program that considers in an integrated simultaneous fashion generation dispatch and transmission expansion.[6] This exercise is to be repeated annually, and will provide CFE (and subcontracted private agents) a guidance on which transmission links to expand. Once a new transmission expansion project is being built, the CRE will regulate it aiming to reach a balance between risk management and incentive provision in the actual planning process of expanding networks according to PRODESEN (*Programa de Desarrollo del Sistema Eléctrico Nacional*).[7] The CRE preliminary plans to use a system of tenders (*ex-ante* competition) to select the private market agents that would cooperate with CFE to develop new transmission links.[8] These tenders would define the transmission tariffs that will be regulated through cost-plus regulation with additional periodical efficiency adjustments based on international price and performance transmission benchmarks.[9]

In this paper, we firstly propose a bi-level programming model to study the use of incentive price-cap regulation to incentivize the expansion of Mexican networks. One level (*upper level*) models the profit maximizing behavior of a transmission company (Transco) subject to price-cap regulation, and the second level (*lower level*) models the power-flow dispatch problem of the ISO.[10] Secondly, we analyze optimal centrally-planned expansion of the Mexican network through the use of a power-flow stylized model where an ISO maximizes net welfare (the sum of consumer and producer surpluses plus congestion rents minus the cost of expanding networks). Both the bi-level regulatory model and the centrally-planned expansion model are further compared to each other, also relying on simulations for other systems in North America. This exercise provides clues on the welfare-efficiency properties of the expansion plans proposed by CENACE in the design of the national transmission development plan, PRODESEN, a planning process which relies on generation-cost minimization and transmission power-flow modeling. We additionally show that incentive regulation results in a welfare-optimal expanding process, and therefore should provide the CRE with a hint on how to implement its final regulation on transmission tariffs.

Our document is organized as follows. We initially present in Section 2 a literature review on optimal transmission planning and regulation. Section 3 addresses the details of the PRODESEN plan. In Section 4 we develop our models, including data and results. First, 4.1 presents the bi-level regulatory price-cap HRV model[11] that aims to incentivize convergence of transmission tariffs to a welfare-optimal benchmark. Data used is further shown in 4.2, while 4.3.1 depicts the results of our HRV regulatory model in terms of capacity expansion, congestion and nodal-price convergence. We additionally carry out in 4.3.2 a comparison of the expansion promoted by the HRV price-cap model in Mexico with similar expansion processes in other regions in North America, as well as with the welfare-optimal planning model of an ISO which centrally decides network expansion. Section 5 concludes with hints derived from our analyses on the welfare properties of the PRODESEN plan, as well as with discussion on needed future research.

2. Literature on transmission expansion planning and regulation

In this document, we address welfare-optimal expansion of the Mexican transmission grid under a nodal-pricing system. Two institutional regimes are typical in electricity transmission. The independent-system-operator (ISO) regime, and the transmission-system-operator (TSO) regime. In the ISO regime, generation system-operation and grid-expansion planning are taken care by a system operator while ownership remains within the transmission firm(s). Oppositely, in the TSO regime system operation, planning and ownership of the grid are integrated into a single company.

The Mexican electricity transmission system follows an ISO approach as is the case throughout some Canadian provinces (Ontario, Alberta), various US states (Texas, California, New York, New England, Pennsylvania-New Jersey-Maryland and Mid-West), the Americas (Argentina, Chile, and Brazil), Australia and some European countries (Ireland and Switzerland). In the rest of Europe, the TSO approach prevails (e.g., Nederland, Germany, France and Belgium).

Both in the ISO and TSO regimes, the aim is to efficiently develop transmission networks. Optimal transmission expansion planning and regulation are widely explored in academic literature. Optimal mechanisms for transmission expansion are difficult to design because of the physical characteristics of electricity network flows governed by the Kirchhoff's laws, which cause negative local externalities due to loop flows.[12]

A traditional approach to transmission expansion has been central planning, either carried within a vertically integrated utility or by a regulatory authority. Transmission planning schemes have been ana-

[4] CFE (2015).

[5] U.S. Energy Information Administration (2016).

[6] Integrated transmission planning is not a trivial issue. There are other systems that carry out the transmission expansion process decoupled from generation dispatch, usually resulting in inefficient excessive capacity investments (see Kemfert et al., 2016).

[7] The role in practice of the regulator, CRE, only comes after the expansion planning process carried out by SENER and CENACE in the PRODESEN. We do not explicitly address in this paper how the CRE regulates tariffs. However, our HRV model –that in our paper is mainly used to provide a decentralized benchmark against which to compare the PRODESEN—could provide a qualitative incentive-regulation alternative to regulators. However, again, we do not carry out an explicit comparison between the actual CRE's tariffs and the implied tariffs resulting out from our HRV model. We neither analyze in this paper regulation in a vertical sense that considers regulation of power generation, nor potential-strategic behavior of the regulator. Our two models –the HRV price-cap model and the centralized ISO model—provide welfare results and capacity expansion results. We compare the latter with the expansion results proposed by the PRODESEN.

[8] The CRE has only recently published a set of preliminary transitional transmission tariffs based on three-year CFE's transmission costs. The final regulatory methodology for electricity transmission is expected to be announced in the near future.

[9] The task of carrying out explicit comparisons between the actual CRE's tariffs and the implied tariffs resulting out from the HRV model are again beyond the scope of the current paper. The reason is that such a task requires careful laborious analyses of regional systems. Espinosa and Rosellón (2017) illustrate how such analyses might be performed for the isolated electricity system in Baja California. The comparison of the HRV tariffs with the CRE's tariffs for Southern Baja California is done under two cases on nodal structure, using real data from CENACE. In a first aggregated case, a three-node market is assumed. In a second disaggregated case, a more detailed thirty-one node structure is modelled. The second case allows for more detailed results on planned capacity-increase for each transmission line in the system. Tariffs are calculated by taking into account the fixed tariff resulting from the HRV model as well as congestion rents. Additionally, weights are applied using the same logic as the CRE's tariffs. That is, 70% is considered a charge to consumers, and 30% to generators. Demand projections by SENER are used for 10 years. The expected payoff for consumers is calculated, as well as their savings or excess expenditures. In all cases, the HRV tariffs align better than the CRE's tariffs regarding investment incentives to efficiently expand transmission links as well as on eventually converging to optimal social welfare.

[10] This is explained in more detail below in Section 4.1.

[11] HRV stands for the model in Hogan-Rosellon-Vogelsang price-cap mechanism (Hogan et al., 2010)

[12] The issue of optimal transmission expansion has been addressed through a range of different regulatory schemes and mechanisms that have been proposed and applied (e.g., Léautier, 2000, Kristiansen and Rosellón, 2006, Tanaka, 2007, Léautier and Thelen, 2009, Hogan et al., 2010).