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The economic value of transmission lines and the implications for planning models

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ABSTRACT

Many connections between economic efficiency, regulation, the environment and energy markets are evident in the planning for transmission upgrades in an electricity network. Transmission owners have to make decisions about investing in new assets while facing uncertainty in the generation plans, regulatory and environmental constraints, and current system endowments. In this paper, we demonstrate an analytical method for determining the economic value of individual transmission lines in a meshed network by calculating the total welfare effects for the system. While many regulators believe that traditional congestion rents provide the correct incentives for investing in transmission upgrades, we show that the uncertainty in system conditions breaks down this paradigm. The analysis uses an existing Security Constrained Optimal Power Flow (SCOPF) model and a test network to demonstrate how the method can be used to determine the welfare effects of changing the capacity of selected transmission lines. The results show that a substantial portion of the economic benefits for an individual line may come from maintaining system reliability when equipment failures occur. Furthermore, these benefits can change dramatically when inherently intermittent sources of renewable generation are added to a network, and the changes in benefits are not captured effectively by changes in the expected congestion rents.

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1. Introduction

On the afternoon of September 8th, 2011, the southwestern United States and Northwestern Mexico areas were immersed in what has been called *the Great Blackout of 2011*. The event, triggered by a tripping line in Arizona, lasted for around 12 h, curtailing 7890 MW of demand and affecting around 2.7 million people in the U.S. alone (Peevey et al., 2011). The series of cascading events that over 12 min culminated in the loss of power highlight some of the challenges for Regional Transmission Organizations (RTOs). While small deviations in frequency are allowed, supply and demand need to be balanced in real time, with the available units committed and ready for dispatch. Given the current sources of uncertainty, RTOs have developed a set of operating practices that imply temporal separation. However, many RTOs will see increased amounts of Renewable Energy Sources (RES) entering their generation fleets in the coming years (EIA, 2014). The main policy question in this case is how to better integrate these stochastic resources, and what are the transmission capacity needs. This in turn requires proper appraisal of the economic value of transmission assets in the system.

The objective of this article is to present an analytical framework to determine the economic value of transmission lines. In particular, we propose a methodology for assessing the economic welfare changes with transmission expansion, in the presence of large sources of uncertainty. This is a situation that is especially important due to the integration of inherently intermittent sources of generation (e.g., wind capacity) into the network (DOE, 2008). We illustrate our methodology with a detailed analysis of an IEEE test case system.

Transmission has long been recognized as a critical component in the reliable supply of electricity. However, as the management paradigm of the system changed, the traditional appraisal of the value of a transmission line may not reflect the contribution of interconnection. Traditionally, the system was operated using dispatchable resources located in far locations, usually close to fuel sources, and transferring this energy to demand centers. Therefore,

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transmission lines provided a spatial arbitrage function, transferring energy from cheap sources to expensive sinks. As the system has evolved to include more distributed and smaller size resources, the function that a transmission line plays goes beyond the spatial arbitration role. Optimal transmission planning in the presence of policies supporting Renewable Energy Sources (RES) such as renewable portfolio standards (RPS) should take into account the physical and idiosyncratic characteristics of the system (Munoz et al., 2013).

At this point, it is important to question why connecting or improving a connection between two regions is a welfare increasing measure. Eto (2002) found that there are significant savings that can be accrued by improving interconnection links, adding to nearly 13 billion USD per year due to the lower costs of generation. A related question then is what is, if any, the cost of congestion of the transmission system? Table 1 shows estimates of recent congestion costs in two of the deregulated markets in the U.S. After the Energy Policy Act of 2005 (USCongress, 2005), the U.S. Congress directed the Department of Energy (DOE) to investigate and track the congestion in the interconnected systems (DOE, 2009). Actually, some of the measures enacted after the financial crisis of 2008 envision the strengthening of the bulk transmission system (USCongress, 2008).

But transmission expansion involves the interaction of many components that need to be evaluated, and depending on the topology of the system, in certain cases the strengthening of transmission links can lead to welfare reductions and/or increased congestion. This is an important feature of the flow in transmission systems; the topology of the network and the degree of connectivity amongst buses will affect the externalities observed, and the cost structure of transmission projects leads to lumpiness in the investments made (Joskow and Tirole, 2005).

Our paper fills a gap in the literature by including a nuanced model of the transmission system and the non-linear constraints that are observed in the electricity system for evaluation of transmission assets. Our methodology is the first one to our knowledge to appraise transmission lines according to the value they provide in planning, using a security constrained Alternate Current (AC) Optimal Power Flow (OPF) and taking into account the deliverability of endogenously determined ancillary services. We however do not include integer variables in our evaluation of transmission lines (Munoz et al., 2013).

This paper is organized as follows. Section 2 reviews the relevant literature and presents a model for analyzing the effects of uncertainty in the network. Section 3 discusses the suggested measures of congestion and reliability and outlines our methodology using a stochastic model. Sections 4 and 5 describe the data we utilize and summarize the main results. Section 6 offers concluding remarks.

2. Theoretical framework and related literature

The process of transmission expansion in a regulated environment obeys criteria focused on assuring the reliability of the system (Baldick and Kahn, 1993). As deregulation in the generation system advanced, different mechanisms were developed to allow the entry of investors with merchant transmission lines. Nowadays, Regional Transmission Organizations (RTO) and Independent System Operators (ISOs) have different tools to manage congestion using market based mechanisms (e.g., Financial Transmission Rights FTRs Hogan (1992)). One of the challenges faced by the expansion of the transmission system is that the output must be able to both operate in real time, and accommodate the long term changes on generating capacity. Therefore, planners and operators need to provide a cohesive set of incentives for investors in merchant transmission lines to deal with both purposes (Cardell et al., 1997).

However, market structure and competition can distort the signals in the market (Borenstein et al., 2000; Oren, 1997). Moreover, the existence of market power alters the incentives to support transmission enhancements (Sauma and Oren, 2009); the correction of negative externalities in the presence of congestion can lead to welfare decreasing equilibria (Downward, 2010; Sauma and Oren, 2007); and the uncertainties associated with both political economy issues such as approving and jurisdictional limits, and the inherent difficulty in construction of transmission projects (Schuler, 2012) add to the challenges in transmission planning.

In this context, it is important to take into account that the bulk electricity system has to comply with the reliability criteria set forth by NERC (NERC, 2013). As a matter of fact, the reliability standards point out to the inherent tension in the time scales considered, with Resource Adequacy focusing in long horizons (e.g., Loss of Load Expectation), while operating reliability focuses in short term feasibility (e.g., $n-1$ security).

A further strain comes from the subsidiarity principle and the interactions between local (e.g., state) and national (e.g., federal) governments: adequacy implies that past investments in the capacity of the electric delivery system must be sufficient to make the real-time operations meet the reliability standards. The responsibility for ensuring that adequacy standards are met rests with State regulatory authorities. In recent years, and in part exacerbated by the development of wind capacity, the new generation capacity built has focused on the areas with the largest generation potential. These locations are usually far from the main demand centers, which requires the development of inter-state transmission corridors. Due to the economic and financial implications of maintaining adequacy standards, these developments have implications affecting the total annual cost of delivering real energy to customers that need to be recognized by regulators.

2.1. Transmission investment management

The use of market based mechanisms to manage congestion has traditionally relied on the use of Locational Marginal Prices (LMP) to indicate the need for expansion on transmission (Lin, 2009). The use of LMPs is closely associated with the idea of transferring electricity from cheap sources to expensive sinks. This concept is applicable when the topology of the network is radial, as is the case with the high tension network for the Western Electricity Coordinating Council. In such case, there are major interconnection corridors, linking the urban centers in California to inexpensive hydroelectric sources in the Pacific Northwest. Other more meshed network topologies may yield more or less accurate results, and this has been a subject of ample debate. The criticisms to this approach come from both the economic point of view and the technical point of view.

The calculation of congestion revenues derived from transferring energy between node A as a source and node B as a sink using the LMPs is defined as follows.

Definition 1. Denote the flow on AB as (F_{AB})

$$F_{AB} = \frac{(Energy\ at\ Node\ A - Energy\ at\ Node\ B)}{2}. \quad (1)$$

The source (Node A) provides positive energy to Line AB and the sink (Node B) withdraws negative energy from Line AB. Energy at

Table 1
Estimated cost of congestion.

	Sales revenue	Congestion cost
NE	17 billion USD[a]	\$125–600 million USD[a]
PJM	25 billion USD[b]	\$425.2 million USD[b]

[a] 2011 full year, ISONE (2012).
[b] First nine months of 2012, Bowring (2012).

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