SHOULD WE EXPECT INCREASINGLY VARIABLE INTER-REGIONAL ELECTRICITY FLOWS? WHAT IMPLICATIONS FOR ELECTRICITY MARKET DESIGN AND SYSTEM PLANNING

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Overview

Power systems are highly integrated, allowing for electricity flows across state and national borders. Therefore, facilitating trade in electricity is a cornerstone of the development of regional and supra-regional competitive wholesale electricity markets around the world. Historically, the direction of inter-regional electricity flow has been predictable, driven by legacy supply mix, subdued load growth, seasonal weather patterns, and economic activities. For example, over the decades, energy flows have been overwhelmingly moving from Canada to the U.S. in North America; but more recently, we have started to see a major change in the pattern of electricity trade between the U.S. and Canada.[1] When a region is a net importer of electricity from neighboring regions, we have also observed that flows into the importing region are relatively stable throughout the day (with some seasonal variability given the underlying load patterns and the nature of supporting generation resources). However, in recent years, we have seen inter-regional electricity flows switch directions more frequently (i.e., Region A sending electricity to Region B over the course of one day/hour and the next day/hour, Region B sending electricity to Region A) and predictability deteriorate.

In this paper, we will first examine how the evolution of supply and demand affects patterns of inter-regional and international electricity trade (as measured by physical flows). We will then develop numerical models to describe the evolution of these patterns of electricity flow, specifically addressing whether the unpredictable nature of electricity flow on interties between regional markets in the US and between the US and Canada will become more unpredictable or stabilize in the future. Finally, by reviewing various archetype market design constructs, we will consider how various market designs interact with more variable (less predictable) electricity flows on interties in the future. While our research focuses on North American jurisdictions, the framework can be adapted to other parts of the world where there are interconnected power grids and active levels of trade between nations and states.

Methods

We begin this research study by compiling historical interchange data from various North American Regional Transmission Operators ("RTOs") and Independent System Operators ("ISOs") to assess the hypothesis that the direction of inter-regional transmission flows at one time was stable, but has recently become more variable (in terms of direction of flow) and increasingly unpredictable. The analysis covers both inter-regional interfaces (i.e., flows on interties between established wholesale markets within the US) and international interfaces (between US and Canada).[2] The level of directional variability is quantified by the number of times inter-regional (or international) electricity flow switches direction over a set period of time, such as a year.

Second, we analyze the likelihood of a continued increase in the variability of inter-regional electricity flow. This is done by decomposing the trade flow patterns to their fundamental supply and demand factors. We also assess the efficacy of pricing regimes in matching those demand and supply factors and observed trade patterns, by evaluating price differentials between regions and measuring profitable trade opportunities. In a forward context, we look at system plans and other reliable projections to identify additional factors in the future that would contribute to incremental variability (directionally) and potentially less predictable inter-regional electricity flows.

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[1] *See* Shift In U.S.-Canada Electricity Trade: U.S. Exports Surge Amid Canada's Drought-Driven Power Shortages - SolarQuarter; U.S. electricity exports to Canada have increased since September 2023 - U.S. Energy Information Administration (EIA)

[2] Based on prior work, we had confirmed this hypothesis for the ISO-NE and Quebec intertie, ISO-NE and NYISO intertie, Ontario-Michigan intertie, and Ontario-NYISO intertie over a 3-year period. We will expand the analysis over a longer period and across more inter-regional transmission interfaces, to confirm that this observation can be generalized to a wider geographic area.

Finally, we consider, through numerical examples and the use of archetypes, the implications of an increasingly unpredictable inter-regional electricity flow. This is done by reviewing which electricity market design decisions and parameters are set based on an assumed level of inter-regional electricity flow. For example, ISO-NE's forward capacity market demand curve hinges on a parameter linked to a backward-looking average import volume from Quebec. We identify other administrative parameters based on similar research methodologies and discuss how a more unpredictable inter-regional electricity flow could impact the outcome of the market, and how these considerations eventually affect the costs and reliability of electricity service.

Results

The study first demonstrates that, in recent years, the frequency of inter-regional electricity flows switching direction has increased as compared to historical levels.

Based on our research, several factors contribute to this increased frequency of directional changes in electricity flow along interties. For example, the retirement of baseload and mid-merit power plants combined with the rapid development of renewable resources fosters the occurrence of supply imbalances caused by the intermittency of renewable generation (and the lack of dispatchable resources).

We also expect that the trend of increasing frequency of inter-regional electricity flows switching from one direction to another will continue in the near- to medium-term future. For example, the rise of data centers, which can be built at locations far away from traditional areas of high economic activity (and load), generate new electricity flow patterns on the power grid. Furthermore, we expect that data centers will shift their workload from one data center to another more frequently in the future, or schedule workload to other hours of the day. This will result in more dynamic load patterns which were not previously observed.

Finally, this paper will explore implications of variable electricity flows on market design. We have anecdotally observed that policymakers and system planners frequently use static and sometimes outdated (because they are based on historical data) assumptions with respect to the volume and direction of imports and exports in their studies. We will use actual examples in current market designs in North American markets to illustrate how such a static assumption could result in sub-optimal market outcomes.

Conclusions

Based on the observation that the frequency of inter-regional electricity flow switching from one direction to another has increased in recent years and that the underlying drivers that cause the increasing frequency will continue in the near- and medium-term future, we argue that consumers may benefit from electricity market designers and policymakers reconsidering the role of inter-regional (and international) trade in electricity.

There are multiple implications of an increasingly unpredictable inter-regional electricity flow pattern to system planning and policy. If system planners and electricity market designs continue to use a static flow relationship to configure electricity market parameters, a more dynamic flow pattern may result in over- or under-procurement of generating resources needed to meet reliability standards or may result in procurement of the wrong type of resources best suited to serve demand. It could also engender affordability issues (linked to under-purchasing or over-purchasing through longer-term instruments, such as power purchase agreements). Ultimately, working with more directionally variable and less predictable electricity flows will become an increasingly important lever to effectively control the costs and maintain the reliability of future electricity systems.

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