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Congestion Measures for Organized Markets in the U.S.

Emily Fisher and Joseph H. Eto

Environmental Energy Technologies Division

December 2013

This report is a pre-print of an article accepted for publication in the *Proceedings of the IEEE 47th Hawaii International Conference on Systems Science (HICSS)*, January 6-9, 2014, Waikoloa, HI.

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Congestion Measures for Organized Markets in the U.S.

Lawrence Berkeley National Lab
Prepared for the
Office of Electricity Delivery and Energy Reliability
National Electricity Division
U.S. Department of Energy

Principal Authors

Emily Fisher
esfisher@lbl.gov

Joseph H. Eto
jheto@lbl.gov

Ernest Orlando Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90R4000
Berkeley CA 94720-8136

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Abstract

Transmission lines deliver electricity that is generated at power plants to loads. When there is not sufficient transmission capacity to schedule or transport all desired electricity transfers, the transmission system is constrained, and the particular line, flowgate or interface is congested. While it is useful to measure congestion for several reasons—to identify where and how much congestion exists and how this changes over time, to determine whether or what to do about it, and to assess the effectiveness of actions taken—it is challenging to measure congestion in a meaningful and consistent way across markets or over time in the same market. This paper examines current public reporting of congestion measures for organized markets in the U.S., and what these measures can and cannot tell us about congestion across regions or over time in the same region.

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1. Introduction

Transmission lines deliver electricity that is generated at power plants to loads for consumption. These lines provide value in different ways, including improving reliability by connecting systems to each other and allow resources to be shared during contingencies and planned outages, improving economic operation of a power system by interconnecting loads and generators of different systems to dispatch the cheapest power to meet the load, and furthering public policy by connecting new kinds of generation or generation in new places that are desirable for public policy reasons (e.g., low carbon or other environmental objectives, promoting jobs).

When there is not sufficient transmission capacity to provide all these services, the transmission system is said to experience a constraint. A transmission constraint occurs when there is not enough transmission capacity—be it an individual piece of equipment like a transmission line or substation, or a set of transmission lines and other equipment that form a path or interface—to satisfy electricity transactions that people wish to make in a reliable way. Transmission congestion occurs when a constraint limits the desired schedule or actual flow of power.

Congestion occurs on all bulk electricity systems, and it is useful to measure this congestion for several reasons: to identify where congestion exists in a system; to determine how much congestion exists (and whether it is consistent, seasonal, or temporary); to track changes in congestion over time; to inform decisions about whether to mitigate the congestion and if so, what investments or operational changes should be made to mitigate it; and to assess the effectiveness of actions taken.

In order to serves these purposes, congestion needs to be measured and reported clearly and consistently. However, it is challenging to measure congestion in a meaningful and consistent way both across organized markets and sometimes for a single organized market over time. A meaningful measure of congestion would reliably reveal where and how much congestion exists, inform decisions about what congestion can (and should) be addressed and how, and what the consequences of alleviating the congestion are (e.g., changes in reliability, production cost savings, or progress toward a policy objectives). Consistent measures of congestion would allow the measure in one region to be compared to the same measure in another region, or in the same region over time.

This paper begins to explore what measures of congestion are publicly reported currently, what factors go into them, and how these factors affect what can or cannot be compared consistently across regions or over time.

Different entities publicly report measures of congestion for organized markets in the US. Although similar terms and calculated measures are reported for all of them, they are not necessarily defined or calculated in the same way. This paper explores publicly reported measures for six organized markets in the U.S.: ISO New England (ISO-NE), New York Independent System Operator (NYISO), PJM Interconnection (PJM), Midcontinent Independent System Operator (MISO), Southwest Power Pool (SPP) and California Independent System

Operator (CAISO).[1] We identify what congestion measures are reported and the factors that intrinsically impact the measures. These factors are market rules and congestion management procedures, in particular ones that fundamentally affect the amount of flow that pays for using constraints or that change the price of congestion.[2] We then explore what these measures can and cannot tell us about congestion across regions or over time in the same region.

The remainder of the paper is organized as follows. Section 2 discusses the publicly reported measures of congestion for each market. Section 3 identifies market characteristics, congestion management procedures, and other factors that impact the measurement of congestion in each market. Section 4 discusses what measures can and cannot be compared between markets. Section 5 concludes.

[1] ERCOT it is not included here because it is not in the Eastern or Western interconnection and thus does not face the same need or burden to cooperate with its neighbors on transmission issues.
[2] We do not address external drivers (e.g., changes in fuel price or load, weather) that can change the amount of congestion that exists on the grid.

2. Publicly reported measures of congestion

The six markets analyzed here have some measures of congestion that are reported publicly. They are summarized in Table 1.

Currently, entities reporting congestion measures for all the US organized markets use similar terms and methodologies. This is a change from several years ago when markets were using different conceptual methods for incorporating congestion pricing into their markets and in their reporting [1] [2]. In the early 2000s, markets were collecting congestion costs not just via locational pricing, but also uplift pricing, where the cost of redispatching generation due to congestion was divided equally among loads, and system redispatch payments, where the cost of paying generators different nodal prices were divided equally among loads. Now, the six markets examined in this paper use locational pricing to manage and price the majority of congestion, which results in a common set of fundamental components to use to quantify congestion.[3] [3]

Locational prices are made up of an energy component, a loss component, and a congestion component. The energy component is the base amount of cost for electricity and is the same for every location in the system. In some markets the energy component is the location price at a specific bus; in others it is the cost of electricity ignoring congestion and losses in the system. [4] [5] The loss component is the cost for the electricity lost on transmission lines as heat transporting electricity to that particular location. The congestion component represents the additional cost of consuming electricity at a particular location in the electricity system. The additional cost comes from having to dispatch more expensive generation in place of less expensive generation to meet demand at that location in order to operate within transmission system limits.

Table 1. Congestion measures reported for organized markets in the U.S.

Market	Reporting entity	What they report
ISO-NE	External Market Monitor (Potomac Economics)	• Net/Total congestion revenue
ISO-NE	Internal Market Monitor	• Day-ahead congestion revenue • Real-time congestion revenue • Total congestion revenue
NYISO	NYISO Operating Committee	• Bid Production Cost mitigation • Unhedged Congestion • Generator pay • Unhedged load pay by zone
NYISO	External Market Monitor (Potomac Economics)	• Day-ahead congestion revenue • Congestion on major transmission interfaces
PJM	Independent Market Monitor (Monitoring Analytics)	• Congestion charges (sliced by entity, market time-frame, etc)

[3] All the markets operate locational pricing markets in both day ahead and real-time time frames except SPP which only uses locational pricing in their Energy Imbalance Services market, essentially a real-time imbalance market. SPP therefore manages the majority of their congestion with other, non-pricing congestion management procedures. Uplift charges are still used by some/all of the markets in certain circumstances, but the majority of congestion management is done through locational pricing.

MISO	Independent Market Monitor (Potomac Economics)	• Day-ahead and Real-time congestion costs • Real-time congestion value
SPP	Internal Market Monitoring Unit	• Intervals with flowgate congestion • Intervals with breached or binding flowgates • Top binding and breached flowgates • Top binding and breached flowgates
CAISO	Department of Market Monitoring	• Frequency, average and total charges, and shadow price of congestion on inter-ties • Price impact of congestion in load areas
all	FERC report	• Ratio of congestion cost to total load [$/MWh]

In analyzing the publicly-reported data, we found three general categories of congestion measurement that are used for the six markets analyzed here. These are: total congestion cost and value, congestion reporting on individual flowgates, and ratio of total congestion cost to load. These categories of measures, listed in Table 2, will be described in the following subsections. There are also a few measures of congestion that are unique to one market, and those will be described in the final subsection ("Other").

Table 2. Categories of congestion measures reported for each market

	ISO-NE	NYISO	PJM	MISO	SPP	CAISO
Total System Congestion Cost	X	X	X	X		
Total System Congestion Value				X		
Congestion on individual interfaces/ flowgates:						
Frequency		X until 2010			X	X
Charges						X
Value		X until 2010			X	X
Price impact						X
Ratio congestion cost to load	X	X	X	X	X	X
Other		X			X	

In this paper we do not consider equity issues, including the effect of hedging mechanisms such as financial transmission rights. The question of who is paying for congestion, taking into account transmission rights as well as congestion payments, is a matter of fairness rather than a measure of where and how much congestion exists. Because of this, even though hedging and risk management are important congestion-related issues and are addressed to some extent by all organized markets, we do not discuss them in this paper.

2.1 Total system congestion cost and value

Congestion cost is an accounting measure of the money paid for use of a constraint. It is generally defined as the money, either to or from individual market participants or the sum of payments to or from all market participants, collected by the market operator from payments of congestion component of locational price. Total congestion cost and/or value is reported for four out of six markets, but any market that uses locational prices for congestion management could theoretically calculate congestion cost and value. Congestion cost is called congestion revenue in ISO-NE and NYISO; for PJM congestion cost is reported as congestion charge.

Congestion value, on the other hand, is an economic measure of marginal value. It is generally calculated as the amount of flow on a congested line times the shadow price on that constraint. The shadow price indicates the marginal change in total system generator dispatch cost for a marginal change in the constraint limit.[4] Total congestion value is the sum of congestion value for all constraints in the system.

Four markets have total congestion cost reported publicly: ISO-NE, NYISO, PJM, and MISO. For ISO-NE, day-ahead and real-time congestion revenue are reported, annually and by month, as well as total congestion revenue. [6, pp 50, 97, 100] [7, pg 20] The NYISO External Market Monitor reports day-ahead congestion revenue and real-time redispatch costs due to real-time congestion (this is called balancing congestion shortfall). [8 pp 73, 81] [9, pg 103] The PJM external Market Monitor reports annual congestion charges and costs for individual facility types, market participant (load and generator), and day-ahead and balancing time frames. Congestion charges are based on a variety of congestion costs that are incurred by (or paid to) market participants: net congestion costs, explicit congestion costs, and inadvertent congestion costs.[5] Each of these congestion costs accrues during both day-ahead and balancing (or deviations between day-ahead and real-time) time frames. [10, pg 53] The MISO Independent Market Monitor reports day-ahead and real-time congestion costs. [11, pp 39-40]

The MISO Independent Market Monitor also reports real-time congestion value. [11, pg A-84] [12 pg 85] [13 pg 82-83, 98-105] The MISO State of the Market report details several situations in which flow that uses congested lines do not pay for congestion; in these cases this congesting usage of the line is not included in the reported congestion cost, but is included in the reported congestion value.

Total system congestion cost and value are fairly straightforward to calculate when markets use locational prices. These measures reveal how much congestion is occurring in the system footprint from an accounting and marginal value perspective. However, these measures do not reveal where in the system congestion is occurring, what measures would alleviate the

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[4] In optimization terminology, the shadow price is the dual variable on the transmission limit constraint. [24]

[5] *Net congestion* is the congestion costs accrued by market participation; *explicit congestion*, congestion costs associated with point-to-point energy transactions; and *inadvertent congestion costs*, differences between actual flow and scheduled flow into and out of the PJM control area. [10, pg 53]

congestion, or how much money would be saved by alleviating congestion (which supports decisions about whether it should be alleviated).

In particular, congestion value may be a misleading measure for assessing the usefulness of actions that might be taken to reduce congestion. It is calculated as flow times the shadow price, which is a marginal value and thus it represents improvement in dispatch cost *on the margin*. If a constraint were entirely eliminated the total value or cost savings to the system would be much smaller. Additionally, if a constraint were eliminated entirely, it is likely another constraint would become binding. Congestion cost and value does not capture any information about what would happen to congestion if existing constraints were alleviated.

2.2 Congestion reporting on individual flowgates

Congestion measures can also be reported for individual flowgates or interfaces. These measures can include the frequency with which a flowgate or interface is congested, or the charges (costs) and/or value associated with an individual flowgate or interface. Congestion information is reported for individual flowgates in SPP and CAISO. Until 2010, individual flowgate congestion information was also report by the NYSIO External Market Monitor in the annual NYISO State of the Market report.

The CAISO Market Monitor reports on congested interfaces (lines that connect the CAISO with other systems) and on top internal constraints.[6] [14, pp 132-139] [15, pp 110-122] [16, pp 5.4-5.10] The frequency of congestion on interfaces is reported, as a percent of hours congested. Average congestion charges, in dollars per MW, and total import congestion charges, in dollars, are also reported for these interfaces. The most congested internal constraints are identified, and the number of hours they are congested over the year is reported. The Market Monitor also reports the price impact on the three major load regions because of congestion on these internal constraints, and the average congestion price as percent of system total price for each load control area (LCA).[7] Some of these measures are reported for each quarter, and all are reported for the entire year.

The SPP Market Monitor reports the top ten constrained flowgates by shadow price (summed over the year), and the number of 5-minute intervals those flowgates were congested or breached. [17, pg 83-84]

Congestion reporting on individual flowgates or interfaces reveals where in the system and how much congestion exists (although perhaps not where *all* congestion occurs, depending on exactly what is reported—if the top ten constraints are reported but those do not represent all congestion, some information is missing). Reporting on individual flowgates may also provide useful, but not complete, information to help with decisions about whether to take actions to alleviate

[6] In 2009 CAISO implemememented a market redeisgn, with a major change in congestion management procedures. Congestion reporting was different prior to this change.

[7] More specifically, it reports the average congestion component of locational price in the load areas, and the percent of congestion component to total average zonal locational price in the load areas. These values are reported for all hours and for hours only in which congestion occurred on the constraints.

congestion and what actions might be effective. This reporting could even help track congestion in one area over time, if the same constraints are reported annually. The usefulness of individual constraint reporting to answer these important questions depends heavily on the particular measures reported for each constraint.

2.3 Ratio of congestion cost to load

In 2010, FERC developed a set of standardized metrics that were reported by all organized markets in 2010 and 2011 for the purpose of analyzing organized market benefits and performance. [18, pg 5] The metric chosen to represent congestion management was the ratio of total annual congestion cost to total load served, reported as dollars per megawatt hour. [19, pg 22] All six organized markets covered in this paper reported this metric.

This is a unique case of a standard measure that is required from all markets. However, the FERC requirement does not specify exactly how congestion cost should be calculated. This means the inconsistencies in determining congestion cost that were identified above (inclusion of different temporal market settlements, not all flow on constraints pays for congestion) exist in the values reported to FERC.

This metric provides information about the scale of congestion cost in comparison to the size of the market (as measured by load). It can be loosely interpreted as the price load is paying, on average, for congestion per megawatt-hour. Because it is normalized with respect to system load it does allow for some comparability between markets of the magnitude of congestion. The measure does not provide information about where the congestion exists or whether or not to take actions to alleviate. If this measure were reported consistently over time, it would provide information to track changes in congestion over time; however there are no plans to make this an annual reporting requirement, thus the measure will not necessarily be available for tracking changes over time.

2.4 Other measures

In addition to the congestion measures listed above, SPP and NYISO both report additional information on congestion. The SPP Market Monitor reports how often there was any congestion or breached flowgates in the system, as a percentage of 5-minute intervals, a measure not reported by any other market. [17, pp. 79-83] This measure describes how much congestion is in the system in general (not the value of it), but not where it is or on what to do about it. It could be tracked to get some information on how congestion is changing over time.

The NYISO Operating Committee has questioned the value of traditional measures of congestion cost and value, and has therefore developed their own method of reporting congestion. They run a model (the Portfolio Ownership and Bid Evaluation, or PROBE, model) that evaluates market participant offers and bids to determine the market clearing conditions both with congestion (representing actual system conditions) and without congestion. They then report the difference between the two model runs for a variety of measures: production cost, congestion payments, generator payments, and load payments. [20, pg 25] This method of measuring congestion is more complex than calculating congestion measures from market data, because it involves building, maintaining and running a model of the system, but it does produce results that are closer to how much system cost would be saved by relieving congestion (unlike the measures of congestion cost and value described above). These measures can also provide information on how much congestion there is in the system: the difference between congestion payments with and without congestion is simply the congestion payments in the presence of congestion, because without congestion these payments are zero. Therefore the difference in congestion payments provides information about total congestion costs. However, these measures do not provide information on where the congestion is or what to do about it. (Using the model to do more detailed analysis of flows and congestion could provide that insight, but this paper is only considering the publicly-reported measures.)

Despite the similarities between reported measures across regions and across years in the same region, there are significant differences as well. These can be as straightforward as different measures being reported in the same region for different years (for example, NYISO reported frequency and value of individual flowgates up to 2010 but not after), or more complicated reasons, such as different markets including different kinds of flows in congestion cost measures or a single market modifying congestion management procedures. The next section presents an analysis of the factors that go into calculating the publicly-reported congestion measures discussed here and what impact they can have on the calculated measures.

3. Factors in congestion measures

Congestion measures reported in the six markets all depend on underlying market rules and data. Congestion measures are based on a set of building blocks, including congestion component of locational price and flow over constraints. Some of these building blocks have similar universal characteristics or factors, such as the same settlement markets (e.g., day-ahead or real-time), but some are different because they are intrinsically dependent on market rules and congestion management practices that are different in various markets or over time in the same market. Examples of the differences in factors between markets or over time within the same market include types of prices used for settlement (zonal or nodal), whether or not TLRs are used to manage congestion (and thus whether any congestion is mitigated and managed outside the locational pricing mechanism), and changes in market footprint or congestion management practices over time. In this paper we focus on the factors that are under the control of the market operators, not external influences like fuel price or weather.

All markets can track usage of lines and flowgates, necessary for the frequency and congestion reporting on individual constraints. All markets examined here use locational pricing, therefore the same general type of pricing data are available in each market. However, simply because the markets have similar data available to describe congestion does not mean all markets should have the same measures reported for them. We are not suggesting markets should standardize reporting of congestion.

In general, congestion measures reported for these markets depend on market rules and procedures that can be broken into three main groups: market rules and congestion management procedures, rules about what flow is exposed to congestion pricing, and rules that affect the congestion price. Each of these factors is described in the subsections below.

3.1 Market rules and congestion management practices

Market rules and congestion management practices determine the system dispatch and flow on transmission lines, how often and when locational prices are calculated (e.g., settlement periods), and other fundamental characteristics of the markets. Together, these factors influence both how much flow is on the lines (and therefore where and how much congestion exists), and how that flow can be measured.

Market settlement periods and types of prices

The organized markets discussed here manage congestion through locational price. The majority of congestion is managed through the day-ahead market because the majority of power is typically traded in day-ahead markets (where one exists). If markets do not have the same market settlement periods it is difficult to compare any measure that depends on market prices that are settled in these periods, including congestion component of locational prices or shadow constraint prices.

All markets analyzed here have locational (nodal) prices in the market settlement periods for which they run centralized clearing markets. All markets are able to calculate the shadow price on a constraint.

Types of prices used for settlement

Market participants can be settled at nodal or zonal prices. In the markets analyzed here, generators are paid nodal prices for the power they produce; loads pay either nodal or zonal prices for the power they consume.

As mentioned above, locational prices are made up of three components: energy, loss and congestion. The energy component of locational price is the same across the market footprint for nodal and zonal prices. The congestion component of locational price varies by location (as does the loss component). The congestion component of nodal prices indicates the cost of congestion at that point in the system. The congestion component of zonal prices is the load-weighted average of the congestion component of nodal prices in a pre-defined area, or zone. On an individual node, use of zonal prices will change the congestion component from what it would be using nodal prices; over time this tends to dampen the volatility of the congestion component.

Any measure of congestion that uses individual market participant settlements at zonal prices might be a distorted measure of congestion because of this. However, because zonal prices are load-weighed, measures of congestion that are based on the *sum* of congestion payments (price times quantity of load or generation) over the system will be equivalent to using nodal prices.

Use of TLRs to manage congestion

Transmission loading relief (TLR) procedures are an administrative, as opposed to a market-based, method of prioritizing requests for transmission use to avoid congestion.[8] Using TLR procedures for congestion management may be less economically efficient than using market mechanisms like locational prices because they can result in more curtailment of trades than is necessary. [21, pg 83] Most importantly for this analysis, the congestion avoided or mitigated through TLR procedures is not captured or measured through the current ways of measuring congestion in organized markets (e.g., locational prices and congestion components, or frequency, cost or value of congestion on an individual interface). Thus the congestion TLRs manage is not included in publicly reported congestion measures. This will tend to under-represent congestion in regions that use TLRs (NYISO, PJM, MISO and SPP), in relation to regions that do not use TLRs (ISO-NE, CAISO) all other things being equal (and they are not).

Changes in the RTO/ISO footprint

Increasing or decreasing the geographic size or membership of a market will change how much congestion might be expected. Put another way, if a market changes its membership, it would be

[8] TLRs are only used in the Eastern Interconnection. In the Western interconnection a similar procedure is called Unscheduled Flow Mitigation. However, because the only Western Interconnection market under analysis in this paper, CAISO, does not use this procedure, we limit the discussion to TLRs.

inappropriate to compare congestion measures before and after the change and conclude that transmission usage is increasing or decreasing.

At least two forces are at work on congestion when market membership changes, possibly in opposition. On the one hand, if the footprint increases the market may incorporate more existing constraints, thus potentially increasing congestion simply because a constraint is included that was not included before. On the other hand, if a market is managing congestion over a broader area it may have new, and potentially more efficient, options for managing congestion than it did before—optimizing dispatch over a larger area can serve load more efficiently than optimizing it over multiple smaller areas. This would tend to decrease congestion (frequency, cost or value) within the market footprint.

The footprints of markets can change, sometimes substantially. PJM, for instance, significantly increased its footprint between 2002 and 2005 when it incorporated Allegheny Power's transmission system, AEP, Commonwealth Edison and Dayton Power & Light.[9] SPP is in negotiations currently to incorporate Entergy. Large changes like these can have an impact on measured congestion, rendering a year-to-year comparison of reported congestion in the market before and after the change quite challenging.

Changes in market rules

Some changes in market rules, including adoption of nodal prices, will change how congestion can be measured. It will also change how much congestion exists because congestion management will be different. When market rules change, comparing congestion measures over time can be challenging if not impossible. For instance, when CAISO implemented the Market Redesign and Technology Upgrade (MRTU) in 2009, the market changed from one where congestion was managed through real-time redispatch within zones and via market prices between zones, to one where congestion was managed primarily through locational pricing across the system. [16, pp 5.2-5.3] [22, pp 10-11] Because congestion could only be measured between regions prior to 2009, it is difficult and inappropriate to compare congestion measures before and after this time. [16, pp 5.2-5.4]

3.2 Factors that affect amount of flow exposed to congestion prices

The amount of flow on a line, and thus the amount of congestion, is a result of many things, including market settlement periods, types of prices, congestion management procedures, and market footprint. These affects were examined above. This section focuses on a related issue: how much of the flow on a constraint must pay congestion price. This factor affects the congestion cost accounting measures, and any measures that are derived from congestion cost such as the ratio of congestion cost to served load as reported in the FERC ISO/RTO Metric Report.

In general, congestion cost is calculated as the amount of money a market operator collects from the net settlement payments to and from market participants. If market rules exempt any usage of

[9] http://www.pjm.com/about-pjm/who-we-are/pjm-history.aspx

the transmission system from paying for congestion and/or use of the system, those flows that use constrained lines will not be included in the measured cost of congestion in the same way that flows that do pay for congestion. The decision to exempt certain usage from paying congestion is not a technical decision and can be different in different market regions.

There are many classifications of flow that use the transmission grid in day-ahead or real-time markets, and thus may be taking up capacity on congested portions of the grid, either through actual usage or in the scheduling or day-ahead time frame. Each market has rules governing the specifics of how these classifications of usages are considered with respect to congestion. These include:

- Internal bilateral transactions
- Grandfathered rights
- Virtual bids
- Unscheduled loop flow
- Agreements with neighboring markets
- Usage of interfaces between markets

For instance, MISO does not charge unscheduled loop flow congestion costs, and has agreements with PJM that some of PJM's usage of MISO constraints is also not charged congestion costs.

Each of these types of flows do not occur in all markets. For instance, ISO-NE experiences very little loop flow, while NYISO, PJM and MISO do. Not all markets clearly define how each of these types of flows are treated with respect to paying for congestion, thus making it difficult to completely understand the impact on congestion cost measures.

3.3 Factors that affect congestion prices

Congestion management and market rules dictate dispatch and flows, other market rules determine which flows pay congestion prices, and still other market rules can influence congestion and shadow prices. We now explore this last factor that causes inconsistencies in congestion measure reporting.

Use of zonal prices

In some markets, loads are charged zonal prices instead of nodal prices. While this alters the congestion component at individual nodes in the system, the zonal prices do not have a distorting affect on congestion measure that multiplies the price times quantity and adds congestion within a region. This is because the zonal price is based on a load-weighed average within the zone. On the other hand, any congestion measure that is based on individual congestion payments by market participants exposed to zonal prices may be distorted (compared with use of nodal price). None of the measures of congestion presented in this paper currently fall into this category, but it is possible new measures may be developed where zonal versus nodal pricing would create a difference.

Use of reference bus

The use of a reference bus can change the proportion of a locational price that is classified as congestion (versus energy or loss), and thus have an impact on the amount calculated as congestion cost. In other words, the total locational price will be the same regardless of where the reference bus is, but the energy, congestion and loss components will change if a different reference bus is used to calculate the dispatch. Thus, while total payments do not change with a change in the location of the reference bus, the fraction counted as congestion payment as opposed to losses will change. This results in a change in total congestion cost. [23, pg 106- 115]

Use of constraint shadow price limit

Putting a limit on constraint shadow price is a management mechanism for limiting the dispatch cost of respecting transmission limits. If the shadow price limit is exceeded, the constraint is relaxed, and the resulting constraint shadow price is different (in some cases far lower) than it would be with the constraint enforced. This changes the congestion component of locational prices used in calculation of congestion costs, and the constraint shadow price used in calculation of congestion value (total or for individual constraints). Whether a market implements constraint shadow price limits, what the limit is, and when and how often it relaxes the limit, can affect the amount of price affect and the subsequent impact on congestion measures.

4. Comparing measures across markets or over time

We have reviewed the publicly-reported congestion measures for organized markets in the U.S. We have also identified factors that can influence these measures and limit their comparability and consistency. This section discusses to what degree the measures can and cannot be compared, either among markets or over time in the same market.

4.1 All measures of congestion

Congestion management processes can have an effect on how much congestion is experienced on a system, and how much is calculated using any of the measures discussed in this paper. Additionally, any market rule or management practice that changes either the amount of power flowing over the constraint that pays for congestion or the prices associated with the constraint would have an effect on the calculated congestion cost or value, and any congestion measure that uses congestion cost or value in its derivation. Because of this, it is important that any market rules that alter the amount of flow over a constraint, the flow paying for congestion, or the congestion-related price, are publicly known so the meaning of the measure can be fully understood. It cannot be determined whether measures are comparable unless their derivations and the market rules that underpin them are fully understood.

Change in a market footprint can have an impact on measured congestion. It is not straightforward to meaningfully compare congestion between markets or within a single market before and after a footprint change. This is because a footprint change could increase measured congestion (because more existing constraints reside in the expanded market) or decrease (because congestion can be managed more efficiently over a wider area). To deal with differences in measured congestion, it would be helpful to review studies that have preceded footprint-expansions and learn from their techniques.

As mentioned above, TLRs are administrative congestion management procedures that influence the amount of congestion that materializes or is managed by locational prices. TLRs manage congestion, thus their use can have an effect on the frequency and value of congestion on individual flowgates or interfaces. They also manage congestion outside of the locational pricing mechanism, and any congestion they mitigate will not be included in congestion cost and value measures. NYISO, PJM, MISO and SPP use TLRs; ISO-NE and CAISO do not. The markets that use TLRs do so to different degrees and for different purposes, and can change that usage over time. For instance, NYISO began using TLRs in 2009 when high levels of clockwise unscheduled Lake Erie loop flow were exacerbating congestion on the system. [19, pg 205] Varying usage of TLRs makes comparing the publicly reported congestion measures difficult, because some represent congestion measured after the implementation of TLRs and some do not.

4.2 Congestion cost and value

To calculate either total congestion cost or value in a consistent way across markets, the markets would need to have the same temporal market settlements (e.g., day-ahead and real-time), and use locational prices. It matters less whether the market participants settle at nodal or zonal prices, or whether the market model uses a reference bus, because all the congestion cost or value is being summed over the entire market. If an individual congestion costs were reported or used as a component in another measure, it would make a difference as to whether that cost was determined with a nodal or zonal price.

Currently SPP does not have a day ahead locational price market, so there are no locational prices in the day-ahead timeframe. This makes it difficult to compare SPP congestion measures to any other market. When SPP does implement locational prices in a centrally-run day ahead market, anticipated to begin in March 2014, it will create a step-change in congestion management procedures and, presumably, reporting. It is possible that the majority of congestion will start being managed in the day-ahead market, making it possible to measure day-ahead congestion cost in a similar way to other markets.

This change in congestion management will not change the ability to calculate and report on currently-reported measures (frequency and congestion on individual flowgates), if the market monitor chooses to continue this reporting. However, it will still be challenging to compare these congestion measures before and after implementation of the new day-ahead market, because the change in the procedure for managing congestion will fundamentally influence the amount of congestion that exists. In other words, it will be difficult to attribute a change in congestion to the change in congestion management or to other factors.

The other major inconsistency that influences calculation of congestion cost is how much flow over the system is required to pay for congestion, and what those congestion prices are. As mentioned above, market rules can affect both of these factors, and as long as these are different between markets it will be difficult to compare congestion cost between markets in a meaningful way.

4.3 Congestion reporting in individual flowgates

Congestion on individual flowgates is generally straightforward to determine and report because they depend on knowing which lines or flowgates are congested and when, information readily available to the markets. Because there can be various ways of defining and measuring frequency and price impact, these measures have the most value when the calculation method is clearly defined and consistent. Reporting top constraints can present a consistency problem when different constraints are highly congested in different years.

4.4 Ratio of congestion cost to load

This measure faces the same challenges as congestion cost reporting in terms of being comparable across markets, because it uses congestion cost in its derivation. Any inconsistencies that exist in congestion cost will manifest in the ratio of congestion cost to load. This could be addressed by having an industry-wide standard for how congestion cost is calculated, but it may not be appropriate to develop such a standard measure.

4.5 Other

The measures developed by the NYISO Operating Committee are an interesting counterpoint to the measures reported for other markets. They are the only measures that incorporate what the system would look like without congestion, which results in a more comprehensive understanding of the value of mitigating congestion. However, being able to calculate these measures requires building and maintaining a model of the system, and having sufficient trust from stakeholders in the model and calculations methods. Whether other markets would be able and willing to take these steps is unknown.

5. Conclusions

This paper reviewed publicly-reported congestion for six organized markets in the U.S., and the factors that intrinsically shape those measurements, including markets rules and congestion management practices, rules governing what flow pays for congestion, and factors that can change locational and constraint shadow prices.

While none of these measures communicates full information about how much and where congestion exists, what should be done about it, or tracking changes, they all provide important and useful information about the markets for which they are reported. Many of the measures are based on the same analytical building blocks, such as locational price and flow over constraints. These components are influenced by a number of factors, such as congestion management procedures, which are under the control of the market operator.

All markets are different and have different needs for congestion measures. Thus it would not be appropriate at this time to suggest all markets define their market rules or congestion measures in the same way. However, if there were more transparency in how the measures are calculated it would aid all stakeholders seeking to better understand the demands being placed on the nation's transmission system.

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